Science of the Total Environment 494–495 (2014) 9–17

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

A mini-review on the impacts of climate change on wastewater reclamation and reuse

Phuong Tram VO [a], Huu Hao Ngo [a,*], Wenshan Guo [a], John L. Zhou [a], Phuoc Dan Nguyen [b], Andrzej Listowski [c], Xiaochang C. Wang [d]

[a] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia
[b] Faculty of Environment, Ho Chi Minh City University of Technology, 268 Ly Thuong Kiet, District 10, Ho Chi Minh City, Viet Nam
[c] Sydney Olympic Park Authority, 7 Figtree Drive, Sydney, NSW 2127, Australia
[d] Key Lab of Northwest Water Resources, Environment and Ecology, Ministry of Education, Xi'an University of Architecture and Technology, Xi'an 710055, China

HIGHLIGHTS

- Wastewater reclamation and reuse is crucial for sustaining fresh water supplies.
- Improved social awareness and growing water-reuse market elevates reuse practices.
- Direct and indirect impacts of climate change on wastewater reuse are synthesized.
- GHGs emission from wastewater reclamation had been underestimated.
- Uncertainty in trend prediction hindered efforts for resilient reclamation project.

ARTICLE INFO

Article history:
Received 23 May 2014
Received in revised form 19 June 2014
Accepted 20 June 2014
Available online xxxx

Editor: Damia Barcelo

Keywords:
Climate change
Impacts
Wastewater reclamation and reuse
Opportunities

ABSTRACT

To tackle current water insecurity concerns, wastewater reclamation and reuse have appeared as a promising candidate to conserve the valuable fresh water sources while increasing the efficiency of material utilization. Climate change, nevertheless, poses both opportunities and threats to the wastewater reclamation industry. Whereas it elevates the social perception on water-related issues and fosters an emerging water-reuse market, climate change simultaneously presents adverse impacts on the water reclamation scheme, either directly or indirectly. These effects were studied fragmentally in separate realms. Hence, this paper aims to link these studies for providing a thorough understanding about the consequences of the climate change on the wastewater reclamation and reuse. It initially summarizes contemporary treatment processes and their reuse purposes before carrying out a systematic analysis of available findings.

Contents

* Corresponding author. Tel.: +61 2 9514 2745; fax: +61 2 9514 2633.
E-mail address: h.ngo@uts.edu.au (H.H. Ngo).

http://dx.doi.org/10.1016/j.scitotenv.2014.06.090
0048-9697/

1. Introduction

Climate change is no longer a scientific fiction. It has been convinced by an enormous amount of publications from various disciplines since the 1960s when technological advances allowed researchers to monitor the transformation of CO_2 in the atmosphere and predicted the changes of global temperature by computer models (Isobe, 2013; Moss et al., 2010; Parry et al., 2007; Seinfeld and Pandis, 2006; Vittoz et al., 2013). Despite skepticisms from the anti-climate change movement, Intergovernmental Panel on Climate Change reconfirmed the phenomenon by its long-term observation through representative indicators such as temperature, greenhouse gases (GHGs) concentrations, extreme events, sea level changes and hydrological cycle (IPCC, 2013).

As United Nations Water (2012) expressed, water is the fundamental medium that transfers the effects of climate change to the ecology and human beings. This has led to an ultimate concern over the water sector in the medium confidence stand of strongly fluctuated precipitation (*more precipitation in medium and high latitudes, less in subtropical countries*), increased Global Mean Surface Temperature (*average surface temperature in the period of 2016–2035 will be* $+0.3$–0.7 *°C higher than that of 1880–1950*), sea level rise ($+0.2$–0.6 *m by 2100*) and extreme weather situations (*stronger cyclones in North Pacific, Indian Ocean and Southwest Pacific, more prolonged droughts, heavy rainfall and flooding in certain areas*) (IPCC, 2013; World Bank, 2009). Water security has been consequently violated through changing patterns of the hydrological cycle, water availability, water demand and water quality (World Bank, 2009).

To tackle this issue, one of the promising trends adopted under the thirst of precious freshwater resources is wastewater reuse. It has been considered as an essential part of Sustainable Water Management Scheme (Marlow et al., 2013). The last three decades have indeed experienced a rising attention on wastewater reclamation and reuse in various parts of the world (National Water Commission, 2011; Sa-nguanduan and Nititvattananon, 2011). The research themes were very diverse, ranging from its applications and advantages (Guest et al., 2009); treatment technologies and operational issues (de Koning et al., 2008; Venkatesan et al., 2011); economics of water reuse (Daniels and Porter, 2012; Listowski et al., 2013; Molinos-Senante et al., 2011) to its impacts on the environment, public health and safety (Peterson et al., 2011; Rose, 2007; Zhang et al., 2011) as well as social reactions of end-users (Hartley, 2006; Po et al., 2003; Russell and Hampton, 2006).

Water reclamation often refers to the treatment of storm-water, industrial wastewater and municipal wastewater for beneficial reuse (National Research Council, 2012). Its technical infrastructure basically comprises transmission pipes, treatment facilities and distribution structures. While the use of treated wastewater often bears larger financial, technical, and managerial challenges than conventional water sources, wastewater can be exploited at different levels for diverse end-use purposes (Chen et al., 2013). The degrees of treatment regarding the common methods were simplified and presented in Table 1. Raw or primarily processed wastewater was used for agricultural purposes in developing countries with arid or semi-arid climate such as Ghana, Bolivia and Mexico, regardless of the environmental degradations it may cause (Bernard et al., 2003; Landa-Cansigno et al., 2013; Zabalaga et al., 2007). This type of service should be banned for future use because its costs would exceed the benefits (World Bank, 2010). Fortunately, the highest fraction of reclaimed water came from the secondary treatment where organic compounds, suspended solids, and pathogens were substantially partially removed (National Research Council, 2012). It could be utilized for agricultural irrigation, landscaping, civil non-potable purposes, cooling or other industrial applications (Buhrmann et al., 1999; Carr et al., 2011; Gori et al., 2003; Lazarova and Savoye, 2003). However, nutrients, predominantly nitrogen and phosphorus, which can cause eutrophication while being discharged to the environment might not be removed in the conventional secondary treatment. These nutrients were commonly treated by chemical or

Table 1
Types of reuse appropriate for increasing levels of treatment (adapted from US EPA (2012)).

	Increasing levels of treatment →			
Treatment level	Primary	Secondary	Tertiary	Advanced
Processes	Sedimentation	Biological oxidation	Chemical coagulation, biological or chemical nutrient removal, filtration, and disinfection	Activated carbon, reverse osmosis, advanced oxidation processes, soil aquifer treatment
End Use	No uses recommended	Surface irrigation of orchards and vineyards	Landscape and golf course irrigation	Indirect potable reuse including groundwater recharge of potable aquifer and surface water reservoir augmentation and potable reuse
		Non-food crop irrigation	Toilet flushing	
		Restricted landscape impoundments	Vehicle washing	
		Groundwater recharge of non-potable aquifer	Food crop irrigation	
		Wetlands, wildlife habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Human Exposure	Increasing acceptable levels of human exposure →			
Cost	Increasing levels of cost →			