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Urban water consumption and its influencing factors in China: Evidence from 286 cities

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ABSTRACT

Factors that affect water consumption should be identified to develop effective public policies. However, factors influencing domestic water consumption in cities in China, particularly on a national scale, are unclear. In this study, urban water consumption and its influencing factors in 286 municipal cities in China were analysed by using conditional inference trees and the random forest method. Results showed that water consumption (per capita per day) of 130 cities had changed significantly (decrease: 69; increase: 61) from 2000 to 2015. Of the 286 cities studied, 112 were classified as low-water consumption cities with water consumption below 70 L per capita per day. In addition, water consumption per capita per day in China was found to be highly affected by meteorological factors, socioeconomic status, water supply and conservation factors. The factors influencing water consumption also varied across different cities. In high-consumption cities, water consumption per capita per day was strongly influenced by precipitation, water conservation investment, water heater for showering or bathing per household and gross domestic product per capita. In medium- and low-consumption cities, water consumption per capita per day was affected by water supply capacity and socioeconomic status, including gross domestic product per capita, education received and Engel's coefficient. Significant disparities in these factors suggest that different policies regarding water consumption should be implemented across China. In high-consumption cities, investment in water conservation should be continued to ensure sustainable use by reducing water consumption. In low-consumption cities, water supply capacity should be improved to guarantee water availability for basic health and hygiene requirements.

1. Introduction

Shortage in fresh water resource has been documented in various regions worldwide and has posed high risks to all aspects of life (WHO/UNICEF, 2015). Currently, approximately 700 million people in 43 countries experience water shortage (Mukheibir, 2010), and this number is predicted to increase to 2.8 billion people in 48 countries and 3.6 billion in 54 countries by 2025 and 2050, respectively (Choi et al., 2016). The global water crisis has been exacerbated by various factors, including urbanisation, population growth and improved livelihood demands (Domene and Sauri, 2006).

In cities, water shortage and crisis are serious and sensitive because of continuous urban development and increasing water demand (Dash, 2013). In 1950, 30% of the global population lived in urban areas (UN, 2007), and an estimated 54.5% of the same population resided in urban settlements in 2016 (UN, 2016). By 2050, this rate is projected to increase to 66% with 6.2 billion people living in urban areas (UN, 2015). Cities in developing countries in Africa and Asia are growing rapidly. Among them, China (additional 292 million urban dwellers), India (additional 404 million urban dwellers) and Nigeria (additional 212 million urban dwellers) will likely account for 37% growth of the world's urban population by 2050 (UN, 2015). With increasing city population, global water consumption in cities has increased by approximately six-fold, which is twice the rate of population growth (Guinness and Walpole, 2012). Recent reports indicate that 22 out of 32 major cities in India faced water crisis (Dash, 2013), while Iranian cities struggled with groundwater depletion (Madani, 2014).

In China, approximately 400 of 669 cities experienced water scarcity in 2010. Of these cities, over 100 suffered from severe water

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shortage, and more than half of the urban dwellers in China were at a high risk of insufficient water supply (Liu and Raven, 2010). An annual water deficit of over 6 billion cubic metres has been reported in China (Feng, 2013), with more than 50 metropolises, including the megacities Beijing, Shanghai, Tianjin and Taiyuan, experiencing severe groundwater overexploitation (Yin et al., 2006). Massive groundwater depletion has resulted in groundwater levels in North China being reduced by more than 40 m (Zhu et al., 2015). Therefore, ensuring a continuous water supply remains challenging because of high-risk, high-cost and low-availability water sources.

Authorities, non-government organisations, private sectors and water stakeholders have cooperated intensively to develop solutions aimed at ensuring sustainable water consumption and thus prevent water crisis (Stevenson et al., 2016). Various strategies, such as policy intervention, education, pricing, water-saving devices and engineering methods, have been proposed and widely discussed to alleviate water shortage (Landon et al., 2016). In India, water is intermittently supplied in most cities to reduce water consumption, and only few cities, such as Kota, Hubli, Dharwad and Nagpur, adopt a continuous mode of water supply (24 h supply) (Vairavamoorthy et al., 2008). In England, water consumption is predicted to decrease by 20 L per capita per day through water-saving devices and water conservation campaigns (Shove et al., 2010). However, such interventions have yielded different results across cities because the key factors affecting domestic water use are highly complex and vary from place to place. For example, education programs and public awareness campaigns in Melbourne have been successfully utilised to reduce water consumption by 57% (Bryx and Bromberg, 2009). Conversely, the same strategies implemented in California, USA only yielded less than 20% reduction in water consumption (Renwick and Green, 2000). Therefore, domestic water consumption profiles and their influencing factors across cities must be determined to establish effective water resource management and related public policies at a national scale.

Domestic water use is highly complex and diverse because it can be affected by many factors, including climate and meteorology (Slavíková et al., 2012), sociodemographic profiles (Duarte et al., 2013), household characteristics (Syme et al., 2004), water availability and conservation (Davies et al., 2014), and pricing and policies (Jorgensen et al., 2009) regarding water usage. These factors vary across indoor and outdoor water uses. Syme et al. (2004) found that outdoor water consumption and use behaviour, mainly on vegetable garden watering, yard cleaning and swimming pool, are highly affected by climate, income, lifestyle and water conservation practices. By contrast, Gregory and Di Leo (2003) found that indoor water use is affected by the use of water appliances and water conservation practices. Key factors affecting water consumption vary across different cities. In Indian and Palestinian cities, water consumption and use behaviour are restricted by available water resource and supply capacity (Andey and Kelkar, 2009). In northern Nigeria, precipitation (rainy and dry seasons) is identified as a key factor influencing water consumption (Nyong and Kanaroglou, 2001). In Hong Kong and Beijing, the national gross domestic product (GDP) is highly related to increase in the rate of base water use (Zhang et al., 2013). In California, water price (WP), water appliances and water-saving subsidies are the main factors associated with water consumption (Renwick and Archibald, 1998). On the basis of previous studies and data availability, this study selected 15 factors that represent climatic, socioeconomic, WP, water appliance, water supply and conservation factors.

In China, current studies have focused on individual cities, such as Beijing, Tian Jing and Hong Kong (Zhang et al., 2013), but have yet to compare differences among them. Zhang et al. (2016) examined water consumption in Tianjin City and found that population growth was the main cause of increased domestic water consumption in this city. On the other hand, Wei et al. (2009) observed that domestic water demand was strongly correlated with time variable, consumer price index, population and income. Yan (2013) showed that domestic water consumption in Urumqi City was highly correlated with temperature and weakly correlated with precipitation. Furthermore, factors affecting water consumption are complicated, and they could be affected by a group of factors. Therefore, current single-city studies lack the much-needed nationwide understanding of water consumption in China. Water consumption profiles and their influencing factors in Chinese cities are largely unknown and thus impede the implementation of policies for efficient water resource management and sustainable use.

To provide a basis for sound policy making, this paper examined household water consumption in 286 cities in China and determined key factors that affect domestic water consumption in these cities. The paper also aimed to identify effective strategies to ensure water use safety and effective water supply management in cities.

2. Materials and methods

2.1. Data sources

This research involved 286 municipal cities from 30 jurisdictions (22 provinces, 4 municipalities and 4 autonomous regions) from 2000 to 2015. The data used in the analysis included daily water consumption per capita (litres of domestic water consumption per capita per day, LPCD) of urban dwellers and the 15 factors affecting household daily water consumption (Table 1). These factors included climatic factors (two variables), WP, socioeconomic

Table 1
Description of data sources.

Item code	Variables	Data source
Water consumption		
LPCD	Litres of water consumption per capita per day (LPCD) (L)	NBSC, 2000–2015
Climatic factors		
T	Average annual temperature (T, °C)	CMDSSS, 2016
PRE	Average annual precipitation (PRE, mm)	
Water price		
WP	Water price (WP, US $/m^3)	E2O Environment Platform, 2016
Social-economic factors		
UA	Urban area (UA, km^2)	DUSS-NBSC, 2000–2015; CEInet, 2016
P	Urban population (P)	NBSC, 2000–2015
GDP	GDP per capita (GDP, US $ y^{-1})	
EC	Engel's coefficient (EC)	
PG	Population growth rate (PG, % y^{-1})	DUSS-NBSC, 2000–2015; CEInet, 2016
EDU	Ratio of high education received (more than 12 years) (EDU, %)	
GR	Gender ratio (GR, male/female)	DPES-NBSC, 2000–2015
Water appliances factors		
WM	Washing machine per household (WM)	DUSS-NBSC, 2000–2015; CEInet, 2016
WH	Water heater for showering or bathing per household (WH)	
Water supply and conservation factors		
WSC	Water supply capacity per capita per day (WSC, m^3)	NBSC, 2000–2015
WUR	Water use recycling rate (WUR, %)	DUSS-NBSC, 2000–2015; CEInet, 2016
IWC	Invest for water conservation per capita (IWC, US $ y^{-1})	