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A study on the spatial and temporal variability of the urban residential water consumption and its influencing factors in the major cities of China

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ABSTRACT

In recent years, urban residential water demand has continually grown with the rapid urbanization in China, which has been the main contributor to the increase of total urban water consumption. The fast growth of urban water consumption poses a great threat to urban water security and sustainable water resources management. To explore the dominant factors influencing the urban residential water consumption and further to propose the effective measures to control the fast growth of water consumption, this study selected the daily water consumption per capita (DWCC) as an indicator to quantitatively characterize the residential water consumption level and analyzed the spatial and temporal characteristics of DWCC in the period of 2005–2014 based on the data collected from 38 major cities in China. The results showed that the average values of DWCC in the 38 major cities were 141.9 L/d, 159.4 L/d and 129.3 L/d in 2005, 2010 and 2014 respectively. The urban residential water consumption showed a significant decreasing trend in the period of 2005–2014 due to the strategy of water-saving society construction in China. Meanwhile, the DWCC was showing a great spatial variability among different cities, which was much greater in southern cities than that in northern cities. The reason behind this is that the main influencing factors differ greatly among different cities. Based on the path analysis, we also identified the dominant factors influencing the DWCC from the 9 main possible factors. The amount of available water resources, the domestic water price and the usage rate of water-saving appliances are recognized as the dominant influencing factors. At last, the differential countermeasures are proposed to improve the urban water-saving management level and guarantee the urban water security in China.

1. Introduction

Under the conditions of global climate change and rapid urbanization, the supply and demand of urban water resources contradict in developing countries. As one of the largest developing countries in the world, China suffers from serious water shortage during urbanization (Nnaji, Eluwa, & Nwoji, 2013). Since 2000, water shortage has happened in more than 400 cities of the 668 cities in China, of which at least 100 cities are in severe conditions (Chen & Wang, 2010). In 2000, the water consumption of urban residents in China was 28.59 billion m^3, accounting for 5.2% of the total national water consumption and by 2010, it grew to 46.2 billion m^3, 7.7% of the total. The alarming growth rate reached to 61.9% and the residential water consumption grew as the fastest one among all water users (Liu, Wang, Li, & Li, 2013). To solve the issue of urban water shortage, it is necessary to control the excessive growth of urban water consumption by developing the urban residents' water-saving potential and shifting water resources management from supply to demand.

Urban water management started with concentration on water supply management [n1]. The initial purpose of urban water management is to meet the needs of water resources for socio-economic development and to match the water supply with the water demand through constructing various water conservancy facilities (Chelleri, Schuetze, & Salvati, 2015). However, with the fast socio-economic development, the water resources demand has a great increase while the water supply capacity is limited. Under this situation, the people began to realize the importance of water demand management [n2]. The concept of water demand management came from Demand Side Management (DSM), which firstly appeared in the field of electrical energy and then was introduced into water management (Breukers, Heiskanen, Brohmann, Mourik, & Feenstra, 2011). The research of water demand management was earlier conducted in Israel, aiming to fulfill the potential of urban and agricultural water saving (Arlosoroff, 2007). The United States, Australia, Japan, Canada and other countries have also

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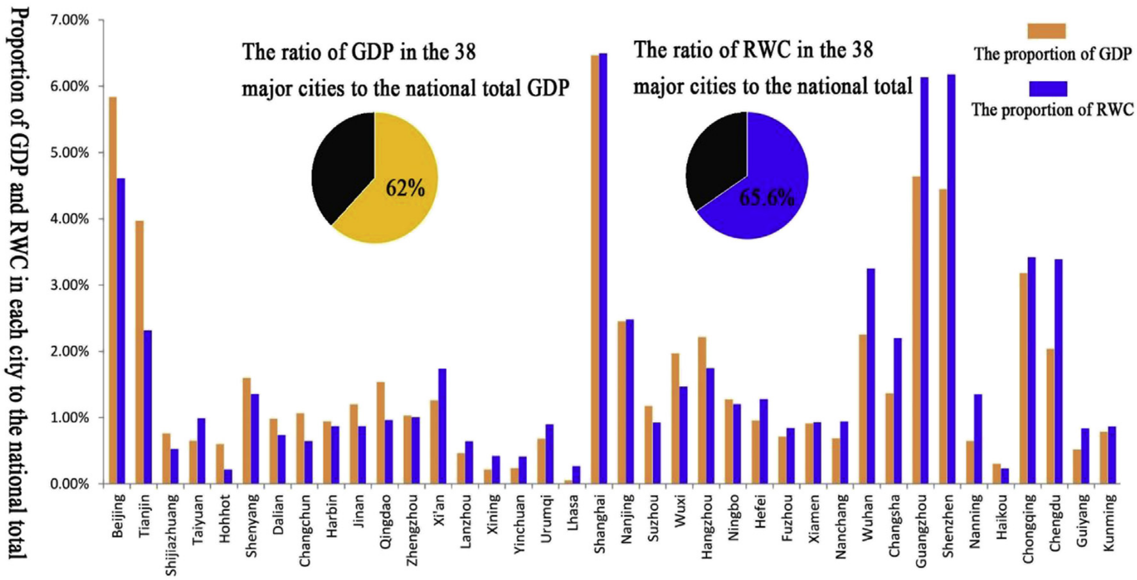

Fig. 1. The statistics of GDP and residential water consumption (RWC) in the 38 major cities.

conducted in-depth studies (Sharma & Vairavamoorthy, 2009) and proposed many innovative theoretical methods based on water demand management. In 2002, the Global Water Partnership presented the concept of Integrated Urban Water Management at the conference of World Summit on Sustainable Development (Medema, McIntosh, & Jeffrey, 2008), which further clarified that the core of urban water management was to ensure that residents, the economy and the ecological environment are under equal water service conditions and to enhance and improve water use efficiency through technological innovation and management.

At present, more than half of the people in the world are living in urban areas (He, Chen, Mao, & Zhou, 2016; Lu et al., 2017), and the scientific urban water management shows great significance of the sustainable use of urban water resources. Researches on the mechanism and process of urban residential water use have attracted more attentions, which has pushed the development of urban water demand management (Corbella & Pujol, 2009). The study conducted by Griffin et al. (Griffin & Chang, 1991) concluded that precipitation and temperature have great impacts on the urban domestic water consumption. The change of temperature would affect the water consumption through home gardening, environment cleaning, drinking and bathing while the change of precipitation had impacts on the water consumption for the environment cleaning, car washing and laundry. Gato et al. (Gato, Jayasuriya, & Roberts, 2007) found that the air humidity, the solar radiation, the precipitation, the temperature and the wind speed would significantly affect the urban household water consumption. Balling et al. (Balling & Gober, 2007) illustrated that the 10% reduction of annual precipitation could lead the residential water use per capita to increasing by 3.9%, while the average temperature rise of 1 °C would result in a 6.6% increase of the residential water use per capita. Robert (Bradley, 2004) investigated the residential water consumption in several Asian cities and found that the increase of urban per capita housing area would lead to an increase of domestic water consumption, especially in developing cities. Peter et al. (Newton & Meyer, 2012) found that the higher-income residents would have higher residential water consumption increasing. Water price is also a primary factor on residential water consumption (Lu, Bao, & Bao, 2016). Espey et al. (Espey, Espey, & Shaw, 1997) introduced the concept of Price Elasticity Effect to quantify the impact of water price on residential water consumption. In addition to the above factors, some related studies have shown that the water resources availability, the city's policies and economy economic development also have significant impacts on urban residential water consumption (Lu, Bao, & Pan, 2016; Willis, Stewart, Giurco, Talebpourb, & Mousavinejada, 2013).

In the past decades, a lot of the studies, focusing on the main factors of urban residential water consumption and the residential water use mechanisms, have been conducted especially in the developed countries (Chen, 2012; Hung & Chie, 2013; Kyessi, 2005; Lu, Zhang, Bao, & Skitmore, 2016). In order to analyze the temporal and spatial variability of the residential water consumption in China, we have collected sufficient data of the residential water consumption, the economic development, the population, the meteorological condition and the water resources availability. The main objectives of this study are as follows: 1) We took the residential daily water consumption per capita (DWCC) as a representative indicator to quantify the water consumption and analyze the spatial and temporal variability of DWCC; 2) The collected data includes population, economic development, climatic conditions, water resources availability and water-saving management in 38 major cities of China. We quantitatively identified the main dominant indicators on DWCC through path analysis; 3) We divided the major cities into different categories and have proposed the respective measures and suggestions for urban water management, aiming to control the excessive growth of water consumption and to ensure the sustainable social and economic development in the major cities of China.

2. Materials and methods

2.1. Study area

During the period of 2005–2014, the urban population in China increased from 0.56 billion to 0.75 billion, ranking the top of the world (National Bureau of Statistics of China). All the aspects of major cities, including the population growth, the urbanization rate, the economic development and the people's living standard, are ranking the top places in China, which requires much more natural resources to support them [n3]. Therefore, the pressure on environmental resources in the major cities is always large, especially on the water resources. According to the statistics in 2014 (as shown in Fig. 1), in the 283 prefecture-level cities of China, there were 38 major cities in total (including the centrally-administered municipalities, the provincial capitals and the regional hub cities) with the total GDP accounting for above 60% of the national GDP. Moreover, the total residential water consumption in the 38 major cities accounted for above 65% of the total urban residential water consumption of China.