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Assessment of the municipal water cycle in China

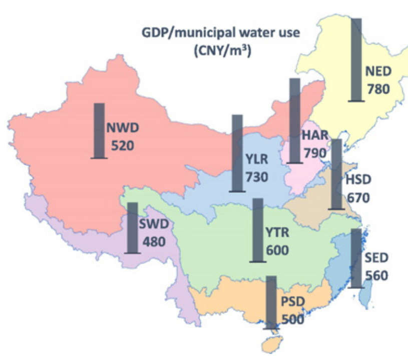
Tao Wang [a,b,c,*], Shuming Liu [d], Xuepeng Qian [e], Toshiyuki Shimizu [a], Sébastien M.R. Dente [f], Seiji Hashimoto [g], Jun Nakajima [g]

[a] Global Innovation Research Organization, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga 525-8577, Japan
[b] Circular Economy Research Institute, Tongji University, Shanghai 200092, China
[c] Institute of Science and Technology for Development of Shandong Province, Shandong Academy of Sciences, 19 Keyuan Road, Jinan 250014, China
[d] School of Environment, Tsinghua University, Beijing 100084, China
[e] Asia Pacific Studies, Ritsumeikan Asia Pacific University, 1-1 Jumonjibaru, Beppu, Oita 874-8577, Japan
[f] Research Organization of Science and Engineering, Ritsumeikan University, Japan
[g] Department of Environmental Systems Engineering, Ritsumeikan University, Japan

HIGHLIGHTS

- The municipal water cycle was characterized for 655 Chinese cities.
- In >100 cities in North China, their municipal cycle is exposed to water scarcity.
- The proposed options may technically secure urban water supply toward 2030.
- Better efficiency and cost-effectiveness of the municipal system is to be achieved.

GRAPHICAL ABSTRACT



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ABSTRACT

Water produced from municipal utilities accounts for nearly 10% of the sum water demand in China. The municipal water cycle that integrates processes of urban water supply, water use, sewage treatment, and water reclamation has been assessed for 655 cities across nine drainage areas in mainland China in 2012. These cities in total extracted 55 km^3 raw water for municipal use from surface waterbodies and ground aquifers, approximate to the country-wide freshwater extraction of Russia or Italy. After purification and transmission, 45 km^3 water was distributed to industrial, service, and domestic users. 36 km^3 of post-use sewage was collected and environmentally safely treated; merely 3.2 km^3 of the treated water was reclaimed. Driven by increasing urbanization, the municipal water demand in cities of China may grow 70% by 2030. The Hai River and the Huai River basins, which harbor 137 cities and occupy a majority of the densely populated North China Plain, are most exposed to physical water scarcity. The municipal water abstraction in these cities can remain constant by promoting demand-side and process conservation in the next two decades. Interbasin transfer and unconventional sources will provide municipal water double than the cities' need. Whereas the urban water security can be technically enhanced, the challenges are to better improve water use efficiency and mitigate economic and environmental costs of the municipal system.

* Corresponding author at: Global Innovation Research Organization, Ritsumeikan University, 1-1-1 Noji-higashi, Kusatsu, Shiga 525-8577, Japan.
E-mail address: a.t.wang@foxmail.com (T. Wang).

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1. Introduction

A secured supply of clean water and sanitation is critical to human health and the urban environment. Municipal water accounts for 10% to 20% of a country's total water extraction (FAO, 2016). It is indispensable for modern cities, streaming through networks of underground pipes that connect environmental water bodies to nodes of collection, purification, and storage facilities, and ultimately to users. Of equal importance are municipal sewerage systems that convey wastewater from urban sources to environmental sinks via drainage pipelines and treatment works. Municipal water supply, sewerage, and drainage constitute the backbone of urban water cycle.

Notable changes have occurred in urban water management in the past decades. Municipal water, sewage, and storm water, once treated independently of each other, had evolved toward system management and integration approaches. A greater focus had been devoted onto interactions between system components and collaborative behaviors of the system agents throughout the cycle of water supply and drainage. Moreover, the municipal water system was coordinated with the hydrosphere and the river basin where the city locates (Hardy et al., 2005; Brown et al., 2009; Marlow et al., 2013; Bach et al., 2014). Higher level of integration in water management systematically explored the nexus between water and other physical (e.g. energy and materials) and non-physical flows (e.g. capital) (Harou et al., 2009; Venkatesh and Brattebø, 2011; Zhou et al., 2013; Pauliuk et al., 2014). It also reconciled the water objectives with its social, economic, environmental, cultural, and institutional context (Brown et al., 2009; Hering et al., 2013; Lanea et al., 2015).

Analyzing the urban water cycle in China will be favorable to enrich our knowledge on water management and the urban environment. Rapid and sustained economic development has rendered China financial and technological capabilities to upgrade its municipal water and sewage services. Since 1980, over 1250 billion CNY (200 billion USD) had been invested into the infrastructure construction and renovation. Over 90% of her urban population, including nearly 500 million living in cities and 130 million in towns, had connection to municipal water networks. >3500 municipal sewage plants were operating throughout the country. Municipal sewage treatment rate ascended to 90% as of 2013, up from 34% in 2000 (MOHURD, 2015).

Despite these achievements, urban water challenges are becoming increasingly compelling and complicated in China. The effects could spill over to the entire globe by shaking public health and economic prosperity. The first and foremost is water scarcity. On per capita basis, China's renewable freshwater availability is barely one-third of the world's average (MWR, 2013a; World Bank, 2015; FAO, 2016). Over 400 cities were reportedly short of water; among them, 108 cities, including megacities of Beijing, were in severe water distress (Cheng et al., 2009; MWR, 2013a). Profound urbanization and the new rich's preference for water-intensive food and products aggravate tensions of water resources. The heavy pollution that accompanies China's industrial development exacerbates the difficulty of water management. Climate change and more frequent weather extremes make the urban water infrastructure vulnerable. Furthermore, the water challenges in China are also driven by "soft" factors, such as institutional shortcomings, poor management, and knowledge gaps (Cheng et al., 2009; Cheng and Hu, 2011; MWR, 2013a).

Understanding the status quo of urban water management in China will help address the above challenges. So far, the urban water cycle has been analyzed for the water-stressed cities in Northern China mainly. Huang et al. (2013) evaluated Beijing's urban water cycle and provided optimization scenarios for its water resource planning. Shao et al. (2013) investigated the regulatory framework of water cycle management in Beijing. Wen et al. (2014) examined the municipal water system and its energy use in Qingdao, a major seaport and industrial center on the north coast of China. Chu et al. (2015) assessed the water cycle and their structure efficiency in 20 cities in the Hai River basin in North China.

In this work, we attempt to make a more comprehensive assessment for municipal water management in China. A systematic and streamlined framework has been devised to assess the municipal water cycle from water abstraction, purification through water use and sewage treatment. For 655 cities with municipal water or sewage services, their water flows and water use efficiency are quantitatively and consistently estimated. This present work follows the principles of parsimony and extensibility. It centers on municipal processes and flows only. But the assessment model can be expanded to investigate industrial, agricultural, and other non-municipal water flows.

2. Materials and methods

The system boundary definition of the municipal water cycle is displayed in Fig. 1. A succession of boxes, characterizing processes of water transformation, transmission, and storage, are plotted from left to right. What connect the boxes in the figure are water flows, whose quantities will be assessed by this work.

A digital label is put to every process for better identification. There are nine major municipal processes, numbered from 1 to 9, as below:

(1) Raw water collection and transmission. Raw water is extracted from rivers, lakes, or aquifers, then transferred via aqueducts or buried pipes to purification plants.
(2) Municipal water purification. Suspended solids and contaminants are removed from raw stream to produce water fit for specific purposes.
(3) Municipal water distribution. It consists of a large network of storage tanks, valves, pumps, and transmission pipes. Purified water qualified for end use is delivered to consumers through the network.

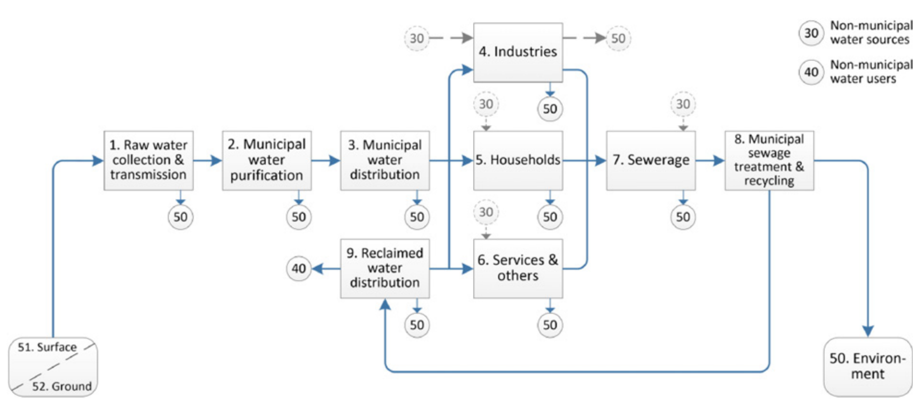

Fig. 1. System boundary definition of the municipal water cycle.