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Water footprints in Beijing, Tianjin and Hebei: A perspective from comparisons between urban and rural consumptions in different regions

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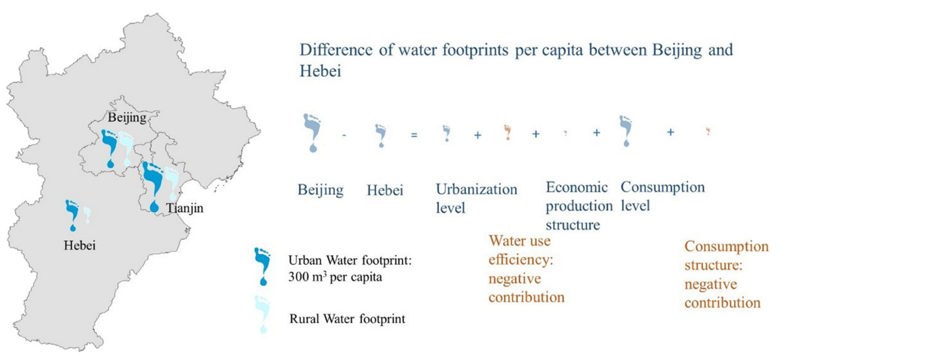
HIGHLIGHTS

- Structural decomposition analysis is adapted to analyze spatial water footprints.
- Urbanization leads to increased water footprint per capita.
- Inhabitant consumption level is the main raison for water footprint difference.
- Policies towards sustainable water resources consumption are informed.

GRAPHICAL ABSTRACT



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ABSTRACT

Examination of a region/country's water footprint and its underlying influencing factors is essential for enhancing understanding of water resource problems and challenges. This study addresses the influencing factors that lead to different consumption-based water footprints (WFs) per capita in different countries/regions, with emphasis on differentiating urban and rural WFs and examining the role of urbanization. Structural decomposition analysis, which is conventionally used for investigating temporal changes of an environmental variable, is adapted to inspect the factors shaping spatial difference. This adapted approach breaks down the difference of WFs per capita between provinces into five contributing factors, i.e., urbanization level, direct water use efficiency, production structure, inhabitant consumption level and consumption structure. According to WF accounting based on input-output tables in Beijing, Tianjin and Hebei in the greater capital region of China in 2010, the urban WFs per capita are between 1.6 and 3.7 times the rural WFs. Residential WFs per capita in Beijing, Tianjin and Hebei show a large variability between 114 m^3 and 463 m^3. The results of the adapted structural decomposition analysis indicate that urbanization and rising consumption levels, which are two foreseeable trends when economic and social conditions improve, result in increasing WF per capita, whereas the direct water use efficiency, economic production structure and consumption structure may contribute to offset the WF. Inhabitant consumption levels dominate other factors resulting in differences of WF per capita between provinces. The results are beneficial for informing policies towards sustainable water resource consumption under the framework of the integrated development of the greater capital region in China.

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1. Introduction

Virtual water (VW), which refers to freshwater used to produce commodities and transferred among countries/regions with international or interregional trade (Allan, 1998; Hoekstra and Hung, 2005; Hoekstra and Chapagain, 2008), makes water a global collective resource that can flow among countries/regions with commodity trading. VW trade has been considered as both a policy instrument and practical means for balancing local, national and global water budget (Yang et al., 2006). VW constitutes a substantial portion of global water consumption (Hoekstra and Mekonnen, 2012). As a result, a country/region does not necessarily rely only on local freshwater resources, and withdrawn water is not necessarily consumed locally (Allan, 1998). The water footprint (WF), defined as the total amount of water used for producing all the products and services consumed by inhabitants in one region/country, extends local water use beyond the regional and sectoral scope. WF has been increasingly used as means of synthesizing water needs of inhabitants in one region/country (Hoekstra and Chapagain, 2007; Godfray et al., 2011; Hoekstra and Mekonnen, 2012; Hoekstra, 2013).

Along with population growth and economic development, water demand keeps rising, resulting in increasing pressure on the available water supply in many parts of the world (Vorosmarty et al., 2000; UNDP, 2006). In addition, over half of the world's population now resides in urban areas, and by 2050, 66% is projected to be urban (UN, 2014). As urban lives are generally characterized by more concentrated natural resource consumption (including water, Vanham et al., 2017), the world, which continues to urbanize, features increasing water resources demand. The number of people subject to water shortages is increasing and a growing proportion of water-scarce populations are faced with more severe water shortages (Kummu et al., 2010).

This article examines human appropriation of water by analyzing the WF, using Beijing, Tianjin and Hebei in the greater capital region of China as a case study. This region has long been under great water pressure, because of a relatively dry watershed and high population density. Annual freshwater availability is on average less than 250 m^3 per capita, which is below the “absolute scarcity” threshold of 500 m^3 per capita (UNDP, 2006). Overexploitation of local water has resulted in decreasing stream flows, groundwater depletion and eco-environmental degradation (Bao et al., 2012; Liu and Xia, 2004). Limited water resources have become a bottleneck to further socio-economic development. Provincial-level WF accounting in China reveals highly unbalanced WF levels in this region (Zhang and Anadon, 2014; Jiang et al., 2015; Sun et al., 2017).

Examination of underlying factors impacting one region/country's WF is essential to enhance understanding of water resource problems and challenges. Decomposition techniques, which usually break down WF changes over time into attributions from a number of factors, have been widely used for examining the driving forces of temporal WF changes (Wang et al., 2015, Wang et al., 2014, Xu et al., 2015, Zhang et al., 2012). In particular, when the WF (or carbon footprint) is accounted for based on input-output tables, structural decomposition analysis (SDA) is often applied (Casler and Rose, 1998; Guan et al., 2008; Peters et al., 2007; Wang et al., 2014; Zhang et al., 2012). For instance, dynamic decomposition of WF changes in China reveals the effects of different factors by applying SDA (Wang et al., 2016; Yang et al., 2016). Similarly, causes that lead to WF changes in Beijing between 1997 and 2007 were analyzed via SDA (Zhang et al., 2012; Yang et al., 2015). In this study, instead of decomposing WF changes over time in one region as in the conventional SDA applied studies, the difference of WFs between different provinces with different socio-economic states will be decomposed in order to identify the influencing factors shaping provincial WFs. Urbanization is rarely considered explicitly as a key factor in previous decomposition analyses of WF changes. This study will conduct a detailed analysis of urban and rural WFs in the greater capital region in China and introduce the urbanization level as a potential factor that impacts a province's WF. This will be particularly useful in developing relevant policy responses towards sustainable urbanization and water resources planning and management, under the framework of integrated development for Beijing, Tianjin and Hebei, which has recently been proposed as a priority national strategy (in 2015) in order to promote sustainable socio-economic development in the greater capital region. Novelties of this study mainly lie in two aspects: 1) adaptation of SDA for decomposition of the spatial difference of WF variables, and 2) inclusion of urbanization level as a potential factor that may impact WF variables.

2. Study region and data

The greater capital region including Beijing, Tianjin and Hebei in China is located on the coast of the Bohai Sea, covering an area of 21.7 million ha (Fig. 1). The region is home to more than 110 million inhabitants, which is approximately 8% of China's total population. As China's ‘ladder-up’ strategy of economic development has increased income and urbanization inequality between regions and urban and rural areas (Guan and Hubacek, 2007), differing regional development policies have led to highly unbalanced socio-economic development in this greater capital region of China. Beijing and Tianjin, which are two province-level municipalities (hereafter referred to as provinces for short), are among the most developed provinces in China, whereas Hebei is one of the poorest provinces, with a much lower urbanization level and GDP per capita less than half of that in Beijing and Tianjin (China National Bureau of Statistics, 2008). This area is highly water stressed with annual averages of available water resources per capita of 149, 107 and 212 m^3 in Beijing, Tianjin and Hebei, respectively, in the last two decades (Fig. 1). Available freshwater per capita tended to decrease as population grew.

The main data foundation of this study is the multi-region input-output (MRIO) table in China in 2007 (Liu et al., 2008) that describes monetary transactions of goods and services for both intermediate and final uses between 30 sectors in provinces in China. The 30 sectors include agricultural (one sector comprising farming, forestry, animal husbandry and fishery), industrial (comprising 23 subsectors) and tertiary sectors (comprising 6 subsectors) (see Table S1 in Supplementary materials). Consumption of final products in the 30 sectors by urban and rural inhabitants is separately provided in the MRIO table. In addition to consumption by rural and urban inhabitants, final consumption of products also includes governmental expenses, investment and export to other provinces or countries, which are not considered here, because this study focuses on rural and urban inhabitant WF.

Similar to many previous studies (e.g., Zhang et al., 2012; Zhang and Anadon, 2014; Sun et al., 2017), this article is concerned only with the blue WF, referring to freshwater including surface and ground water. The green WF, usually referring to the human use of evaporative flows, mostly for rain-fed agriculture, is not taken into account in this study. Since it constitutes a low water use opportunity cost as opposed to blue water (Yang et al., 2006), green water used for agricultural products would not be readily available for production in other sectors (Guan and Hubacek, 2007). Thus, it is less capable of being allocated between different sectors for water management purposes. From this perspective, policies and measures for water resources planning and management are mostly for blue water. Water use data in the agricultural, industrial and tertiary sectors are referred from provincial-level water resources bulletins (PWRB, 2007). Industrial water use is disaggregated into water used in detailed sectors proportional to corresponding water use data in the Chinese Economic Census Yearbook 2008 (the State Council Leading Group Office, 2008), following many previous WF studies in China (Zhang and Anadon, 2014; Sun et al., 2017). Total water use in the tertiary sector is disaggregated into detailed sectors (corresponding to the MRIO tables) according to the proportions of the intermediate inputs from the “water production and supply sector” to different detailed service sectors, following a previous approach