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SCENARIO ANALYSIS FOR URBAN WATER FOOTPRINT AND VIRTUAL WATER TRADE – A CASE STUDY OF BEIJING, CHINA

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The concept of water footprint and virtual water trade highlights the role of consumers and producers on water saving and introduces a global perspective for regional water resource management. However, the impacts of future sectoral final demand changes on water footprint and virtual water trade are seldom studied. This paper applied a single-region input-output analysis to quantify Beijing's water footprint and virtual water trade for the base year. Four scenarios are presented to see if the changes of the consumption pattern of agricultural sector will decrease the water footprint of Beijing in the year of 2020. The results show that simply decreasing the direct agricultural final demand by way of moving it to the import, export or other sectors is not effective in decreasing the water footprint of Beijing. This study suggests that schemes of industrial restructuring towards regional water saving must be cautiously evaluated.

INTRODUCTION

Water supply is often insufficient in North China. With a large population, rapid economic growth and high living standard, mega-cities always face much more pressure for providing enough water for human needs (Zhao et al., 2016a). Beijing is the capital of China, lying on the northern edge of the North China Plain. The administrated area is 16807 km^2, with 14 million people live in it. As a modern mega-city, Beijing ranks first in terms of per capita urban consumer expenditure of China and also has a very poor water resources endowment. The annual average precipitation is 585 mm (1956-2000), about 80% of which falls between June and September. The per-capita water resources in Beijing are insufficient of 300 m^3, about 1/8 of the national average, and 1/30 of the global average. Dominated by a warm temperate continental monsoon climate, Beijing also suffers from a lot of extreme climate events, such as floods and droughts. The city has been hit by continuous droughts since 1999, with the annual rainfall 428 mm on average, only 70% of the annual rainfall in normal years (Chen and Yang, 2009). The water shortage has become the bottleneck for Beijing's further development. In the latest Master Plan of Beijing (2004-2020), water has been regarded as a limiting factor for Beijing's future population growth.

In recent years, global virtual water trade is considered as a useful tool for solving the problem of insufficient water supply in the water scarce regions. Following the virtual water concept, Hoekstra and Hung (2002) advanced the water footprint (WF) concept to highlight the consumers' responsibility and global perspective for saving water. The two concepts together give new hope for solving water crisis by adding global and consumer perspectives for water resources management. However, previous studies paid little attention to the assessment of the economic and social effects on the two indicators in the future through different scenarios. One of a few exceptions can be found in Zhao et al. (2015), who have developed two scenarios in 2030 to investigate the change of water stress within China influenced by both virtual and physical water flows. Since final consumption is the driving force in determining the WF and virtual water trade of a region, our study is intended to find the effects of changing final consumption pattern on the virtual water flows and WF under a city's future structural economic framework.

Choosing Beijing as a case study, this paper aims to analyze the change of virtual water flows and WF using an IO based WF framework under four scenarios of different final demand patterns and water use in the year of 2020. Beijing under severe water stress is a hotspot to study the WF and virtual water flows (Han et al., 2015; Hoekstra and Mekonnen, 2012; Wang et al., 2013; Xu et al., 2015; Zhang et al., 2012; Zhao et al., 2016a). However, none of the above analyses have carried out scenario analysis to look at Beijing's future WF. Scenario analysis was proposed in the 1950s and is widely used in many fields. Combined with scenario analysis, IO method has long been used to study the future human-water interaction under the economic background. For example, Hubacek and Sun (2005) developed a set of scenarios with IO model to investigate the major changes in economy and society and their effects on the water situation in China. Llop (2008) analyzes the economic impact of various water policy scenarios implemented on the Spanish production system using IO framework. Xu et al. (2008) used a physical monetary IO model to analyze China's future material metabolism patterns including water use, with the scenarios to reflect China's consumption structure change and technology development. However, as far as we know, seldom studies have analyzed different scenarios under the changing final consumption pattern for both the WF and virtual water flows for a megacity.

The paper is organized as follows. Section 2 analyzes Beijing's water use and supply at present and in the future. Section 3 introduces the method for estimating future IO transaction table and presents the scenarios. The results of scenarios are presented and discussed at Section 4. Section 5 gives conclusion for the paper.

WATER USE AND SUPPLY IN BEIJING

Usually, Statistics in China decompose the total water use as agricultural water use, industrial water use and domestic water use. Figure 1 shows the total water use and its three components in Beijing from 1988 to 2007. The total water use in Beijing has decreased by 18% in the 20 years statistics. Sharply decrease happened twice respectively in the year of 1996 and 2002, and little changes from 2002 to 2007. Domestic water use has seen a trend of increase, while decrease happened in agricultural and industrial water use. In the year of 2005, domestic water use first exceeds the agricultural water to rank first among the three components, accounting for about 39% of the total water use. The high proportion of Beijing's domestic water use among the total water use is mainly because of the high volume of the per capita domestic water use, which is 269L/d in 2005, ranking 6th among China's 31 provincial administrative regions.

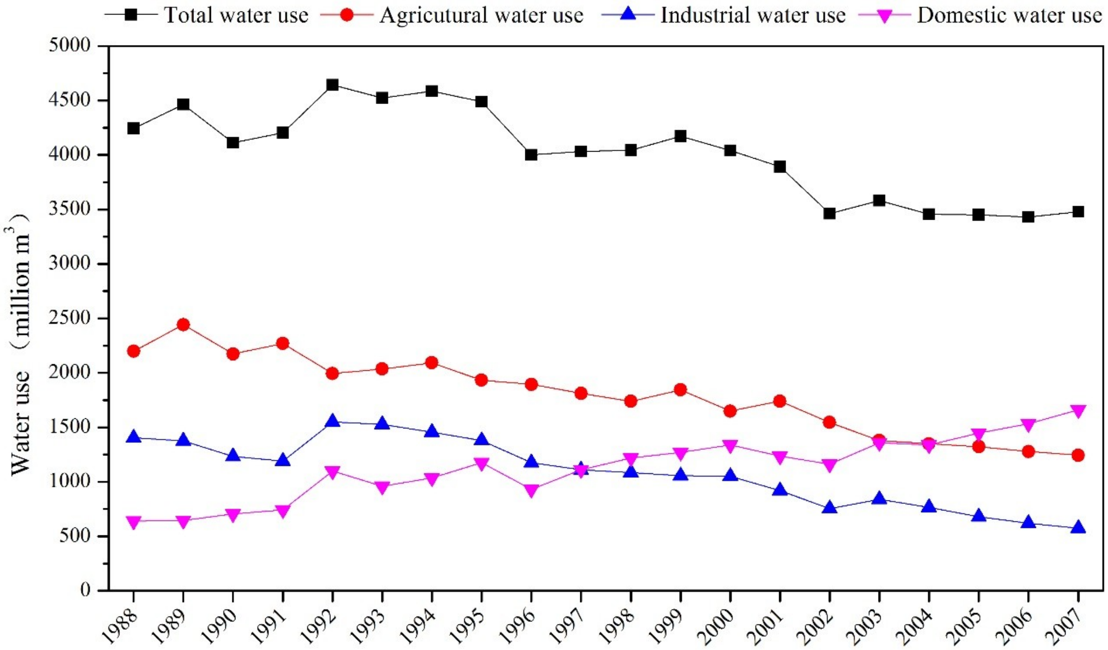

Figure 1. Water use in Beijing 1988-2007

Water supply of Beijing is from surface water, ground water, rain water and reclaimed wastewater. Surface water occupies about only 16% of the total water supply of Beijing finished in 2007. Two reservoirs, Guanting reservoirs and Miyun reservoirs, account for 66% of Beijing's surface water source. In recent years, however, the water storage of the two reservoirs decreases rapidly. To compensate the insufficiency of water supply, Beijing has been relying increasingly on pumping groundwater, which has become the major supplier for Beijing's water use. In 2007, the ground water use accounted for about 70% of the total water supply, whereas in 1980s, it was only about 48% of the total. The withdrawal of groundwater leads to rapid depletion of aquifers, which aggravate the deterioration of Beijing's water environment. Utilizing reclaimed wastewater is another measure to alleviate Beijing's water crisis. After appropriate treatment, sewage water can be used for irrigation and groundwater recharging. The sewage water in Beijing is about 1.3 billion m^3, with 53% being reclaimed for Beijing's urban water use (Wang and Huang, 2008).

Future water deficit can be forecast through water demand and supply projection. The authorized water demand and supply projection of Beijing can be found in Beijing's Integrated Water Resources Planning finished in 2007. According to the projection, Beijing will be short of 2.3-3 billion m^3 of water in 2020, without any water saving measures implemented. However, several water saving measures have already been implemented and projected to prevent Beijing from water crisis. For example, as the Master Plan of Beijing (2004-2020) advocates, Beijing should continuously reinforce rainwater reuse and recycled water use, adjust industrial structure for more water saving direction, and shift the water pricing policy. The projection then reconsidered the water demand with all these above measures included and found that there will be still 1.1-1.8 billion m^3 of water deficit in 2020. The balance of water demand and supply will finally resort to the accomplishment of the South-North Water Transfer Project before 2020. According the projection, Beijing will transfer 0.5-1 billion m^3 of water in 2010, and reach the final aim of transferring 1.2-1.4 billion m^3 in 2020.

Water deficit is always overstated by water demand and supply projections in China as well as in many other countries (Yang, 2003). According to our analysis, the above projection also overestimated Beijing's future water demand. In the projection, water use in agriculture, industrial sector and family of Beijing's future all exceed those of 2007. This is obviously inconsistent with the trend that can be seen in Fig. 1, where only domestic water use has experienced gradually increases in these years. Master Plan of Beijing (2004-2020) project that the GDP derived by agriculture will only account for 1% of the total, compared with the present 2%. So there will be no reason for the increase of agricultural water use with the compressing of agricultural production, not to mention the water saving measures implemented in Beijing's irrigation system. As for industrial water use, it is more reasonable to expect the decrease or at least the steadiness with the effects of structural shift and technology development. Overestimation of the water demand quota is one of the reasons for a large water demand. The projection based on the lower water demand quotas will significantly narrow the water deficit gaps (Yang, 2003). Indeed, in spite of the overestimation, Beijing's water shortage can be manifested through great amount of groundwater over-withdrawal and wastewater reuse. The present system of water supply is not sustainable, nor inclined to protect the urban groundwater environment. As for the forecast of the future water demand in Beijing, we recommend the agricultural and industrial water use should not be projected over the present volume in 2007. In this study for scenario analysis, we set the water demand in 2020 to be the same as in 2007.

METHODOLOGY AND DATA

Quantification of the water footprint and virtual water flows

This study used a single-region input-output analysis to quantify Beijing's water footprint and virtual water flows in base year 2007. The input-output transactions table in 2007 is derived from Beijing Statistics Bureau. The water use data for Agriculture, Industry and Service is from Beijing Water Resources Bulletin. The disaggregation of water use to Industrial and Service sectors is derived from Zhao et al. (2010), The detailed sectoral water use of Beijing in 2002 is shown in Table 1. The method of using input-output analysis to quantify water footprint and virtual water flows can refer to Zhao et al. (2009) and Zhao et al. (2010).

Estimating IO transaction table with RAS method

For the purpose of scenario analysis, an IO transaction table should be estimated for the year of setting scenarios. The most widely used IO table estimating technique is the RAS method. Introduced

Table 1. Sectoral water use of Beijing in base year (million m^3)

	Sectors	2002
1	Agriculture	1545.00
2	Mining	4.08
3	Food and tobacco processing	18.29
4	Textile, leather, and other fiber products	7.49
5	Lumbering and paper products	7.16
6	Petroleum processing and coking	4.55
7	Chemicals	20.53
8	Non-metal mineral products	20.45
9	Metal products	49.12
10	Machinery and equipment	30.51
11	Electricity, gas, and water production and supply	591.82
12	Construction	13.81
13	Wholesale and retail trade and passenger transport	455.03
14	Other services	164.16
Water use for production and environment		2932.00
Domestic water use		531.00

by Stone (1961), the method has the advantages of clarity and operational simplicity for analysis (Toh, 1998). If the base year technology matrix is denoted, then each technical coefficient in the technology matrix is subject to two temporal effects (Parikh, 1979): (a) the substitution effect, measured by the extent to which the output of the *i* sector has been replaced by, or used as a substitute for, other sectoral output in intermediate production; (b) the fabrication effect measured by the extent to which the ratio of intermediate to total inputs decreases in the *j* sector. As the result of the two effects, the new matrix A_1 for the estimated year can be written as:

$$A_1 = \hat{r} \cdot A_0 \cdot \hat{s} \tag{1}$$

where $\hat{r}$ and $\hat{s}$ are diagonal matrices representing the fabrication and substitution effects, respectively. A_0 is the technology matrix for the base year.

Usually, final demand, initial input and output of the estimated year need to be derived first. Then the technology matrix A_1 can be calculated through the RAS method. The method needs for a successive bi-proportional adjustment of the rows and columns of the base matrix, until convergence is reached (Parikh, 1979).

Scenarios for different patterns of final demand

The drivers for the scenarios in this study is Beijing's final demand. Then some other factors is estimated as constant. We first estimate the future GDP and its allocation to sectors. The Master Plan of Beijing (2004-2020) projected that Beijing's future GDP will reach 10000 dollars per capita in 2020. Given the future population limitation as 180 billion, we may have the volume of the total GDP. The industrial structure of Beijing will turn to be a more consumptive oriented way. Before China's economic reform in 1979, industrial development was a major driving force of Beijing under the ideology of "converting consumptive cities into productive centers" (Zhang and Brown, 2005).

However, since 1990s in last century, Beijing refocused his urban development on the characteristics as the nation's capital. The latest issued Master Plan (2004-2020) has reiterated that Beijing should focus on developing tertiary sector (service sector) and adjust the structure of industry toward high-tech sectors as the dominant direction of economic growth of Beijing. To sum up, the Master Plan (2004-2020) formulated that the tertiary sector will account for 70% of total GDP of Beijing by 2020, while agriculture and industry will account for only 1% and 29% of the total, respectively. Combining the information of the three main sectors' GDP and the detailed sector's GDP ratio in 2007, we break down the total GDP into the above used 14 sectors, the results of which will be taken as the initial input to the IO table in 2020.

The WF of a region is composed of the internal WF and external WF, and the virtual water trade of a region is composed of virtual water import and virtual water export. Internal WF is determined by the factors of direct water input, technology coefficients, and domestic final demand, and the first two factors together reflect a technology scale of a region for the water use efficiency; external WF or virtual water import are determined by the coefficients of imports; virtual water export is determined by the domestic export. To derive the WF and virtual water trade, we need to know the domestic final demand, and the volume of import/export of Beijing. Domestic final demand is the determining factor for internal WF. As for external WF, since we assume there is no difference of the water use efficiency and economic structure between the study region and the virtual water importer, the ratio of the imports to total final demand is irrelevant with the volume of the total WF, although it will determine the volume of external WF.

Four scenarios with different final demand are presented. Scenario 1 assumes each sector's final demand has the same proportion among all the final demand as in that the year of 2002. In scenario 1, we use the adjusted ratio of initial input to total output in 2002 to derive the output in 2020. A free of charging software named IOW is used here for deriving the RAS matrix. Then the technology coefficients can be achieved through RAS method. The other three scenarios use the same technology coefficients as in scenario 1. Scenario 2 assumes there is no agriculture export, while the loss will be compensated by the export of the food and tobacco processing. Scenario 3 sets the domestic agricultural final demand as zero, while instead, people's demand on agricultural products are distributed evenly to the sectors of service and the food and tobacco processing. Meanwhile, as the decrease of the agriculture output, the water use in agriculture is assumed to decrease by 80%. In scenario 4, imports replace the domestic production for the domestic agricultural final demand, and the water use in agriculture is assumed to decrease by 80%.

RESULTS

Table 2 shows the results of the WF and net virtual water import for the base year and the four scenarios. Surprisingly, scenario 1 has the lowest WF among the four scenarios, which is also the only scenario that is lower than the WF of the base year. Scenario 2 has the largest estimated WF. Both internal WF and external WF of the scenario 2 are higher than the WF of the base year and Scenario 1. The results of the scenario 3 and scenario 4 are close: they have the same internal WF and the close external WF. The WF of the scenario 3 and scenario 4 are also close to the WF of the base year. Compared to the results of the base year, the differences are the two scenarios have lower internal WF and higher external WF. As for the net virtual water import, scenario 2 is the only net virtual water exporter among the 4 scenarios, and the other 3 scenarios are net virtual water importers.

Table 2. Water footprint and net virtual water import of the base year and four scenarios (million m^3)

	WF	Internal WF	External WF	Net virtual water import
Base year (2002)	3410	1887	1522	478
Scenario 1	2755	1674	1081	106
Scenario 2	4350	2649	1701	-151
Scenario 3	3743	1654	2089	305
Scenario 4	3693	1654	2039	109

The differences are also shown in the virtual water content (VWC, measured as the water use per total output for each sector) of the four scenarios (Fig. 2). Two sectors, agriculture and electricity, gas, and water production and supply, still have high VWC among all the sectors. The VWC of agriculture in the four scenarios all decreased a lot, because of the increase of the output and the decrease of agricultural water use. Except of scenario 1, however, all the other scenarios have a higher VWC of electricity, gas, and water production and supply than the volume of the VWC in the base year.

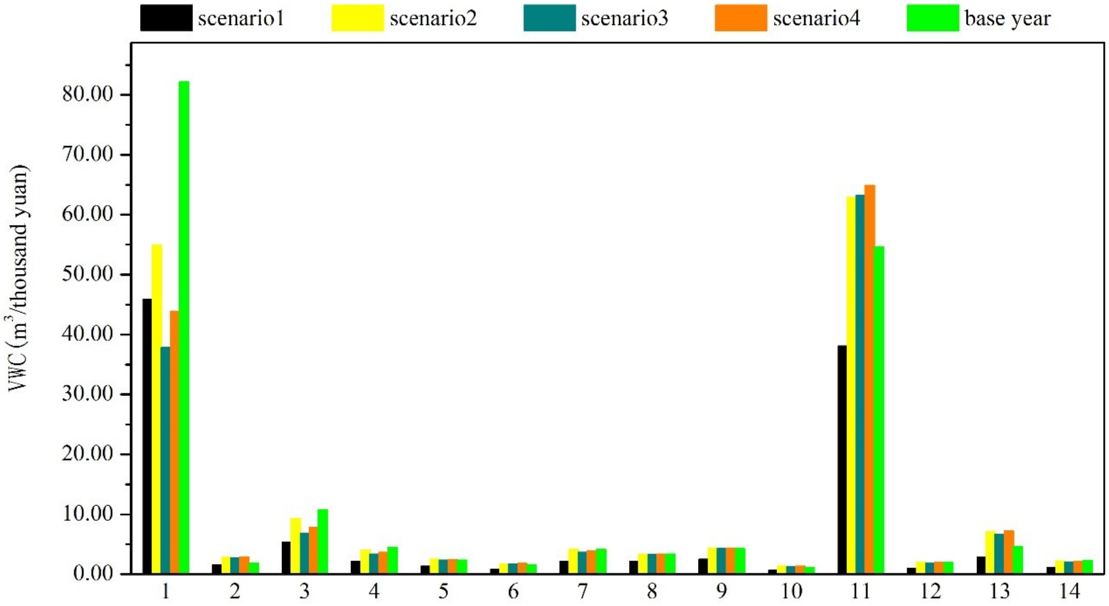

Figure 2. Virtual water content of the 4 scenarios.

DISCUSSIONS AND CONCLUSIONS

The future cannot be foreseen, but exploring the future can reform present decisions (Manos et al., 2007). Aiming to saving more water for Beijing's future, we set the scenarios for deriving the WF and net virtual water import of Beijing with different sectoral final demand, 2020. The parameters for deriving Scenario 1 stick to the economic projection of the Master Plan of Beijing (2004-2020). And as agriculture is the crucial sector for the virtual water strategy, we advanced 3 other agriculture related scenarios to examine if the change of the consumption pattern of the agriculture will decrease the WF of Beijing in the year of 2020. Before scenario analysis, we first forecasted the future water use of Beijing under the analysis of Beijing's trend in water use and supply, and argued that Beijing's water use will not increase in the future. We calculated the WF and virtual water trade of Beijing in the year of 2002 with 14 sectors' disaggregation, and found that Beijing's agriculture contributes a lot to the WF.

The scenario analysis showed that scenario 1 decreases the WF and net virtual water import of Beijing. The reasons is that the increase of the output decreases the VWC, and help decreasing the WF of future; while secondly, the adjustment of future economic structure will have a good effect on saving water. The other scenarios (scenario 2-scenario 4) focus on the adjustment of the final demand of agriculture. It is testified that simply decreasing the agricultural final demand in the way of moving it to the import, export or other sectors is not effective for decreasing the WF of Beijing, even with the corresponding huge drop of agricultural water use. For example, scenario 4 aims to fulfill the domestic agricultural final demand all by importing agricultural products. However, the only change is the external WF of scenario 4 increases by almost one times compared with the indicator of scenario 1, thus leads to the rise of the WF. So when considering the consumption pattern change, the direct and indirect economic effects on the sectors may lead to an unexpected reverse results contrary to what we desire first. The case of this paper suggest that a city with poor water endowment should do more researches when it intends to implement the virtual water strategy or exploring the advantages of WF concept in establishing the future water management policy.

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