Understanding Beijing's water crisis: changes in water footprint of Beijing 1997-2007

Zhuoying Zhang[1], Minjun Shi[2,3] Hong Yang[4]

1 Academy of Mathematics and Systems Science, Chinese Academy of Sciences, 100190, Beijing, China

2 Graduate University of Chinese Academy of Sciences, 100049, Beijing, China

3 Research Centre on Fictitious Economy & Data Science, Chinese Academy of Sciences, 100190, Beijing, China

4 Swiss Federal Institute of Aquatic Science and Technology, 8600, Dübendorf, Switzerland

Abstract

Beijing has experienced deteriorating water crisis in the context of inspiring economic growth. This study conducts a quasi-dynamic input-output analysis to examine the changes in Beijing's water footprint and the contributing determinants during 1997-2007. The results indicate Beijing's water footprint significantly increased from 4342 million m^3 in 1997 to 5748 million m^3 in 2007. An analysis distinguishing "internal" and "external" water footprint reveals an intensified situation of Beijing's water crisis, although external water footprint as a water resource supplement has considerably ameliorated Beijing's water pressure. The structural decomposition analysis shows technological effects are the principal contributors to offset water footprint increase, which confirms the effectiveness of Beijing's water-saving efforts. However, they are not powerful enough to reverse Beijing's exacerbating water shortage resulted from scale effects induced by notably expanded consumption scale and economic system efficiency effects closely associated with the developed bilateral trade between Beijing and other regions. This paper suggests the degradation in economic system efficiency induced by Beijing's overdependence on external product support calls for an attention. The results of this study enrich the

understanding of Beijing's water crisis and provide insights into solutions of water shortage in the future.

1. Introduction

The past decades have seen Beijing's most vigorous changes in economic growth, population expansion and industrial structure transition. During 1997-2007, the GDP of Beijing increased from 181 billion Yuan to 935 billion Yuan and the final consumption expanded from 70 billion Yuan to 508 billion Yuan (National Bureau of Statistics of China, 1998, 2008) (1 Yuan ≈ 0.16 USD). However, there has been a continued intensification of water shortage in the meanwhile. The average annual per capita available water resource (referring to surface and ground water resources in this study) of Beijing fell from 293 m^3/capita to 148 m^3/capita (National Bureau of Statistics of China, 1998 and 2008), revealing the already severe water pressure in Beijing is continuously deteriorating. A scrutiny into the changes in Beijing's water crisis behind the inspiring economic development can enrich the understanding of Beijing's water problem and provide insights for sustainable water resources management in Beijing in the context of its booming economic growth.

Virtual water is defined as the water used for the production of commodities (Allan, 1993, 1997). Another concept closely linked with virtual water is water footprint which refers to the volume of freshwater used to produce the product. Water footprint numerically equals to "virtual water content" but of multi-dimensional scope of the sort of water that was used (green, blue, grey), when and where the water is used. The term water footprint is usually used in a context where we speak about the water footprint of a consumer or a producer, whereas the term virtual water in the context of international (or interregional) flows (Hoekstra et al., 2009). From the perspective of virtual water/water footprint, all the economic behaviors are closely relevant to water and thus affect local water resource condition.

The significance of virtual water/water footprint in affecting local water resource conditions has been discussed by many literatures (Yang and Zehnder, 2002;Yang and Zehnder, 2007; Yang et al., 2006; Zimmer and Renault, 2003; Hoekstra and Hung, 2005; Chapagain and Orr, 2008; Chapagain and Hoekstra, 2011). The previous studies primarily focused on agricultural sectors due to the agricultural sectors' high water intensities and large shares in total water use on the one hand, and the constraint of the difficulties in quantitatively tracing the inter-sectoral connections along the production chain of the industrial sectors on the other. In recent years, input-output analysis, a technique quantitatively depicting the interconnection and interdependences of economic units, has increasingly been applied in the virtual water/water footprint assessment (Guan and Hubacek, 2007; Lenzen, 2009; Wang and Wang, 2009; Wang et al., 2009; Yang et al., 2010). Some studies have effectively extended the assessment to cover all economic sectors (Dietzenbacher and Velazquez, 2007; Zhaoet al., 2009; Zhao et al., 2010; Zhang et al., 2011a; Zhang et al., 2011b; Zhang et al. 2011c).

However, the gaps lying in previous studies should be noted. One is the simplex efforts on providing the "snapshot information" using the data of a single year or an average over a period of time. The dynamic studies investigating the changes in water footprint at different times are rare due partly to data constraint. Besides, the existing studies are apt to provide exhaustive descriptions on "what the situation is like", but lack of explorations on "how the situation is formed".

This study attempts to fill these gaps by conducting a quasi-dynamic analysis on the changes in Beijing's water crisis associated with water footprint in the framework of input-output analysis. The analysis not only represents a full picture of the changes in Beijing's water situation during 1997-2007, but also systematically investigates the key determinants leading to the changes. The results of this study contribute to a better understanding of Beijing's water problems, which might support the policy formulation for alleviating the water resource pressure in Beijing.

2. Data and Methodology

2.1 Data

The main data sources of this study are Beijing input-output tables of 1997, 2002 and 2007 (National Bureau of Statistics of China, 1997, 2008 and 2011). Considering the sector correspondence between Beijing input-output tables and the data for sectoral freshwater uses, the original sector divisions in Beijing input-output tables are aggregated into 30 sectors (see Table 1 for the aggregated sector divisions). In Beijing input-output tables, import includes both interregional import (import from other regions within China) and international import (import from foreign countries). So do the export. Hence, in the following water footprint accountings, the effects of the interregional support and international support are not discriminatively discussed.

In this study, water resources, water uses and virtual water concern only "blue water", i.e., surface and ground water. Soil moisture, the so-called 'green water', is not considered.[1] Except for the agricultural sector and the sectors to which agriculture provides raw materials in the production processes, sectors exclusively use blue water. Including green water would greatly increase the share of agricultural water use and we would thus derive biased conclusions in assessing the value of water use across different sectors.

In this study, the data of the "direct water use coefficient" (DWUC, in m^3/Yuan) indicating the direct freshwater uses per monetary unit of production are preliminarily estimated based on Beijing Sectoral Water Requirement Quotas (Beijing Municipal Water Conservation Office, 2001). Then the annual differences in DWUC are specified through the data calibration on the water use amount of the "three industries" in each year (Beijing Water Authority, 1997, 2002, 2007).

In both agricultural and industrial sectors, part of the water used is returned to the natural water systems through percolation and/or drainage and wastewater discharge. Considering the return flow from agriculture may be available for downstream users, the calculation of the agricultural water use and virtual water trade deducted the return flow by multiplying the direct water use coefficient with the water consumptive use ratio available from Beijing Water Resources Bulletins (Beijing Water Authority, 1997, 2002, 2007). In industrial sectors, The recycling and reuse of

[1]Our definition of blue and green water follows that by Falkenmark and Rockström (2006).

the unpolluted water within the system is excluded in the water use, while the wastewater discharge is not deducted from the industrial water use due to lacking information on the actual discharge rate and the pollution intensity in each industrial sector Neglecting wastewater return flows in the industrial sectors in the calculation of virtual water flows is also seen in other studies, i.e., Hoekstra and Chapagain, 2007, Zhao et al., 2010.

2.2 Methodology

This study quantifies the water footprint of Beijing in the framework of input-output model which represents the monetary transactions of goods and services among different sectors of economic system (Leontief, 1941). Input-output model is a practical tool in water footprint accountings since it provides quantified information on interconnections and interdependences of economic units which is essential for tracing the water used along the whole production process.

The water footprint in this study refers to the water used for the production of the goods and services consumed by the inhabitants of local region (Beijing). Since the products consumed in Beijing are not only produced locally using local water resources, but also produced outside of the region using the water resources of other regions, the water footprint of Beijing consists of two parts: the internal water footprint (the volume of water used from local water resources to produce locally consumed products) and the external water footprint (the volume of the virtual water imported from other regions minus any export of virtual water associated with the re-export of any (part) of the imported products).(Hoekstra et al., 2009; Zhao et al., 2009; Zhang et al., 2011b).

In this study, the approaches for water footprint accountings as well as the basis mathematical structure of input-output model follow Zhao et al. (2009), Zhang et al. (2011a) and Zhang et al. (2011c).

In this study, the quasi-dynamic analysis on the changes in Beijing's water crisis associated with water footprint is conducted by applying the Structural

Decomposition Analysis (SDA) which is an approach quantifying the relative importance of contributing effects by means of a set of comparative static variations in key parameters of input-output tables. SDA can help to identify the underlying determinant effects that influence the changes of a variable over time. (Hoekstra and Van den Bergh, 2002). Extending the input-output model to account for the determinant effects behind the changes can reveal the channels by which the targeted problem (i.e. water footprint in this study) are caused and transmitted throughout the economic system (Butnar and Llop, 2011).

In this study, the contributing effects of Beijing's water footprint changes during 1997-2007 are decomposed into technological effects, economic system efficiency effects, scale effects and structural effects to examine which effects determinately influence the changes in Beijing's water footprint and thus influence its water crisis situation. Technological effects denotes the influence of the changes in the direct water use efficiency reflected by DWUC which numerically equals to the amount of direct water intake to produce one monetary unit of output, representing the direct or the first round effects of the sectoral interaction in the economy (Bouhia, 2001; Hubacek and Sun, 2005). Economic system efficiency effects imply the influence of the inter-sectoral relationships based on supply and demand in the economic system. They are reflected by the impacts of the changes in Leontief inverse matrix on water footprint changes; Scale effects mean the influence of the changes in the total amount of the final consumption of Beijing. Structure effects depict the role of the changes in the sectoral distribution structure of the final consumption in changing water footprint.

The analysis is performed by changing the contributing effects one by one successively in order to quantify the contribution of each effect to the total changes in water footprint. This contribution may be derived based on both "polars": either the "base year value" or the "current year value". In this study, the contribution of each effect has therefore been determined using an average of the "two-polar" decomposition results. This treatment has been widely accepted in the relevant studies since it is intuitive in mathematical format, simple in execution and feasible in comparison of the weights of different effects. The same approach was applied by Vacara and Simon (1968), Fujimagari (1989) and Sawyer (1992).

The decomposition based on “base year value” is represented as the follows:

$$\triangle t_i = (\sum_i w_{i1} b_{ij1}) Y_1 \beta_{i1} - (\sum_i w_{i0} b_{ij0}) Y_0 \beta_{i0}$$
$$= \left[\sum_i (\triangle w_i) b_{ij1}\right] Y_1 \beta_{i1} + \left[\sum_i w_{i0} (\triangle b_{ij})\right] Y_1 \beta_{i1} + (\sum_i w_{i0} b_{ij0})(\triangle Y)\beta_{i1} + (\sum_i w_{i0} b_{ij0}) Y_0 (\triangle \beta_i) \quad (1)$$

and the decomposition based on “current year value” is:

$$\triangle t_i = (\sum_i w_{i1} b_{ij1}) Y_1 \beta_{i1} - (\sum_i w_{i0} b_{ij0}) Y_0 \beta_{i0}$$
$$= \left[\sum_i (\triangle w_i) b_{ij0}\right] Y_0 \beta_{i0} + \left[\sum_i w_{i1} (\triangle b_{ij})\right] Y_0 \beta_{i0} + (\sum_i w_{i1} b_{ij1})(\triangle Y)\beta_{i0} + (\sum_i w_{i1} b_{ij1}) Y_1 (\triangle \beta_i) \quad (2)$$

Therefore, the average of the “two-polar” decomposition is:

$$\triangle t_i = \frac{1}{2}\left\{\left[\sum_i (\triangle w_i) b_{ij1}\right] Y_1 \beta_{i1} + \left[\sum_i (\triangle w_i) b_{ij0}\right] Y_0 \beta_{i0}\right\} + \frac{1}{2}\left\{\left[\sum_i w_{i0} (\triangle b_{ij})\right] Y_1 \beta_{i1} + \left[\sum_i w_{i1} (\triangle b_{ij})\right] Y_0 \beta_{i0}\right\}$$
$$+ \frac{1}{2}\left[(\sum_i w_{i0} b_{ij0})\beta_{i1} + (\sum_i w_{i1} b_{ij1})\beta_{i0}\right](\triangle Y) + \frac{1}{2}\left[(\sum_i w_{i0} b_{ij0}) Y_0 + (\sum_i w_{i1} b_{ij1}) Y_1\right](\triangle \beta_i)$$
$$= \mathbf{T_i} + \mathbf{E_i} + \mathbf{Sc_i} + \mathbf{St_i} \quad (3)$$

In the above equations, the subscript “1” and “0” denotes current year and base year respectively. $\triangle t_i$ is the change in water footprint. w_i is the DWUC of sector *i*, calculated by dividing the water use of sector *i* by total output of sector *i* (in monetary term). b_{ij} is the element of the Leontief inverse matrix. Through multiplying DWUC and the Leontief inverse matrix, the total water use coefficient (TWUC), an indicator of the total water consumption throughout the whole production chain, can be obtained. The final consumption of sector *i* is obtained through the multiplication of the scale of the total final consumption (Y) and the percentages of the final consumption of sector *i* in the whole (β_i). In Eq. 3, the first item $\mathbf{T_i}$ denotes the contribution of the technological effects ($\triangle w_i$) to the changes in water footprint; the second item ($\mathbf{E_i}$) denotes the contribution of the economic system efficiency effects ($\triangle b_{ij}$) to the changes in water footprint; the third item ($\mathbf{Sc_i}$) denotes the contribution of the scale effects ($\triangle Y$) to the changes in water footprint; the fourth item ($\mathbf{St_i}$) denotes the contribution of the structural effects ($\triangle \beta_i$) to the changes in water footprint.

3. Results

3.1 Water use coefficient comparison

As stated in section 2.2, DWUC represents the direct water use intensity at the last stage of a production chain, whereas TWUC indicates the water intensity throughout the whole production chain. Hence, TWUC is higher than DWUC in individual sectors, which can be reflected by the results of water use coefficients (Table 1).

It can be observed that DWUCs of all sectors and TWUCs of most sectors notably decrease during the past decade. The scales of the decreases in TWUCs are 2% - 70%, which verifies the achievement in water use efficiency enhancement. The sectors with the most prominent decreases in TWUC include Sector 4 (manufacture of textile), Sector 5 (manufacture of textile wearing apparel and leather), Sector 19 (production and supply of water), Sector 24 (hotels and catering services), the decrease scales of which amount to over 70%. Agriculture, the sector of the highest water intensity, reveals observable decrease of 41% in TWUC as well.

It should be noted that some sectors experience continuous decreases in DWUC but fluctuations in TWUC. i.e., the DWUCs of sector 3 (manufacture of food) are respectively 73 $m^3/10^4$Yuan, 33 $m^3/10^4$Yuan and 15 $m^3/10^4$Yuan in the three years, whereas the corresponding TWUCs are 481 $m^3/10^4$Yuan, 178 $m^3/10^4$Yuan and 222 $m^3/10^4$Yuan. The “unexpected” increase in TWUC from 2002 to 2007, which seems against the general trend of the improvement in water use efficiency, is closely relevant to the changes in economic system efficiency. Regarding to this issue, more discussion is provided in Section 4.

Table 1. Water use coefficients in 1997, 2002 and 2007 ($m^3/10^4$Yuan)

	Sectors	DWUC			TWUC		
		1997	2002	2007	1997	2002	2007
1	Agriculture	754	414	364	993	637	588
2	Mining	92	41	19	153	109	65
3	Manufacture of Food	73	33	15	481	178	222
4	Manufacture of Textile	50	22	10	285	155	84
5	Manufacture of Textile Wearing Apparel and Leather	9	4	2	150	74	44
6	Processing of Timber and Manufacture of Furniture	14	6	3	119	86	63
7	Manufacture of Paper and Paper Products	151	68	31	234	140	92
8	Processing of Petroleum and Coking	45	20	9	159	109	68
9	Manufacture of Raw Chemical Materials and Chemical Products	79	35	16	228	124	84
10	Manufacture of Non-metallic Mineral Products	53	23	11	149	91	67
11	Smelting, Pressing and Manufacture of Metals	57	26	12	159	102	66
12	Manufacture of Special Purpose Machinery	8	3	2	93	61	39
13	Manufacture of Transport Equipment	12	5	3	107	61	39
14	Manufacture of Electrical Machinery and Equipment	12	5	2	108	63	43
15	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	7	3	2	93	53	38
16	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	9	4	2	80	44	33
17	Other manufacturing sectors	5	2	1	71	27	54
18	Production and Supply of Electric Power and Heat Power	258	133	70	300	178	190
19	Production and Supply of Water	1040	535	282	1176	652	338
20	Construction	11	6	3	109	66	51

21	Freight Transport and Storage	29	15	8	109	61	42
22	Information Transmission, Computer Services and Software	8	4	2	32	37	27
23	Wholesale and Retail Trades	16	8	4	78	37	28
24	Hotels and Catering Services	133	68	36	439	153	130
25	Tourism	36	19	10	157	48	63
26	Scientific Research	6	3	2	40	47	37
27	Education, Culture and Entertainment	8	4	2	44	48	43
28	Health, Sports and Social Welfare	9	5	2	114	72	55
29	Service to Households	37	19	10	104	66	48
30	Other Technical Services	9	5	3	71	59	69

3.2 Water footprint comparison

The total amount of water footprint of Beijing indicates successive increase: the relatively mild increase during 1997-2002 from 4342 million m^3 to 4406 million m^3 and remarkable increase during 2002-2007 to 5748 million m^3 (Figure 1).

An investigation on the distribution of Beijing's water footprint among the three industries is conducted and the results are presented in Figure 1. It can be observed that during the past decade, the proportion of agriculture's water footprint slightly decreases from 21% to 16%, the secondary industries considerably decrease from 62% to 47%, while the tertiary industries represent a remarkable decrease from 17% to 37%. The Changes in the water footprint distribution are resulted from the transformation of Beijing's final consumption structure which is characterized by the increasing significance of tertiary industries in composition of final consumption.

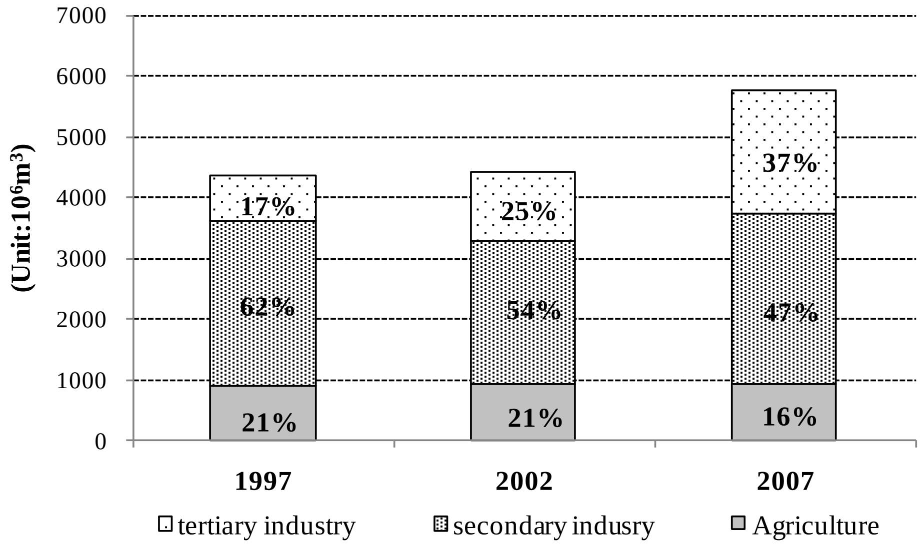


Figure1 The composition of Beijing's water footprint in 1997, 2002 and 2007.

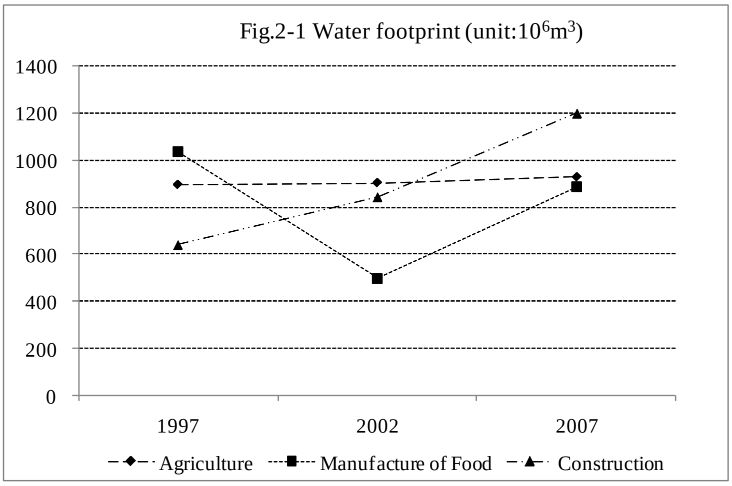
Table 2. The sectoral composition of water footprint of Beijing in 1997, 2002 and 2007 ($10^6 m^3$)

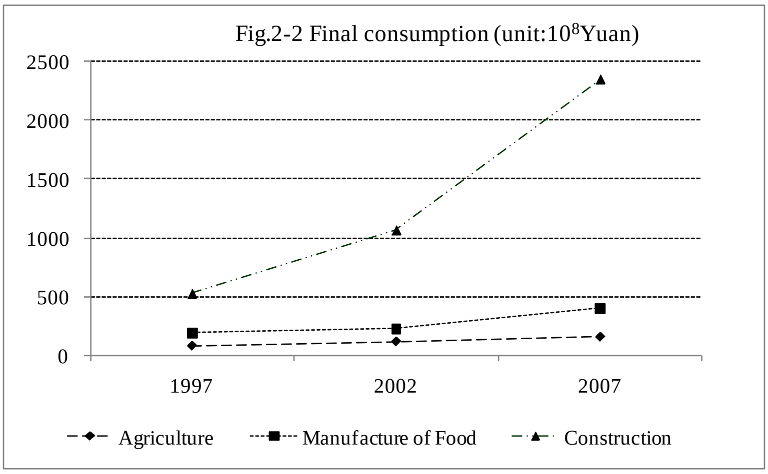
Sectors		Water Footprint		
		1997	2002	2007
1	Agriculture	895	903	929
2	Mining	13	9	5
3	Manufacture of Food	1036	498	888
4	Manufacture of Textile	22	25	39
5	Manufacture of Textile Wearing Apparel and Leather	112	64	54
6	Processing of Timber and Manufacture of Furniture	27	38	16
7	Manufacture of Paper and Paper Products	44	61	12
8	Processing of Petroleum and Coking	3	4	24
9	Manufacture of Raw Chemical Materials and Chemical Products	94	142	83
10	Manufacture of Non-metallic Mineral Products	22	12	3
11	Smelting, Pressing and Manufacture of Metals	16	25	21
12	Manufacture of Special Purpose Machinery	149	211	87

13	Manufacture of Transport Equipment	88	108	57
14	Manufacture of Electrical Machinery and Equipment	108	54	51
15	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	126	125	54
16	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	8	7	7
17	Other manufacturing sectors	11	8	14
18	Production and Supply of Electric Power and Heat Power	163	80	141
19	Production and Supply of Water	16	50	36
20	Construction	641	845	1200
21	Freight Transport and Storage	11	42	30
22	Information Transmission, Computer Services and Software	5	92	191
23	Wholesale and Retail Trades	240	164	418
24	Hotels and Catering Services	179	181	229
25	Tourism	7	4	39
26	Scientific Research	46	58	105
27	Education, Culture and Entertainment	58	168	278
28	Health, Sports and Social Welfare	56	66	329
29	Service to Households	61	245	364
30	Other Technical Services	84	116	43
	Total	**4342**	**4406**	**5748**

A scrutiny on the more micro scale of sector level can help a better understanding on the changes in Beijing's water footprint. The sectors of high water footprint are more or less the same in the three years. Generally, sector 1 (agriculture), sector 3 (manufacture of food) and sector 20 (construction) are the three major sectors for water footprint, with the summation stabilized at over 50% of the total water footprint in the three years. As demonstrated in Figure 2-1, the water footprint of agriculture is generally stable with slight increase; Construction experiences significant increase in water footprint especially in 2007 when the water footprint rises to 1200 million m^3, which might be relevant to the venue construction for

Beijing 2008 Olympics. Instead of a consistent tendency, a line broken in year 2002 is observed in the changes of the water footprint of manufacture of food. Furthermore, the changes in final consumption amount and TWUC which are the two factors directly related to the water footprint assessment are analyzed. It can be seen that the amount of final consumption increases year by year (Figure 2-2); The TWUCs of agriculture and construction reveal evident decrease, which is consistent with the general trend of technology advancement, while the TWUC of manufacture of food increases from 178 $m^3/10^4$Yuan in 2002 to 222 $m^3/10^4$Yuan in 2007 (Figure 2-3). The reason for manufacture of food showing adverse result in the context of the overall trend of technology improvement in water use efficiency is closely related to the degradation in economic system efficiency induced by the overdependence on external support of agricultural products, which will be further discussed in section 4.





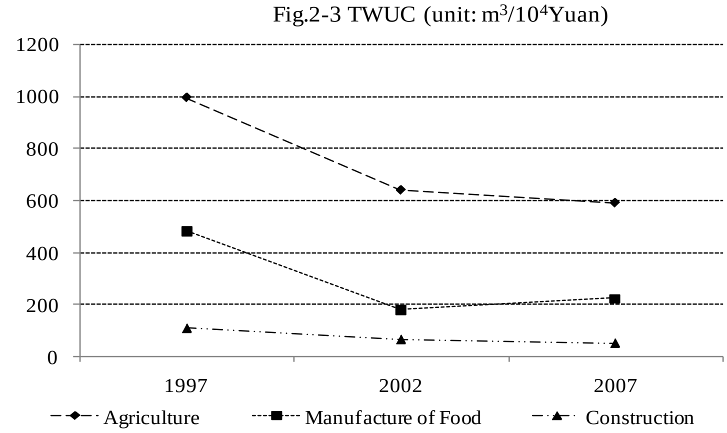


Figure 2. The changes in the major sectors' water footprint, final consumption and TWUC: 1997, 2002 and 2007.

3.3 Determinants for the changes in water footprint

The changes in Beijing's water footprint is decomposed into the contributions of technological effects , economic system efficiency effects, scale effects and structural effects according to Eq. 3. The contributions of the four effects to the changes in Beijing's water footprint are shown in Figure 3. The bar charts above the X-axis mean the positive effects in water footprint increase, while the ones below the X-axis mean the negative effects. In both periods of 1997-2002 and 2002-2007, scale effects and economic system efficiency effects turn out to have fortified water footprint increase, whereas technological effects and structural effects have offset the increase.

On the side of the negative effects for water footprint increase, the contribution of technological effects is remarkable, reflected by its contribution proportion of 43% during 1997-2002 and 36% during 2002-2007. The significant role of technological effects in offsetting water footprint increase verifies the effectiveness of Beijing's continuous efforts in developing water-saving technologies (Beijing Water Authority, 2011). Compared with technological effects, the contribution of structural effects is relatively smaller but innegligible. With the transition of people's consumption mode and the impacts of governmental policy orientation, the role of structural effects is expected to become more significant in offsetting Beijing's water footprint increase in the future.

On the other side of the positive effects for water footprint increase, the contribution of scale effects is dominant, with the contribution proportion of 41% during 1997-2002 and 38% during 2002-2007. Under the stimulation of booming economic development, the scale of final consumption has prominently grown from 224 billion Yuan to 914 billion Yuan (National Bureau of Statistics of China, 1997 and 2011), which results in the expansion in corresponding water footprint. Besides, economic system efficiency effects make considerably positive contribution to Beijing’s water footprint increase and their contribution proportions in the two periods are respectively 9% and 19%.

Table 5 shows the contributions of the four effects to each sector’s changes in water footprint. Technological effects are the principal contributors to offset water footprint increase for most sectors. During both periods, there are more than half sectors (16 sectors) having technological effects as the dominant contributor. i.e., during 1997-2002, the contribution proportions of technological effects for sector 4 (manufacture of textile), sector 7 (manufacture of paper and paper products), sector 8 (processing of petroleum and coking), sector 12 (manufacture of special purpose machinery), sector 13 (manufacture of transport equipment) etc., are over 40%. So are the sector 19 (production and supply of water), sector 20 (construction) and sector 29 (production and supply of water) during 2002-2007. The sectors with economic system efficiency effects as the dominant contributors are relatively rare, including only sector 26 (scientific research), sector 27 (education, culture and entertainment) during 1997-2002 and sector 17 (other manufacturing sectors) during 2002-2007.

It should be noted that the dominant contributors for most sector are not constant during different periods. i.e., the dominant contributor of sector 2 (mining) is structural effects during 1997-2002 while technological effects during 2002-2007, the dominant contributor of sector 9 (manufacture of raw chemical materials and chemical products) is technological effects during 1997-2002 while scale effects during 2002-2007, etc. On the contrary, It is observed that the major sectors for water footprint, sector 1 (agriculture), sector 3 (manufacture of food) and sector 20 (construction) all have constant dominant contributors during both periods: scale effects for sector 1 (agriculture) and sector 3 (manufacture of food), while technological effects for sector 20 (construction).

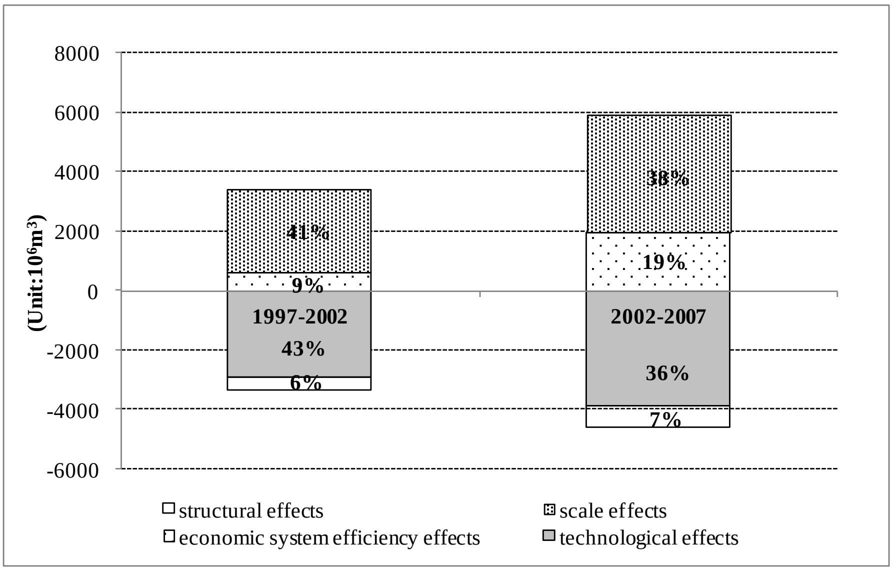


Figure 3 The contributions of the four effects to the changes in the total amount of water footprint: 1997-2002 & 2002-2007

Table 3 The contributions of the four effects to each sector's changes in water footprint: 1997-2002 & 2002-2007 (unit of value: 10^6 m^3)

Sectors		1997-2002							
		technological effects		economic system efficiency effects		scale effects		structural effects	
		value	proportion	value	proportion	value	proportion	value	proportion
1	Agriculture	-505	-35%	164	11%	570	39%	-221	-15%
2	Mining	-8	-28%	5	18%	7	25%	-8	-30%
3	Manufacture of Food	-441	-30%	-245	-17%	467	32%	-319	-22%
4	Manufacture of Textile	-16	-47%	2	7%	15	45%	0	1%
5	Manufacture of Textile Wearing Apparel and Leather	-54	-35%	-1	-1%	53	34%	-47	-30%
6	Processing of Timber and Manufacture of Furniture	-24	-39%	16	25%	20	33%	-1	-2%
7	Manufacture of Paper and Paper Products	-43	-41%	18	17%	34	33%	9	8%
8	Processing of Petroleum and Coking	-3	-42%	2	25%	2	33%	0	0%

9	Manufacture of Raw Chemical Materials and Chemical Products	-91	-40%	22	10%	80	35%	37	16%
10	Manufacture of Non-metallic Mineral Products	-11	-28%	4	11%	10	26%	-14	-35%
11	Smelting, Pressing and Manufacture of Metals	-17	-39%	9	20%	13	31%	4	9%
12	Manufacture of Special Purpose Machinery	-138	-41%	70	21%	115	34%	15	4%
13	Manufacture of Transport Equipment	-74	-44%	23	14%	64	38%	7	4%
14	Manufacture of Electrical Machinery and Equipment	-53	-29%	16	9%	49	27%	-66	-36%
15	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	-90	-42%	26	12%	80	37%	-18	-8%
16	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	-5	-42%	1	9%	5	38%	-1	-10%
17	Other manufacturing sectors	-6	-40%	-3	-16%	6	40%	-1	-5%
18	Production and Supply of Electric Power and Heat Power	-70	-26%	19	7%	74	28%	-105	-39%
19	Production and Supply of Water	-24	-29%	4	5%	24	29%	31	37%
20	Construction	-558	-42%	220	17%	481	36%	62	5%
21	Freight Transport and Storage	-21	-29%	5	7%	19	26%	29	38%
22	Information Transmission, Computer Services and Software	-43	-25%	52	30%	20	12%	58	34%
23	Wholesale and Retail Trades	-128	-39%	-10	-3%	127	38%	-66	-20%
24	Hotels and Catering Services	-113	-27%	-94	-23%	141	34%	69	16%
25	Tourism	-3	-31%	-3	-28%	4	35%	-1	-6%
26	Scientific Research	-37	-23%	50	31%	36	22%	-37	-23%
27	Education, Culture and Entertainment	-89	-31%	106	37%	63	22%	29	10%

28	Health, Sports and Social Welfare	-44	-41%	19	18%	39	37%	-4	-4%
29	Service to Households	-122	-28%	55	13%	101	24%	150	35%
30	OtherTechnical Services	-72	-33%	61	28%	63	29%	-20	-9%
Total		**-2904**	**-43%**	**614**	**9%**	**2784**	**41%**	**-430**	**-6%**

Sectors		2002-2007							
		technological effects		economic system efficiency effects		scale effects		structural effects	
		value	proportion	value	proportion	value	proportion	value	proportion
1	Agriculture	-327	-21%	76	5%	715	46%	-438	-28%
2	Mining	-7	-38%	2	9%	5	31%	-4	-22%
3	Manufacture of Food	-376	-26%	395	27%	521	36%	-150	-10%
4	Manufacture of Textile	-23	-31%	-7	-10%	29	39%	15	20%
5	Manufacture of Textile Wearing Apparel and Leather	-43	-42%	0	0%	47	45%	-13	-13%
6	Processing of Timber and Manufacture of Furniture	-19	-25%	6	9%	20	27%	-29	-39%
7	Manufacture of Paper and Paper Products	-26	-23%	7	6%	25	22%	-55	-49%
8	Processing of Petroleum and Coking	-18	-33%	6	11%	13	24%	18	32%
9	Manufacture of Raw Chemical Materials and Chemical Products	-85	-32%	21	8%	85	31%	-79	-29%
10	Manufacture of Non-metallic Mineral Products	-5	-23%	2	9%	5	22%	-11	-46%
11	Smelting, Pressing and Manufacture of Metals	-22	-40%	8	14%	18	33%	-7	-14%
12	Manufacture of Special Purpose Machinery	-119	-30%	29	7%	107	27%	-142	-36%
13	Manufacture of Transport Equipment	-68	-33%	17	8%	61	29%	-61	-29%
14	Manufacture of Electrical Machinery and Equipment	-49	-40%	18	15%	41	34%	-13	-11%
15	Manufacture of Communication Equipment, Computers and Other Electronic Equipment	-69	-27%	27	10%	67	26%	-94	-37%

16	Manufacture of Measuring Instruments and Machinery for Cultural Activity and Office Work	-6	-37%	3	17%	5	31%	-3	-15%
17	Other manufacturing sectors	-11	-25%	17	36%	10	21%	-9	-19%
18	Production and Supply of Electric Power and Heat Power	-114	-38%	99	33%	83	27%	-7	-2%
19	Production and Supply of Water	-37	-44%	-1	-1%	34	41%	-11	-13%
20	Construction	-1021	-43%	541	23%	804	34%	31	1%
21	Freight Transport and Storage	-31	-35%	11	12%	28	31%	-20	-22%
22	Information Transmission, Computer Services and Software	-141	-37%	62	16%	115	30%	63	17%
23	Wholesale and Retail Trades	-275	-34%	123	15%	235	29%	171	21%
24	Hotels and Catering Services	-143	-35%	68	17%	159	39%	-36	-9%
25	Tourism	-22	-28%	24	30%	12	15%	21	27%
26	Scientific Research	-77	-38%	39	20%	64	32%	20	10%
27	Education, Culture and Entertainment	-198	-39%	128	25%	170	34%	10	2%
28	Health, Sports and Social Welfare	-205	-30%	98	15%	162	24%	208	31%
29	Service to Households	-273	-41%	106	16%	244	37%	42	6%
30	Other Technical Services	-50	-16%	47	15%	76	24%	-146	-46%
Total		**-3946**	**-3862**	**-37%**	**1972**	**19%**	**3961**	**38%**	**-729**

4. Discussion

The water footprint in section 3 includes two parts, the internal water footprint associated with local water resource consumption and the external water footprint associated with the water resource consumption outside Beijing. The two parts play distinctive roles in impacting local water situation: the former is a sort of water loss, while the latter is a sort of water supplement to meet local final consumption since the local water resources can be saved through receiving the outside commodities which would have to be locally produced using local water resources.

Figure 4 shows the composition of the water footprint in the three years. The results indicate a rising dependence of Beijing's final consumption on external water support, reflected by the increasing external water footprint in both amount and proportion. During the period of 1997-2007, the volume of external water footprint nearly doubled from 1494 million m^3 to 2874 million m^3. Besides, the proportion of the external water footprint in composition of Beijing's total water footprint increased from 34% to 50%. It is undeniable that the external water footprint made considerable contribution in ameliorating Beijing's water pressure, which is representatively proved by the slight decrease in internal water footprint during 1997-2002. However, the exacerbating tendency of Beijing's water crisis turned out to be not reversed by the effects of external water footprint due to the notably expanded scale of water footprint exceeding external water footprint, which is reflected by the observable increase in internal water footprint from 2695 million m^3 to 2874 million m^3 during 2002-2007.

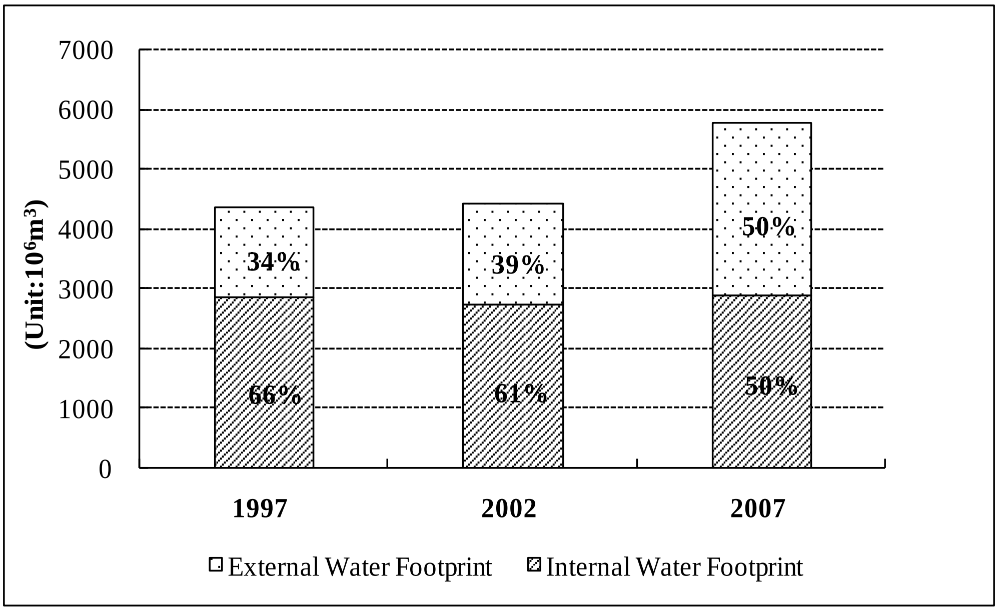


Figure4 Internal and external water footprint in 1997, 2002 and 2007.

It is worth attention that economic system efficiency effects have expedited Beijing's water footprint increase. Under input-output framework, economic system efficiency is reflected by Leontief inverse matrix, the change of which is basically resulted from the changes in the direct input coefficient, an indicator representing the inter-sectoral connections based on product supply and demand. The changes in the inter-sectoral connections might be resulted from the intermediate product substitution caused by technique modification or price fluctuation, decreased consumption of intermediate product cased by scale effects, economized raw material input caused by management advancement, etc. Since the factors influencing economic system efficiency effects are multiple, it is difficult to evaluate the changes in economic system efficiency through the value changes in Leontief inverse matrix or the direct input coefficients. The economic system efficiency effects' positive contribution to water footprint increase can be explained through a further investigation on direct input coefficient. Sector 3 (manufacture of food) is selected as the representative sector to demonstrate this issue in that it is not only the major sector of high water footprint, but also has economic system efficiency effects providing considerable positive contribution (27%) for its water footprint increase during 2002-2007. The direct input coefficient of agriculture to manufacture of food reveals a noticeable increase from 0.13 in 2002 to 0.25 in 2007, suggesting the amount of input from agriculture required to produce one monetary unit output of manufacture of food nearly doubly increased. Since agriculture is the most water-intensive sector, its increase in input consequently leads to the increase in TWUC and then water footprint increase. The increased agricultural-product input is speculated to be relevant to the more and more convenient trade condition between Beijing and other regions (within China and abroad) along with the resulted Beijing's growing dependence on the external support on agricultural products. This speculation can be verified by relevant statistics: in 2002, the net import of agricultural products in Beijing was 6.5 billion Yuan, accounting for 26% of its local production, 56% of its final consumption, whereas in 2007 the figures dramatically rises to 25 billion Yuan, 92% and 158% (National Bureau of Statistics of China, 2008 and 2011). Therefore, Beijing's economic system has experienced a "degradation" period from the perspective of virtual water, which fosters the increase in water footprint and thus intensifies Beijing's water crisis.

5. Concluding remarks

This study quantitatively examines Beijing's water crisis from the perspective of water footprint through a quasi-dynamic input-output analysis. It not only represents how the water footprint has changed during 1997-2007, but also investigates the determinants of the changes. The results of this study are expected to provide useful information for the relevant policy addressing Beijing's water pressure.

The empirical analysis on the evolution of Beijing's water footprint reveals a significant increase from 4342 million m^3 in 1997 to 5748 million m^3 in 2007. An analysis distinguishing "internal water footprint" and "external water footprint" implies the water crisis in Beijing is intensified even when the external water footprint, a water resource supplement to ameliorate Beijing's water pressure, has become observably more and more active during the past decade.

This study decomposes the contributing effects for the water footprint increase into technological effects, economic system efficiency effects, scale effects and structural effects using structural decomposition analysis (SDA). The results show that the increase of water footprint during 1997-2007 can be attributed to scale effects induced by notably expanded consumption scale and economic system efficiency effects closely related to the increased interregional trade between Beijing and other regions in China. Technological effects make remarkable contribution to offset water footprint increase, which confirms the effectiveness of Beijing's efforts in developing water-saving technologies. However, they are not powerful enough to reverse Beijing's exacerbating water condition. This study also points out that the degradation in economic system efficiency induced by the overdependence on external products (especially agricultural products) calls for an attention.

References

Allan, J. A. 1993. Fortunately there are substitutes for water otherwise our hydro-political futures would be impossible, ODA, Priorities for water resources allocation and management, ODA, London, 13-26.

Allan, J.A. 1997. ‘‘Virtual water’’: A long term solution for water short Middle Eastern economies? occasional paper, Water Issues Group, Sch. of Orient. and Afr. Stud., King’s College, London, U. K.

Beijing Municipal Water Conservation Office. 2001. Beijing Sectoral Water Requirement Quota.

Beijing Water Authority, 1997. Beijing Water Resources Bulletin. Standards Press of China, Bejing, China.

Beijing Water Authority, 2002. Beijing Water Resources Bulletin. Standards Press of China, Bejing, China.

Beijing Water Authority, 2007. Beijing Water Resources Bulletin. Standards Press of China, Bejing, China.

Beijing Water Authority, 2011. The official website of Beijing Water Authority: http://www.bjwater.gov.cn/tabid/134/InfoID/17035/frtid/77/Default.aspx

Butnar, I. and Llop, M. 2011. Structural decomposition analysis and input–output subsystems: Changes in CO_2 emissions of Spanish service sectors (2000–2005). Ecological Economics, 70, 2012-2019.

Chapagain, A.K. and Hoekstra, A.Y. 2011. The Blue, Green and Grey Water Footprint of Rice from Production and Consumption Perspectives. Ecological Economics, 70, 749-758.

Chapagain, A.K. and Orr, S. 2008. UK Water Footprint: The Impact of the UK’s Food and Fibre Consumption on Global Water Resources. Godalming, UK, WWF-UK.

Dietzenbacher, E. and Velazquez, E. 2007. Analysing Andalusian Virtual Water Trade in an Input - Output Framework. Regional Studies, 41, 185-196.

Falkenmark, M. and J. Rockström. 2006. The New Blue and Green Water Paradigm: Breaking New Ground for Water Resources Planning and Management. Journal of Water Resources Planning and Management, 132, 129-132.

Fujimagari, D. 1989. The Sources of Shange in Canadian Industry Output. Econ. Syst. Res,1, 187-202.

Guan, D. and Hubacek, K. 2007. Assessment of Regional Trade and Virtual Water

Flows in China. Ecological Economics, 61, 159-170.

Hoekstra, A. Y. and Chapagain, A. K., 2007. Water Footprints of Nations: Water Use by People as a Function of Their Consumption Pattern, Water. Resour. Manag., 21(1), 35-48.

Hoekstra, A.Y. and Hung, P.Q. 2005. Globalization of Water Resources: International Virtual Water flows in Relation to Crop Trade. Global Environmental Change, 15, 45-56.

Hoekstra, A.Y., Chapagain, A. K., Aldaya, M. M. and, Mekonnen, M. M. 2009. Water Footprint Manual State of the Art 2009, Water Footprint Network. Enschede, The Netherlands.

Hoekstra, R. and Van Den Bergh, J. 2002. Structural Decomposition Analysis of Physical Flows in the Economy. Environmental and Resource Economics, 23, 357-378.

Lenzen, M. 2009. Understanding Virtual Water Flows: A Multi-Region Input-Output Case Study of Victoria. Water Resources Research, 45, W09416.

National Bureau of Statistics of China. 1997. China Regional Input-output table 1997, China Statistics Press.

National Bureau of Statistics of China. 1998. China Statistical yearbook. China Statistical Press, Beijing, China.

National Bureau of Statistics of China. 2008. China Regional Input-output table 2002, China Statistics Press.

National Bureau of Statistics of China. 2008. China Statistical yearbook. China Statistical Press, Beijing, China.

National Bureau of Statistics of China. 2011. China Regional Input-output table 2007, China Statistics Press.

Sawyer, J. 1992. Forecasting with Input-output Matrices: Are the Coefficients Stationary? Econ. Syst. Res., 4, 325-348.

Vaccara, B. N, Simon, N. W. 1968. Factors Affecting Postwar Industry Composition of Real Product. In: Kendrick, J.W. The Industrial Composition of Income and Product, Columbia University Press, New York, 19-58.

Wang, H.R. and Wang, Y. 2009. An Input-Output Analysis of Virtual Water Uses of the Three Economic Sectors in Beijing. Water International, 34, 451-467.

Wang, Y., Xiao, H.L. and Lu, M.F. 2009. Analysis of Water Consumption Using a Regional Input-Output Model: Model Development and Application to Zhangye City, Northwestern China. Journal of Arid Environments, 73, 894-900.

Yang, H. and Zehnder, A. 2002. Water Scarcity and Food Import: A Case Study for Southern Mediterranean Countries. World Development, 30, 1413-1420.

Yang, H. and Zehnder, A. 2007. 'Virtual water': An Unfolding Concept in Integrated Water Resources Management. Water Resources Research, 43, W12301.

Yang, H., Wang, L., Abbaspour, K.C. and Zehnder, A.J.B. 2006. Virtual Water Trade: An Assessment of Water Use Efficiency in the International Food Trade. Hydrology and Earth System Sciences, 10, 443-454.

Yang, Y., Hubacek, K., Feng, K.S. and Guan, D.B. 2010. Assessing Regional and Global Water Footprints for the UK. Ecological Economics, 69, 1140-1147.

Zhang, Z. Y., Shi, M. J., Yang, H., Chapagain, A. 2011a. An Input-output Analysis of the Trend in Virtual Water Trade and the Impact on Water Resources and Uses in China. Economic Systems Research, 23(4), 431-446.

Zhang, Z. Y., Yang, H., Shi, M. J. 2011b. Analyses of Water Footprint of Beijing in an Interregional Input–output Framework. Ecological Economics, 70, 2494-2502.

Zhang, Z. Y., Yang, H., Shi, M. J., Zehnder, A. J. B., Abbaspour, K. C. 2011c. Analyses of Impacts of China's International Trade on its Water Resources and Uses. Hydrology and Earth System Sciences, 15, 2871-2880.

Zhao, X., Chen, B. and Yang, Z.F. 2009. National Water Footprint in an Input-Output Framework – A Case Study of China 2002. Ecological Modelling, 220, 245-253.

Zhao, X., Yang, H., Yang, Z., Chen, B. and Qin, Y. 2010. Applying the Input-Output Method to Account for Water Footprint and Virtual Water Trade in the Haihe River Basin in China. Environmental Science & Technology, 44, 9150-9156.

Zimmer, D. and Renault, D. 2003. Virtual Water in Food Production and Global Trade: Review of Methodological Issues and Preliminary Results. In A.Y. Hoekstra (ed.) Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual

Water Trade (Value of Water Research Report Series no. 12). Delft, The Netherlands: UNESCO-IHE.