Indexed in
Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 03

June 2016, P.P. 924-933

wWater Consumption among Productive Sectors and Virtual Water Trade Based On an Input-Output Approach: Beijing City as a Case Study

YUPING HAN[1], HONGYAN LIU[1], YONG ZHAO[2] AND HUIPING HUANG[1]
[1]North China University of Water Resources and Electric Power, Zhengzhou, 450045, China;
[2]State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, China Institute of Water Resources and Hydropower Research, Beijing, 100038, China
***Email:** han0118@163.com, 13526882916@163.com*

Abstract: Problems related to water resources have become an important bottleneck to the sustainable development of Beijing city in China. Based on input-output analysis, this paper establishes three kinds of mathematical models for evaluating water consumption in regional economics, namely, an analysis model of industry water consumption efficiency, a comprehensive evaluation model of industrial water characteristics, and an evaluation model of the regional virtual water trade. Taking Beijing city as an example, an empirical study is conducted using the models above. The results show a higher level of water consumption in agriculture, accommodation and catering tourism, the paper industry and other services than in other productive sectors. The amount of net virtual water reached 18.41×10^8 m^3 in Beijing city in 2010, the largest amount of which was in agriculture at 17.79×10^8 m^3, and the largest amount of net virtual water output in the service industry reached 11.62×10^8 m^3.The results of this study will provide reference for the adjustment of regional industrial structure and the management policy of water resources.

***Keywords:** input-output approach; characteristics of water consumption; virtual water trade; Beijing city*

1. Introduction

It is imperative to construct a water-saving national economy in order to solve the water shortage problem. Firstly, water consumption in each industry should be assessed, and the input-output method developed in recent years offers an effective way to accomplish this. When we take water resources into the industry sector directly, an input-output table can be developed and regional water consumption can be analyzed. Carter (1972) at the University of California put forward an analysis of water consumption and exchange problems using the input-output table approach in the 1970's. Chen Xikang (1987) put forward the use and production of water resources (extraction and reuse), wastewater discharge and treatment as two kinds of production departments included in the input-output model. Xie Mei (1991) compiled and published an input-output table of water resources for Beijing. Wang Weiping (1995) calculated the direct water consumption coefficient and the indirect water consumption coefficient among the 16 departments of Yantai. In recent years, a series of studies on the input-output method regarding the efficiency and benefits of water resource utilization has appeared (Yu Leng, 1998; Ni Hongzhen, 2004; 2005), and the method is well-developed.

Allan (1994) at the University of London and Africa and East Asia Research Institute put forward the concept of "virtual water." It refers to the quantity of water resources involved in the production process of agricultural products. Numerous studies followed with relevant findings (Qadir M, 2003; Allan J.A., 1999). Research on the virtual water trade is an important aspect of virtual water theory, and analysis of the virtual water trade can be a guide for regional virtual water strategies in spite of the difficulties in its calculation. The input-out method is indeed a powerful tool for evaluating the regional virtual water trade. Huang Xiaorong (2005) first deduced the input-output calculation methods for virtual water and gave virtual water output and consumption figures for Ning Xia Province. Velázquez (2006) analyzed the direct and indirect consumption of virtual water of Spain's Andalusia branch using the extended input-output model and identified some of the largest sectors of virtual water consumption. Zhang Zhuoying (2011) quantified the virtual water flows associated with China's international trade in the framework of the input–output model, and investigated the impacts of China's international trade on its water resources and uses between 2002 and 2007. M. Antonelli (2012) presented a systemic quantification of virtual water 'flows' by means of the input–output approach, and distinguished the green and blue water components 'embedded' in traded commodities.

In Beijing, capital of the People's Republic of China, the problem of water resources has become a bottleneck in social and economic development. It is necessary to carry out an analysis of water consumption efficiency of the national economy and virtual water trade. The results are not only of considerable referential importance to the adjustment of industrial structure and management policy, but also of great practical application value. In this paper, we first construct a water resources input-output table joining the industry water using quadrants and establish a water resource input-output model based on a regional input-output table. Second, we establish an analysis model of industry water consumption efficiency, a comprehensive evaluation model of the industrial water characteristics and an evaluation model of the regional virtual water trade. Third, we take Beijing city as an example to develop an input-output table of water resources on the basis of the extended input-output table for Beijing city in 2010, and further analyze the efficiency of water consumption, characteristics of industry water consumption and the virtual water trade. Finally, we summarize our results.

2. Methods

2.1. Input-Output Table of Water Resources and Input-Output Model of Water Resources

The input-output method of economic quantitative analysis is used to study the interdependence between the performance of the inputs and outputs in an economic system (as part of production units or consumption sectors, products and so on). In 1933, USA economist Wassily W. Leontief proposed that the theoretical basis of input-output analysis is the general equilibrium theory. Input-output analysis absorbs the interdependence perspective on economic activity from the general equilibrium theory and describes this interdependence using a system of algebraic equations. Its characteristic is that we can find the effect of any original change on each part of the economic system in the study of inter-departmental perplex input-output relations. Developing the input-output table is a prerequisite for input-output analysis. In the input-output table all sectors of the output are input in lines (or rows) and the source of input in columns, which explains two basic relations. One relationship is that total output of each sector equals its intermediate production and final production; intermediate products should meet the requirement of each department of investment and final products should meet the needs of accumulation and consumption. The other relationship is that investment in each sector is the intermediate products each department consumes directly. On the premise of stable technology conditions, the total input depends on the output. It is feasible to construct an input-output table because water resources lie in every part of national economic production and consumption.

A water resources input-output table can be developed when national economy industry water use is brought into the table based on the input-output model (Wang Dangxian, 2002; Gao Feng, 2002). The V quadrant (the diagonal matrix) added in Table 1 is used mainly to reflect the use of water in every economic sector.

The following mathematical model can be built from Table 1:

$$X = (I - A)^{-1} Y \tag{1}$$

Where X is the line value of the total input (total value), Y is the column value of the final products, and $(I - A)^{-1}$ is the Leon Leontief inverse matrix.

The introduced water quota (a water consumption coefficient, also known as the direct intake coefficient) of industry j is k_j, with a diagonal matrix k_j of matrix K; the matrix in quadrant V of Table 1 is expressed as:

$$W = XK \tag{2}$$

Where W is the line value of the water consumption of every economic sector, $W = (W_1, W_2, \ldots W_n)$.

Formula (1) and Formula (2) form the water resource input-output model. The model reflects the balance between total input and total output, and the occupation of water resources in each industry.

Table 1: *Water resource input-output summary table*

Input \ Output		Intermediate consumption					Ultimate consumption										
							Consumption				Accumulation						
		Industry 1	Industry2		Industry n	summation	City resident	Rural residents	Society	Summation	Fixed	circulating	Summation	Input	Output	Summation	Total output
Intermediate input	Industry 1	X_{11}	X_{12}	…	X_{1n}	μ_1	C^c_1	C^r_1	C^s_1	C_1	F^f_1	F^s_1	F_1	M_1	E_1	Y_1	X_1
	Industry2	X_{21}	X_{22}	…	X_{2n}	μ_2	C^c_2	C^r_2	C^s_2	C_2	F^f_2	F^s_2	F_2	M_2	E_2	Y_2	X_2
	.	…	…	…	…	.	.	.	.		.	.		.		.	.
	.	…	…	I	…	.	.	.	.		.	.		.		II	.
	.	…	…	…	…	.	.	.	.		.	.		.			.
	Industry n	X_{n1}	X_{n2}	…	X_{nn}	μ_n	C^c_n	C^r_n	C^s_n	C_n	F^f_n	F^s_n	F_n	M_n	E_n	Y_n	X_n
	Summation	τ_1	τ_2		τ_n	τ	C^c	C^r	C^s	C	F^f	F^s	F	M	E	Y	X

Initial input	Depreciation	D_1	D_2		D_n	D	
	Income	V_1	V_2	Ⅲ	V_n	V	
	Profit and tax	Z_1	Z_2	…	Z_n	Z	
	Summation	N_1	N_2	…	N_n	N	
Total input		X_1	X_2		X_n	X	Ⅳ
water consumption	Industry 1	W_1		…			
	Industry 2	0	W_2	…	0		
	.	0	V	…	.		
	Industry n	0	0	…	W_n	W_n	
	Summation	W_1	W_2	…	W_n		

2.2. Analysis of Industrial Water Consumption Efficiency

The water consumption coefficients, which represent water consumption efficiency, can be obtained from the water resources input-output table; namely, the direct water consumption coefficient, the complete water consumption coefficient and the water consumption multiplier.

2.2.1. Direct Water Consumption Coefficient

The direct water consumption coefficient is often expressed as water consumption per million Yuan. It reflects the direct use of natural water resources consumed by unit yield of various sectors of the economy. The index measures only part of the virtual water consumption of the industrial sector. The expression is:

$$K_j = W_j / X_j \quad (j = 1, 2, \ldots\ldots, n) \tag{3}$$

Where k_j is the direct water consumption coefficient of jth industry, W_j is the water consumption of the jth industry, and X_j is the output of the jth industry.

By calculation of the direct water consumption coefficient of n industries, the row 1 and column n water consumption coefficient vector can be obtained. The row vector is:

$$k = k_1, k_2, \ldots, k_n \tag{4}$$

2.2.2. Complete water consumption coefficient

The amount of water for unit production needed in the actual production includes not only the natural water, but also the water as intermediate products occurring in other industries, which includes direct water consumption and indirect water consumption. In fact, it reflects the consumption of virtual water in the industry sector. The expression is:

$$k'_j = k_j + \sum_{i=1}^{n} k'_i a_{ij} \tag{5}$$

Given the simple transformation, the expression of complete water consumption coefficient vectors can be obtained:

$$k' = k(I - A)^{-1} \tag{6}$$

Where k'_j is the complete water consumption coefficient of the jth industry, k' is the line vector of the complete water consumption coefficient, a_{ij} is the direct water consumption coefficient, I is the unit matrix of order n, A is the direct water consumption coefficient matrix, and the other variables are as above.

2.2.3 Water consumption multiplier

The water consumption multiplier can express water consumption relations among industries, and is expressed as the ratio of the complete water consumption coefficient to the direct water consumption coefficient. It reflects the indirect consumption degree of virtual water in the industries through industry associations. Its expression is:

$$\theta_j = k'_j / k_j \tag{7}$$

The expression of the line vector is:

$$\theta = (\theta_1, \theta_2 \ldots, \theta_n)$$

Where θ_j is the water consumption multiplier of the jth industry and the other variables are as above.

2.3. Comprehensive Evaluation of Water Characteristics

2.3.1 Relative water consumption coefficient

The relative water consumption coefficient of one industry is the ratio of the direct water consumption coefficient to the general average direct water consumption coefficient for the economic system. This index serves to analyze and compare water consumption among different industries of the economy (Wang Dangxian, 2005). The expression is:

$$Rk_j = k_j / k_0 \qquad k_0 = \sum_{j=1}^{n} W_j \Big/ \sum_{j=1}^{n} X_j \tag{8}$$

Where Rk_j, is the relative water consumption coefficient of the jth industry, and k_0 is the general average water consumption coefficient of the system. When the relative water consumption coefficient is less than 1, the water consumption of the industry is less than the average of the whole economic system; if it is equal to 1, then the both are the same; if it is more than 1, then the former is larger than the latter.

2.3.2 Relative water consumption multiplier

The relative water consumption multiplier of one industry is the ratio of the water consumption multiplier to the average water consumption in an economic system. The index mainly measures total impact of the water consumption change of each industry on the total water consumption of the economic system (Wang Dangxian, 2005). The expression is:

$$R\theta_j = \theta_j / \left(\sum_{j=1}^{n} \theta_j / n\right) \quad (9)$$

Where $R\theta_j$ is the relative water consumption multiplier of the jth industry, n is the number of industries, and the other variables are as above.

Different from the relative water consumption multiplier coefficient, the lower the value of the relative water consumption multiplier of an industry the lower the contribution to total water consumption increases in an economic system.

2.3.3 Relative water consumption structure coefficient

The relative water consumption structure coefficient reflects the impact of water consumption of an industry on the comprehensive evaluation index of water consumption characteristics in an economic system. The expression is:

$$RC_j = (W_j/W_0) / \left(\sum_{j=1}^{n} (W_j/W_0)/n\right) \quad (10)$$

Where $W_0 = \sum_{j=1}^{n} W_j$ is total water consumption.

According to the water consumption coefficient, industries can be divided into high water consumption productive sectors, average water consumption productive sectors, high potential water consumption productive sectors, and average potential water consumption productive sectors (Wang Dangxian, 2005).

In the high water consumption productive sector, industries have a relative water consumption coefficient or a relative water consumption structure coefficient greater than or equal to 1. The criterion is:

$$Rk_j \geq 1 \text{ or } RC_j \geq 1$$

In the average water consumption productive sector, industries have a relative water consumption coefficient or a relative water consumption structure coefficient less than 1. The criterion is:

$$Rk_j < 1 \; and \; RC_j < 1$$

In the high potential water consumption productive sector, industries have a relative water consumption structure coefficient greater than or equal to 1. The criterion is:

$$R\theta_j \geq 1$$

In the average potential water consumption productive sector, industries have a relative water consumption structure coefficient less than 1. The criterion is:

$$R\theta_j < 1$$

2.4. Analyses of Virtual Water Trade

2.4.1 Product consumption and water consumption

Because Water consumption is hidden in product consumption, consumption of product can be seen as consumption of water indirectly. It can be seen from the input-output table that consumption includes consumption of urban residents, consumption of rural households and consumption of government. The formula including all kinds of water consumption is as follows:

Water consumption of urban residents:

$$Q^C r = k_j' R \quad (11)$$

Where, R is the consumption of urban residents in input-output table. k_j' is the total water consumption coefficient and k_j' in formula (12) and (13) is the same meaning.

Water consumption of rural households is:

$$Q^C s = k_j' S \quad (12)$$

Where, S is the consumption of rural residents in input-output table.

Water consumption of government is:

$$Q^C t = k_j' T \quad (13)$$

Where T represents consumption of government in input-output table.

Total water consumption in the consumption field is:

$$Q^C = Q^C r + Q^C s + Q^C t \quad (14)$$

The units of consumption is 10^4 Yuan or 10^8 Yuan, and unit of K'_j is $m^3/(10^4$ Yuan). Q^c is the virtual water based on consumption and we can save water resources by adjusting consumption structure.

2.4.2 Accumulation and water depletion

The process of accumulation includes the depletion of water. Accumulation includes fixed asset accumulation and liquid asset (stock) accumulation. Fixed assets or inventories also need water. The formula including all kinds of accumulations of water consumption is as follows:

Water consumption of fixed assets:

$$Q^F m = k_j' M \quad (15)$$

Accumulated water consumption of liquid assets (stock):

$$Q^F n = k_j' N \quad (16)$$

Total water consumption of an accumulated field:

$$Q^F = Q^F m + Q^F n \quad (17)$$

Where M represents the formation of fixed assets and N represents the increase in goods in stock in the same year; the units are in $\times 10^4$ Yuan or $\times 10^8$ Yuan. k_j' is the complete water consumption coefficient.

2.4.3 Trade and water allocation

Economic trade, which is also known as the input and output of goods, includes domestic and international trade. Input and output of products contains input and output of water. Economic trade can be regarded as an effective economic means to realize regional water allocation and is also an important measure for water diversion.

Output of trade and water:

$$Q^E = k_j' E \quad (18)$$

Input of trade and water:

$$Q^I = k_j' I \quad (19)$$

Net output of trade:

$$Q^{net} = Q^E - Q^I \quad (20)$$

Where E and I represent the output and input products in the same year, respectively. The units are in $\times 10^4$ Yuan or $\times 10^8$ Yuan. k_j' is the complete water consumption coefficient.

3. Empirical Analyses

Beijing is the capital of the People's Republic of China (Fig.1). The resident population is more than 0.2×10^8, but the average water resources amount to $37.39\times10^8 m^3$. The per capita water resource level is far below 1000 m^3 per capita, which is the international lower limit of water shortage, and not on the 1/4 scale of the international minimum standard. According to the water resource standards set by the United Nations, Beijing is in severe shortage of water, for its per capita water resource level is less than 500 m^3. The total water resources of Beijing in 2010 were only $23.08\times10^8 m^3$, and the water supply was 1.53 times the total amount of water resources, meanwhile groundwater exploitation accounted for 61% of the total water supply, so there is a sharp contradiction between supply and demand of water resources. In order to maintain current levels of population and economic growth, Beijing adopted a series of measures to deal with water resource issues, such as the overexploitation of groundwater, water reuse, promotion of water-saving technology, industrial structure adjustment, external water input, virtual water input and so on. The aim of this paper is to analyze and evaluate water consumption of different industries in Beijing city based on the input-output approach. In addition, we calculate the input and output of virtual water, and provide reference information for water management policy.

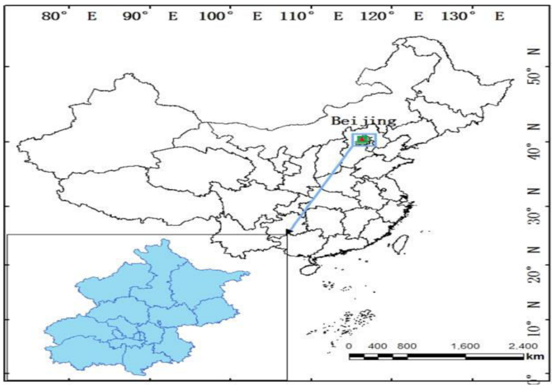


***Figure1**. Location of Beijing city*

3.1. Data Sources and Data Processing

Because the input-output table in China is compiled only in years with a mantissa of 2 and 7, we construct the input-output table of water resources using an extended input-output table of 42 productive sectors of Beijing city in 2010. This paper merges input-output table of 42 productive sectors into 18 productive sectors to reduce the number of sectors and to adjust for the lack of internal data. The corresponding relations can be seen in Table 2.

Data sources of water consumption of different departments in Beijing were as follows:

(1) The amount of water used for agriculture was obtained from the Beijing Water Resources Bulletin in 2010;
(2) The amount of water used in the construction industry was calculated as the added value of the construction industry multiplied by the water quota of the construction industry in Beijing city;
(3) The amount of water used for industry was determined by classifying and summarizing water consumption of industrial added value in Beijing city according to new standards in 2010, deducing the industry water quota, calculating water consumption combined with industrial added value, and then calculating the adjustment coefficient compared with data in the Beijing Water Resources Bulletin in 2010.
(4) The amount of water used for the third industry was determined by the calculation methods for industry above.

Using these consumption figures, the input-output table of water resources in Beijing city in 2010 can be obtained. It is shown in the Appendix (Table 1).

***Table 2** Eighteen productive sector classifications in 2010*

No.	Department	Composition	Abb
1	Agriculture	Agriculture, forestry, animal husbandry and fishery	A
2	Coal Mining and Processing	Coal mining and washing	CMP
3	Oil and Gas	Oil and gas exploration industry, petroleum processing, coking and nuclear fuel processing, gas production and supply	OG
4	Other Mining	Metal mining industry, non-metallic minerals and Other mineral Dressing	OM

5	Food Industry	Food manufacturing and tobacco processing industry	FI
6	Textile Industry	Textile, leather feather and other products industry	TMI
7	Paper Industry	Paper printing and Educational and Sports Goods	PI
8	Chemical Industry	Chemical Industry	CI
9	Building Materials Industry	Non-metallic mineral products industry	BMI
10	Metallurgical Industry	Metal smelting and rolling processing industry, fabricated metal products	MI
11	Machinery and Equipment Industry	General, special equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing	MEI
12	Electronic Instrument Industry	Communications equipment, computers and other electronic equipment manufacturing, instrumentation and Cultural Office Machinery	EII
13	Electric Power Industry	Electricity, heat production and supply industry	EPI
14	Other Manufacturing Industries	Wood processing and furniture manufacturing industries, handicrafts and other manufacturing scrap waste, water production and supply industry	OMI
15	Building Industry	Building Industry	BI
16	Transportation Post and Telecommunication	Transportation and warehousing, postal services	TPT
17	Accommodation and Catering Industry	Accommodation and Catering Industry	ACI
18	Other Services	Information transmission, computer services and software industry, wholesale and retail trade, finance, real estate, renting and business services, research and experimental development, comprehensive technical service, water, environment and public facilities management, residential services and other services, education, health, social security and social welfare, culture, sports and recreation, public administration and social organizations	OS

3.2. Water Efficiency Evaluation in Beijing City

3.2.1 Water consumption efficiency of productive sectors

The direct water consumption coefficient, complete water consumption coefficient and water consumption multiplier of the 18 productive sectors can be calculated according to the input-output table of water resources in Beijing City. The results show that the direct water consumption coefficient and the complete water consumption coefficient are highest in the agricultural sector, far exceeding those of other departments. The levels reach 347.5$m^3/(10^4$ Yuan) and 433.87$m^3/(10^4$ Yuan), respectively, demonstrating that the efficiency of water consumption in the agriculture sector is not high, which is typical of farming production. The direct water consumption coefficient, complete water consumption coefficient and water consumption multiplier for each of the 17 productive sectors other than agriculture in Beijing City are shown in Table 3 and Figure 2.

Table 3 *The calculation results for water efficiency index and sorting in Beijing in 2010 (units: $m^3/10^4$Yyuan)*

	Direct water Consumption coefficient	**Rank**	**Complete water Consumption coefficient**	**Rank**	**Water Consumption Multiplier**	**Rank**
A	347.5	1	433.8	1	1.2	18
CMP	1.1	15	17.3	17	15.7	5
OG	7.2	5	23.8	8	3.3	15
OM	2.0	12	21.8	9	10.8	7
FI	1.3	13	89.7	2	69.0	3
TMI	5.5	8	28.7	5	5.2	11
PI	9.7	3	28.6	6	3.0	16
CI	6.9	6	35.1	4	5.1	12
BMI	2.4	11	19.8	12	8.2	9
MEI	2.5	10	21.5	11	8.7	8
MEI	2.6	9	19.1	14	7.5	10
EII	0.3	16	18.0	16	63.6	4
EPI	7.2	4	28.2	7	3.9	13

OMI	0.2	18	19.7	13	105.5	1
BI	0.2	17	18.4	15	92.5	2
TPT	1.2	14	15.3	18	13.1	6
ACI	39.7	2	85.3	3	2.1	17
OS	5.9	7	21.8	10	3.7	14

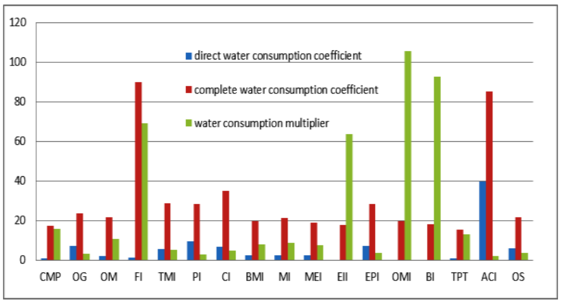


***Figure 2** Results for the direct water consumption coefficient, complete water consumption coefficient and water consumption multiplier by productive sector*

According to the calculated results (Table 3 and Figure 2), the largest direct water consumption coefficient after agriculture is accommodation and catering tourism, followed by the paper industry and the power industry; the smallest is the building industry and other manufacturing industries. The direct water consumption coefficient reflects the efficiency of water consumption; accordingly, water consumption efficiency of agriculture is lower than that in other productive sectors. Water consumption efficiency of accommodation and catering tourism is low, while that of construction industry and other manufacturing industries is high.

The rank order changes for the complete water consumption coefficient and the direct water consumption coefficient (Table 3). Agriculture still ranks first for the complete water consumption coefficient, but other productive sectors are in different order than before. The food industry moved from No. 13 up to No. 2, the textile industry moved from No. 8 up to No. 5, the machinery and equipment industry moved from No. 9 down to No. 14, and the transportation industry moved from No.14 down to No.18. Considering the water consumption multiplier, other manufacturer industries climbed to No.1 with the direct water consumption coefficient at No.18 and the coefficient water consumption coefficient at No.13. The construction industry climbed to No.2 with the direct water consumption coefficient at No.17 and the complete water consumption coefficient at No.15; meanwhile, the water consumption multiplier of agriculture decreased to No.18.

The direct water consumption coefficient and the complete water consumption coefficient for agriculture are much higher than those of other productive sectors. The two coefficients rank the highest, but the gap is relatively minor, and at the corresponding water consumption multiplier ranks near the bottom. This indicates that the main consumption of agriculture is natural water resources, and the indirect pull on water consumption of other productive sectors is small. It also shows that the virtual water of agricultural products comes mainly from the direct consumption of natural water resources. Direct water consumption coefficients of other manufacturing industries, the construction industry, and the food industry are relatively small. However, the complete water consumption coefficient is relatively large, and the water consumption multiplier ranks high. These productive sectors need to consume a large number of products from other sectors in order to meet their water needs, which lead to a rather large indirect pull on water consumption in other productive sectors. Virtual water contained in these productive sectors is derived mostly from that of other productive sectors.

3.2.2 Characteristics of water consumption in productive sectors

The relative water consumption coefficient, the relative water consumption structure coefficient of productive sector and the relative water consumption multiplier can be calculated with Formulas (8-10). The results are shown in Figure 3.

It can be seen in Figure 3 that in addition to agriculture, the relative water consumption coefficient and relative water consumption structure coefficient of the paper industry, service, accommodation and catering tourism are relatively high and they can also be classified as high water consumption sectors. The remaining productive sectors have average levels of water consumption. The relative water consumption multipliers of the food industry, electronic instruments, other manufacturing industries and the construction industry are greater than 1, indicating that they are high potential water consumption sectors; in other productive sectors the corresponding values are less than 1, indicating that they are average potential water consumption sectors (Table 4).

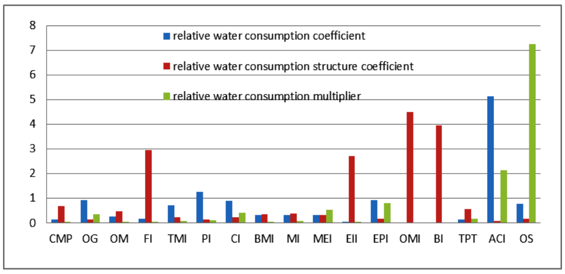


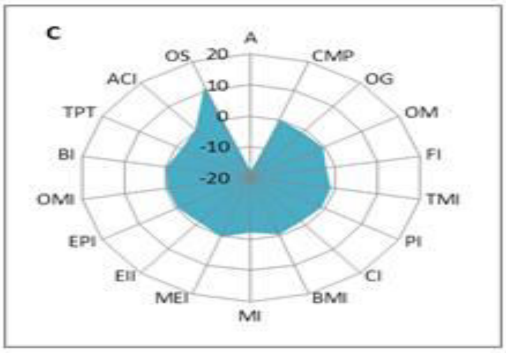
***Figure 3** Relative water consumption coefficient, relative water consumption structure coefficient and relative water consumption multiplier by productive sector*

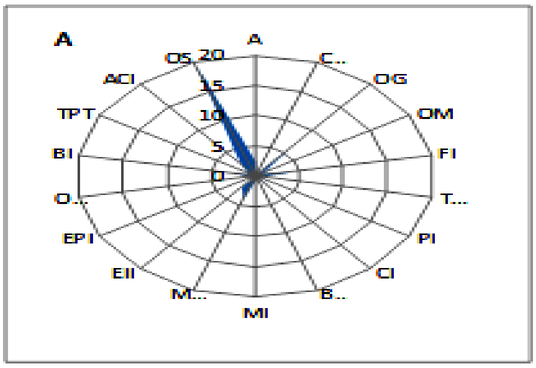
***Table 4**: Water consumption level and potential level of water consumption of each productive sector*

Productive sector	Water consumption level	Potential level of water consumption	Productive sector	Water Consumption Level	Potential level of water consumption
A	High	Average	MI	Average	Average
CMP	Average	Average	MEI	Average	Average
OG	Average	Average	EII	Average	High
OM	Average	Average	EPI	Average	Average
FI	Average	High	OMI	Average	High
TMI	Average	Average	BI	Average	High
PI	High	Average	TPT	Average	Average
CI	Average	Average	ACI	High	Average
BMI	Average	Average	OS	High	Average

3.2.3Trade and consumption of virtual water in Beijing city

Figures 4 and 5 show the results for virtual water in Beijing city. The net input amount of virtual water for Beijing city in 2010 is 18.41×10^8 m^3, accounting for 52.3% of the total water consumption. The highest output of virtual water is in other services, which reaches 11.62×10^8 m^3. In addition, output industries of virtual water include the coal mining industry, machinery industry, construction industry, and accommodation and catering tourism, but the output is not large. The rest are input productive sectors of virtual water, among which the maximum is 17.79×10^8 m^3 in agriculture, followed by the metallurgical industry, food industry, chemical industry, transportation and telecommunication industry, and electronic instrument industry, with inputs of 2.34×10^8 m^3, 2.07×10^8 m^3, 1.62×10^8 m^3, 1.29×10^8 m^3 and 1.27×10^8 m^3, respectively. Virtual water input in the remaining sectors is relatively low.





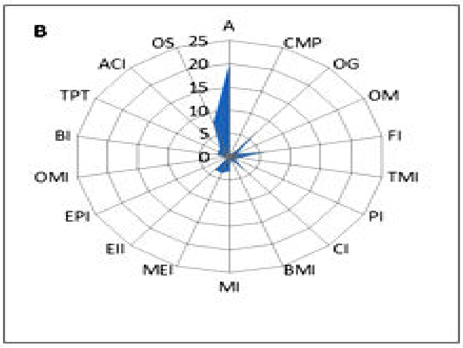
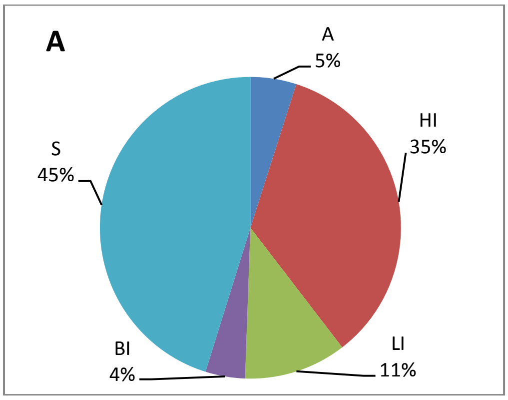


***Figure 4** The virtual water output, input and net output of each productive sector in Beijing city (A: Virtual water output structure; B: Virtual water input structure; C: Virtual water net output structure)*



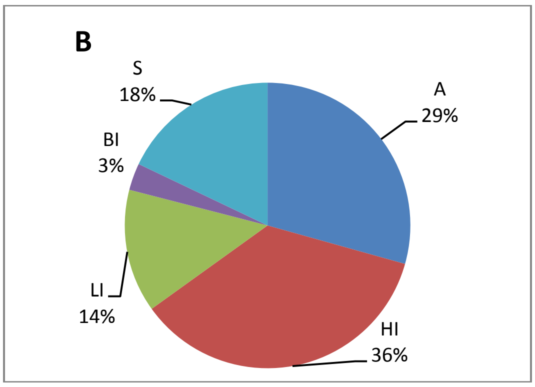


***Figure 5** The virtual water input and output structure and proportions of Beijing city (A: Virtual water output structure; B: Virtual water input structure)*

There are great differences in the proportion of virtual water trade among various productive sectors (Figure 5). The largest proportion in the virtual water trade is industry and the proportion is 50% for industrial output, among which heavy industry outputs account for 35%, light industry outputs account for 11%, and the construction industry accounts for 4%. Industry accounts for 53% of the input of virtual water, among which heavy industry accounts for 36%, light industry accounts for 14%, and the construction industry accounts for 3%. The second largest proportion in the virtual water trade is the service industry, which accounts for 45% of the output in virtual water trade. In comparison, agriculture accounts for 5%. However, the service industry and agriculture account for 18% and 29%, respectively, of the input of virtual water trade. The input-output table shows that economic input of the service industry is far greater than that of agriculture, but the input of virtual water in the service industry is smaller than that of agriculture, because agriculture has the highest complete water consumption coefficient and low water consumption efficiency.

The final consumption of virtual water is 27.05 $\times 10^8$ m^3 from resident consumption, 9.26 $\times 10^8$ m^3 from government consumption, and 15.19 $\times 10^8$ $m^3$from capital formation, yielding a net input of virtual water of 18.41 $\times 10^8$ m^3 (Figure 6).

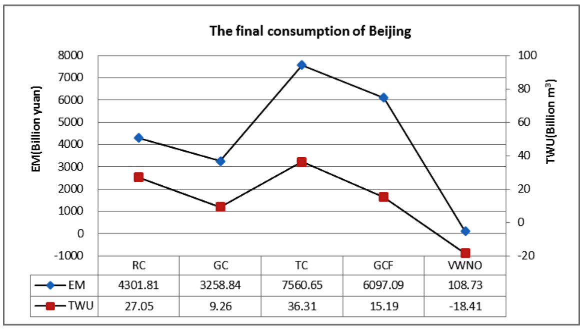


Figure 6 *The final consumption of Beijing*

4. Conclusions

Based on an input-output approach, models of water characteristics of industrial sectors and regional virtual water trade analysis are constructed. In the example of Beijing city, analysis and calculation results are consistent with the actual local industry water consumption. The study results are as follows and can provide information to help guide regional industrial policy.

(1) The largest direct water consumption coefficient and complete water consumption coefficient with its low efficiency in Beijing city indicate that the main consumption of agriculture is natural water resources, and that the indirect pull on water consumption of other productive sectors is small. In addition to agriculture, there is a higher level of water consumption than that of other productive sectors in the paper industry, accommodation and catering tourism, and other services, which can also be classified as industries of high water consumption. Others are classified as average water consumption productive sectors because of their low water consumption per output. Among them, the direct water consumption coefficient of other manufacturing industries, the construction industry and the food industry is relatively small, but the complete water consumption coefficient is relatively large. These sectors consume a large number of products of other productive sectors to meet their needs, so the indirect pull of water consumption on others is relatively large. Except for the food industry, electronic instruments, other manufacturing industries and the construction industry, which are high potential water consumption sectors, other sectors have average potential consumption.

(2) The net input amount of virtual water for Beijing city in 2010 is 18.41×10^8 m^3, accounting for 52.3% of the total water consumption. The highest output of virtual water is in other services, which reaches 11.62×10^8 m^3. In addition, output industries of virtual water include the coal mining industry, machinery industry, construction industry, and accommodation and catering tourism, but the output is not large. The rest are input productive sectors of virtual water, among which the maximum is 17.79×10^8 m^3 in agriculture, followed by the metallurgical industry, food industry, chemical industry, transportation and telecommunication industry, and electronic instrument industry, with inputs of 2.34×10^8 m^3, 2.07×10^8 m^3, 1.62×10^8 m^3, 1.29×10^8 m^3 and 1.27×10^8 m^3, respectively. Virtual water input in the remaining sectors is relatively low.

(3) The water consumption coefficient, which was used to analyze water properties, depends only on intermediate inputs of productive sectors, without establishing contact with final demand. Calculation of virtual water trade cannot fully characterize the real transforming situation of virtual water, but simply reflects the input-output relationships of virtual water among various productive sectors.

Acknowledgements

This study was supported by the National Natural Science Foundation of China (Grant No. 51279063), and the Program for New Century Excellent Talents in University (Grant No. NCET-13-0794), and it was also supported by the Plan for Scientific Innovation Talent of Henan Province in China.

References

[1] Allan J A(1999)Fortunately there are substitutes for water other-wise our hydro-political futures would be impossible[C]//Priorities for water

resources allocation and management. London: DA, 1993:13-26.

[2] Allan J .A. A Convenient Solution. The UNESCO Courier 52(2):29-31

[3] M Qadir, Th.M Boers, S Schubert, et al(2003)Agricultural water management in water-starved countries: challenges and opportunities . Agricultural Water Management (62):165-185

[4] Yu Leng, Yang Minghai , Dai Youzhong , Sun Licheng(1998) Effects of Water Resource Utilization in Jilin Province, Transactions of the Chinese Society of Agricultural Engineering (3)：107-111(in Chinese).

[5] Ni Hongzhen, Wang Hao, Wang Dangxian(2004)Water Use Analysis for Industrial Sectors. Water resources and Hydropower Engineering 5 : 91-94(in Chinese).

[6] Ni Hongzhen, Wang Hao, Wang Dangxian Zhang Qinghua(2005)The Analysis of Products Trade Impact on Regional Water Resources. Journal of Natural Resources4：582-589 (in Chinese).

[7] Wang Dangxian, Wang Hao, Ni Hongzhen, Ma Jing(2005)Analysis and Assessment of Water Use in Different Sectors of National Economy. Journal of Hydraulic Engineering 36(2)167-173(in Chinese).

[8] Wang Dangxian(2002)Study on Water Resources Demand Analysis Theory and Practice. Ph.d. dissertation, China Institute of Water Resources and Hydropower Research. (in Chinese).

[9] Gao Feng (2002) Economic Model Research on Water-saving Agriculture Areas. Ph.d. dissertation, WuHan University (in Chinese).

[10] Huang Xiaorong, PEI Yuansheng, L IANG Chuan (2005)Input-output method for calculating the virtual water trading in Ningxia. Advances in Water Science, Chinese16 (4) : 564-568(in Chinese).

[11] Velázquez E (2006)An input-output model of water consumption: Analyzing intersectional water relationships in Andalusia [J].Ecological Economics 56: 226-240.

[12] Wang Wei ping, Qi Hong, Li Hui (1995) Macro-economy Water Resource Input-output Analysis. Journal of Economics of Water Resources2 : 58-65(in Chinese).

[13] Chen Xikang, Chen Minjie (1987) Calculation of Water Price and Input-output of Water Resources Model. System Sciences and Comprehensive Studies in Agriculture 2:10-17(in Chinese).

[14] XIE Mei, NIE Guisheng, JIN Xianglan(1991)Application of an input-output model to the Beijing Urban Water-use System [C]// POLENSKE

[15] K R, CHEN Xikang (1991) Chinese Economic Planning and Input-Output Analysis. Hong Kong: OzfordUnicersity Press:239-257

[16] CARTER H O, IRERI D (1972) Linkage of California-Arizona input-output models to analyze water transfer pattern [C]//Carter A P, Brody A.Applications of Input-output Analysis. North-Holland Publishing Co.: 139-168

[17] Zhang Z, Shi M, Yang H, Chapagain A (2011) An input–output analysis of trends in virtual water trade and the impact on water resources and uses in China. Econ Syst Res 23(4):431–446

[18] M. Antonelli, R. Roson,M. Sartori.(2012) Systemic Input-Output Computation of Green and Blue Virtual Water ‘Flows’ with an Illustration for the Mediterranean region. Water Resource Manage 26:4133–4146