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## Changes of virtual water trade based on input-output model in Shandong Province and environment response in representative region

To cite this article: Fengli Li *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **310** 052059

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# Changes of virtual water trade based on input-output model in Shandong Province and environment response in representative region

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**Abstract.** The purpose of this paper is to analyze the change trend of the virtual water trade for a 15-year period in Shandong Province, and to discuss how ecological environment is affected by numerous virtual water trade in a representative region. To carry out the analysis, the authors derived a water balance model from lateral economic balance formula in the input-output table. The model was combined with the economic data from Shandong Province's input-output tables and environmental Kuznets curve for an analysis of the change trend of virtual water trade of different industries. Findings - The agriculture is the largest industry that consumes water among three industries, and it plays a conclusive role on whether Shandong Province export virtual water or import virtual water. The virtual water of the province was exported in 1997 and 2002 and imported in 2007 and 2012. This situation was in line with the change of the environmental Kuznets curve and such transformation can be considered a kind of repair to the ecological environment. When the net output volume of virtual water was zero, the total output value of agriculture was  $257.86 \times 10^9$  Yuan. About the representative region (Shouguang City), the annual irrigation water of vegetables is approximately  $1.6 \times 10^8$  m<sup>3</sup>, of which 84.5% water is exported to other areas in the form of vegetable trade. The virtual water quantity exported in the form of vegetable accounted for approximately 73% of the annual average groundwater resources. Shandong Province has insufficient water resources, and this study can provide a scientific basis for allocating water resources and repairing ecological environment.

## 1. Introduction

Shandong is an important province in the eastern coastal area, facing Bo Sea and Huang Sea in the East. Its per capita volume of water resources is only 344 m<sup>3</sup>, and considered as a water crisis area. Shouguang City is known as 'vegetable's hometown'. It has many large planting areas that supply many parts of China. Thus, exporting a considerable quantity of vegetables will cause massive virtual water exportation, thereby causing long-term damage to the local water environment. As an alternative mean of water supply, virtual water trade can reduce the pressure of water shortage. There are a lot of researches on virtual water. In the last two years, the problem of water saving and the strategy of virtual water trade have been examined from the perspective of virtual water [1]. Experts evaluated the upstream virtual water and embodied energy in food consumption in the Tamar catchment, South West England, distinguishing between domestic production and imports origin [2]. Recently, virtual



water export and import in China's foreign trade was researched, and the detailed destinations and origins of China's virtual water export and import also were analyzed[3]. In terms of the virtual water trade in Shandong Province, Ma [4] also conducted a quantitative research regarding the virtual water trade between Shandong Province and other regions. Furthermore, relationships between regional economic sectors and water use in Shandong using an input–output model for virtual water resources were quantitatively analyzed [5]. However, studies on the relationship between regional virtual water and water ecological environment are still limited.

Numerous studies regarding the virtual water of certain regions and specific years are available, but the annual water consumption cannot truly reflect the amount of regional water resources and bearing capacity. Only a long series of analyses of regional virtual water trade can precisely reveal the relationship between transferred products and water resources. However, these analyses are unavailable. Therefore, this paper utilized the input–output method to examine the change of the virtual water trade of Shandong Province for a 15-year period, and the influence of the net output of virtual water on water ecological environment, especially the passive influence on Shouguang City, was quantitatively analyzed.

## 2. Method and data

### 2.1 Input–output model

The input–output table is a chessboard balance sheet composed of various sectors, describing the source and use direction of output occurring in all sectors of the national economy. This table can reflect the interactive relationship between the departments. Calculating the data from all social sectors are difficult because the macroeconomic system is enormous. The data of various sectors in the input–output table of Shandong Province were classified as three major industries (agriculture, industry and service) to roughly analyze the trade situation of imported or exported products. This table has  $n$  sectors, including  $n_1$  agricultural sectors,  $n_2$  industrial sectors and  $(n-n_1-n_2)$  service sectors. The input–output table shows the following horizontal economic equilibrium formulas as follows.

$$\begin{cases} Y_{intermediate(i)} + Y_{final(i)} + \Delta Y_{(i)} = Y_{(i)} \\ \Delta Y_{(i)} = Y_{exported(i)} - Y_{imported(i)} \end{cases} \quad (1)$$

$$\begin{cases} Y_1 = \sum_{i=1}^{n_1} Y_{(i)}; Y_2 = \sum_{i=n_1+1}^{n_1+n_2} Y_{(i)}; Y_3 = \sum_{i=n_1+n_2+1}^n Y_{(i)}; Y_n = \sum_{i=1}^n Y_{(i)} \end{cases} \quad (2)$$

where  $i$  refers to the  $i$ -th sector,  $Y_{intermediate}$  indicates intermediate use,  $Y_{final}$  denotes final use,  $\Delta Y$  is the difference between the exported and imported product, and  $Y_1$ ,  $Y_2$ ,  $Y_3$  and  $Y_n$  are the agricultural, industrial, service's and total output value.

### 2.2 Virtual water balance formula

A water balance formula can be derived from the horizontal economic equilibrium formula in the economic input–output table.

$$\begin{cases} W_{intermediate(i)} + \Delta W_{(i)} = W_{(i)} \\ \Delta W_{(i)} = W_{exported(i)} - W_{imported(i)} \\ \sum_{i=1}^n W_{(i)} = W \end{cases} \quad (3)$$

where  $W_{intermediate}$  is the water volume consumed by intermediate use,  $\Delta W$  is the water volume consumed by the difference between exported and imported product, and  $W_{(i)}$  and  $W$  are the water volume consumed by the output value of the  $i$ -th sector and the total output value of  $n$  sectors, respectively.

### 2.3 Calculation of net output virtual water

In order to reasonably compare the changes of water use in different years, the factor of price change should be deducted, namely, the output value of all years are comparable price. 1997 is the base year and its relative gross regional product index (RGRPI) is 100.

$$\beta = \begin{cases} 100 & \text{particular year = the base year (1997)} \\ \frac{100 \cdot \eta_2 \cdot \eta_3 \cdots \eta_m}{10^{2m-2}} & \text{particular year = the base year + m - 1} \end{cases}, \quad (4)$$

where  $\beta$  is RGRPI,  $\eta$  is the gross regional product index (GRPI, its base year is its last year).

$$\begin{cases} \alpha_1 = \sum_{i=1}^{n1} (W_{(i)} / 0.01Y_{(i)}\beta) \\ \alpha_2 = \sum_{i=n1+1}^{n1+n2} (W_{(i)} / 0.01Y_{(i)}\beta) \\ \alpha_3 = \sum_{i=n1+n2+1}^n (W_{(i)} / 0.01Y_{(i)}\beta) \end{cases}, \quad (5)$$

$$\begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix} \begin{bmatrix} \sum_{i=1}^{n1} \Delta Y_{(i)} \\ \sum_{i=n1+1}^{n1+n2} \Delta Y_{(i)} \\ \sum_{i=n1+n2+1}^n \Delta Y_{(i)} \end{bmatrix} = \begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} \quad (6)$$

where  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  are agricultural, industrial, service's water-use quota, and  $K_1$ ,  $K_2$  and  $K_3$  are agricultural, industrial, service's net output virtual water, respectively.

### 2.4 Data

The data of all sectors are all provided from the input-output tables for Shandong province. All branches of the macroeconomic system in the I-O table for 1997, 2002, 2007 and 2012 were aggregated into 42 sectors. Water use data of all sectors are collected from Shandong provincial water resources bulletins. The GRPI are obtained from Shandong Statistical Yearbook for 2013 and shown in Table 1.

Table 1. The GRPI of 1997-2002

Year	$\eta_1$	$\eta_2$	$\eta_3$	$\eta_4$	$\eta_5$	$\eta_6$	$\eta_7$	$\eta_8$
GRPI	111	110	110	110	110	111	113	115
Year	$\eta_9$	$\eta_{10}$	$\eta_{11}$	$\eta_{12}$	$\eta_{13}$	$\eta_{14}$	$\eta_{15}$	$\eta_{16}$
GRPI	115	114	114	112	112	112	110	109

## 3. Results and discussion

### 3.1 Virtual water trade of Shandong Province

#### 3.1.1 Situation of imported or exported products

Shandong Province's change trend of imported or exported products was analyzed. The net value of outputting was obtained by using the total value of outputting to subtract the total value of inputting, and the result is shown in Table 2. Table 2 shows that the agricultural products from the net output became the net input, and the data of net input were approximately 379 billion Yuan in 2012. Moreover, the products of the industry and service industries were always net output, and the net output in 2007 and 2012 were considerably larger than that in 1997 and 2002.

Table 2. Net output of three industries

Industries	Net output of three industries/ $10^8$ Yuan			
	1997	2002	2007	2012
Agriculture	31.17	158.81	-756.32	-3797.18
Industry	139.37	383.76	1928.86	1950.37

Service	11.12	47.66	946.72	2011.84
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### 3.1.2 Change trend of virtual water trade

The water-use quota and the net outflow volume of virtual water of three industries were calculated, as shown in Table 3. Table 3 shows that agriculture played a decisive role in the problem of whether virtual water was output or input. The net outflow volume of virtual water of industry and service changed, but the changes were nearly negligible compared with those of agriculture. Figure 1 indicates that the development of the total output value of agriculture in Shandong nearly linearly increased. In addition, the net output of virtual water was larger than zero in 1997 and 2002 and less than zero in 2007 and 2012. From the tendency, a zero point where the net output of virtual water was zero could be determined, which meant that the local water volume was exactly equal to the amount of water use required to fulfill the needs of its economic development. By the establishment of regression equations, the total output value of agriculture was calculated to be 257.86 billion Yuan, and the rainfall volume was 530.98 mm when the net output volume of virtual water was zero.

Table 3. The water-use quota and net outflow volume of virtual water

Year	Agriculture		Industry		Service	
	$\alpha_1$	$K_1$	$\alpha_2$	$K_2$	$\alpha_3$	$K_3$
1997	897	27983	33	4643	10	116
2002	745	111824	16	7030	7	353
2007	504	-269152	4	7611	3	2724
2012	381	-736994	3	4076	3	4647

Note : The unit of  $\alpha$  is  $\text{m}^3/10^4$  yuan, the unit of  $K$  is  $10^4 \text{m}^3$ .

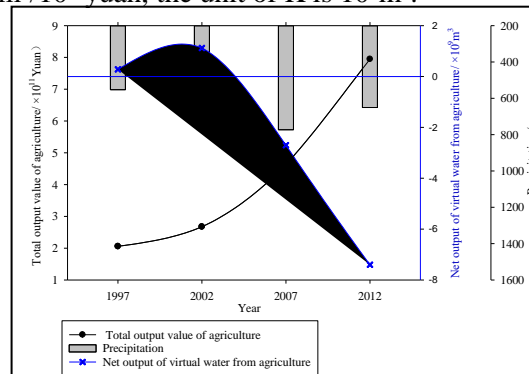


Fig. 1. Relationship of rainfall, net output of virtual water, and total value of agriculture of four years

### 3.1.3 Analysis of virtual water trade

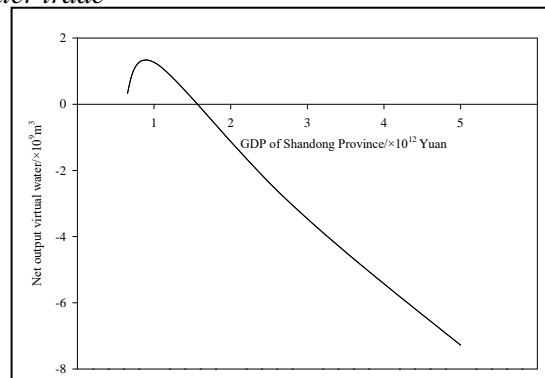


Fig. 2. Relationship of GDP and virtual water quantity of net output of Shandong

The hypothesis of the environmental Kuznets curve was introduced by economists in 1995[6]. Figure 2 shows the relationship between the net output quantity of virtual water and GDP of Shandong

Province. The figure demonstrates an inverted “U” shape of the curve. The massive output of virtual water negatively affects the environment, albeit in a manner different from the environmental pollution expressed by the Kuznets curve. In this sense, Figure 2 can be regarded as an environmental Kuznets curve from the viewpoint of virtual water. Originally, the net output of virtual water gradually increased with economic development, thereby raising the deterioration degree of the local ecological environment. However, up to a certain stage of economic development, the net output of virtual water slowly decreased, thus finally allowing the net output to become net input. This condition could be considered a restoration that improved the ecological environment.

### 3.2 Ecological environment response to numerous vegetable trade in Shouguang City

#### 3.2.1 Groundwater and saltwater intrusion situation

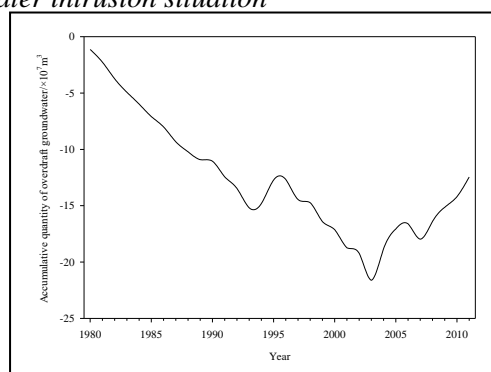


Fig.3. Accumulative quantity of groundwater over-exploitation of Shouguang in 1980-2011

The long-term over-exploitation of groundwater has resulted in a large depression area. The groundwater overdraft area of Zibo–Weifang is the largest overdraft area in Shandong Province, and its area is up to 5400 km<sup>2</sup>. Notably, Shouguang city is the center of this overdraft. After the 1890s, the groundwater depth of Shouguang City was more than 40 m, and it reached the maximum of 49.9 m in 1995 and then gradually reduced. Water was abundant in 2003-2012, thereby causing an increase in groundwater depth to 35-39 m. The multi-year average amount of groundwater was 186.34 million m<sup>3</sup>/a. The groundwater was over-exploited in 1980-2011, and the cumulatively over-exploited area measured 125 million m<sup>3</sup> (Figure 3) with the decrease in groundwater level. According to the interfaces of freshwater and saltwater in 1981, the area of saltwater intrusion was 141.16 km<sup>2</sup>, and the annual average invasion rate was approximately 4.28 km<sup>2</sup>/a. The total area of saltwater intrusion was 1164.25 km<sup>2</sup>, which occupied 58.5% of the total land area of this area.

#### 3.2.2 Vegetable production and water consumption

This city belongs to the hilly area of the middle region in the agricultural irrigation district, which is the third district. The gross water use quota of bare and greenhouse vegetables are 6000 and 2340 m<sup>3</sup>/hm<sup>2</sup> in the third district, respectively. The area of greenhouse vegetable accounts for 80% of the vegetable planting area; therefore, the area of greenhouse vegetable accounts for only 20%. By calculation, the irrigation water use of bare and greenhouse vegetables are  $6.24 \times 10^7$  and  $9.74 \times 10^7$  m<sup>3</sup>, and the total irrigation water use area of vegetable is  $1.6 \times 10^8$  m<sup>3</sup>. The multi-year average water consumption of agriculture was  $2.4 \times 10^8$  m<sup>3</sup>, accounting for 82% of the multi-year average water consumption. According to the calculation result, the irrigation water use area of vegetables accounted for 65.6% of the agriculture water use of Shouguang.

According to the investigation, adults need 200-500 g of vegetables to address their normal needs. The population of Shouguang is 1.2 million, and the daily per capita vegetable consumption is 1.5 kg. The vegetable use of local people was calculated to be  $6.57 \times 10^8$  kg/a, accounting for 15.5% of the annual vegetable yield. Therefore, the output volume of vegetables was approximately  $3.6 \times 10^9$  kg/a, accounting for 84.5% of the annual vegetable yield. From a macro viewpoint, the water used to

irrigate vegetables in Shouguang yearly was approximately  $1.6 \times 10^8 \text{ m}^3$ , of which approximately  $1.35 \times 10^8 \text{ m}^3$  was considered output from the local region in the form of virtual water.

### *3.2.3 Relationship of virtual water trade and water ecological environment*

Approximately the 15% of vegetable production is used to fulfill the daily needs of the local population, and the remaining 85% is exported to other local or international areas in the form of trade, and a total of  $1.25 \times 10^8 \text{ m}^3$  groundwater has been exploited. Therefore, the continuous outputting of large quantities of vegetables with large water consumption is harmful to the local water ecological environment. The groundwater environment of this city is fragile, and the northern region is a saltwater area with shallow groundwater level depth. Given that the southern part is freshwater area, groundwater over-exploitation will inevitably lead to the migration of brackish water boundary to the south and the loss of fresh groundwater resources, thus requiring decades or even centuries to repair the destruction of ecological environment. In this city, the multi-year average water supply of groundwater accounted for 80% of total water supply. The social and economic development has relied on groundwater exploitation for a long time, thereby resulting in a few water ecological environment problems, such as the over-exploitation of groundwater, continuous decrease in groundwater level, and saltwater intrusion. The export of large quantities of vegetables from Shouguang is equivalent to exporting groundwater in the form of virtual water to other regions, according to the preceding problems of the water ecological environment.

Considering the serious over-exploitation of groundwater and increasing saltwater intrusion area, the following measures should be implemented. (1) Adjust the agricultural structure, compress the area dedicated to vegetable planting, and reduce the amount of vegetables exported to decrease the amount of water resources exported in the form of virtual water from. (2) Increase the use of the Yellow River and the Yangtze River water to improve the utilization rate of surface water. (3) Conduct managed aquifer recharge projects to repair the groundwater ecosystem. (4) Limit the exploitation of groundwater, especially near the saltwater interface.

## **4. Conclusion**

A balance formula of the virtual water was derived from the horizontal economic equilibrium formula underlying the input-output table. Agriculture plays a conclusive role on the exported or imported virtual water. The virtual water of Shandong province was exported in 1997 and 2002 and imported in 2007 and 2012. This situation was in line with the change of the environmental Kuznets curve. Such transformation can be considered a kind of repair to the ecological environment. When the net output volume of virtual water was zero, the total output value of agriculture was 257.86 billion Yuan. The annual irrigation water of vegetables is approximately  $1.6 \times 10^8 \text{ m}^3$  in Shouguang City, of which  $1.35 \times 10^8 \text{ m}^3$  water is exported to other areas in the form of vegetable trade, accounting for 84.5% of the irrigation water quantity. From 1980 to 2011, the accumulative overdraft groundwater was 125 million  $\text{m}^3$ , and the virtual water quantity exported in the form of vegetable accounted for approximately 73% of the annual average groundwater resources.

The regional virtual water trade is a market regulation mechanism that has been influenced by the amount of regional water resources and ecological environment for a long time. When water resources are insufficient, especially in areas with fragile ecological environments, outputting large amounts of virtual water may worsen the ecological environment of water. Therefore, the virtual water trade must be further integrated into water resource management measures. Virtual water must be rationally transferred in and out of agriculture to realize the sustainable development of regional water resources and the social economy.

## **Acknowledgment**

This study was supported by the Shandong Provincial Natural Science Foundation (ZR2016DM13).

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