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Regional Virtual Water Trade: The Perspective of Interprovincial Trade in China

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Abstract

With the development of the economy and the improvement of people's living standards, the demand for water resources is also increasing year by year. From the perspective of per capita water resources, China is one of the 14 countries with the poorest water resources in the world. It is seriously short of water and the distribution of water resources is uneven. Water resources have become an important factor restricting China's economic development. This paper attempts to provide a new perspective for alleviating China's water shortage and ensuring China's water resources security from the perspective of "virtual water trade". Based on this, this paper firstly introduces the current situation of China's water resources and the research status of virtual water trade, and then builds a water resource value-based input-output model, and takes the six regions in China's Pan-Beijing-Tianjin-Hebei region as examples to carry out an empirical analysis. The direct water consumption coefficient, complete water consumption coefficient, pulling coefficient and virtual water import and export trade volume of 7 economic sectors in 2018 were analyzed, and the virtual water trade situation was analyzed to reveal the virtual water trade pattern. Finally, based on the above research results, some suggestions are put forward to optimize the virtual water trade structure in the Pan-Beijing-Tianjin-Hebei region. The research results show that: the complete water use coefficient of agriculture and water supply industry in the six regions in the Pan-Beijing-Tianjin-Hebei region of China is relatively large, and the direct water use coefficient of agriculture and water supply industry is larger than the indirect water use coefficient; The overall industrial structure of the Pan-Beijing-Tianjin-Hebei region will aggravate its water resources pressure; from the perspective of virtual water trade, the Pan-Beijing-Tianjin-Hebei region is a net export area of virtual water.

Keywords

Virtual Water, Virtual Water Trade, Input-Output Model, Direct Water Use Coefficient, Complete Water Use Coefficient

1. Introduction

With the development of the social economy and the improvement of people's living standards, the demand for water resources is increasing. The deterioration of the environment has led to the increasingly serious pollution of water resources, and the contradiction between people and water has become more prominent. Although China has a vast territory and a large number of water resources, which has reached 3.16052 trillion cubic meters in 2020 (Ministry of Water Resources of the People's Republic of China, 2021), due to its large population and low per capita water resources, China has been listed as one of the 13 water-poor countries in the world. Meanwhile, the complex topography and diverse climate further aggravate the uneven distribution of water resources in China, affecting the coordinated and sustainable development of the economy and ecology. Therefore, it is necessary to make proper planning for the utilization and management of water resources.

In recent years, virtual water has received widespread attention and become an important tool to balance the budget of water resources (Lu et al., 2021). Virtual water is the number of water resources needed in the production of products and services, that is, the number of water resources condensed in products and services. One country or region buys water-intensive products from another country or region through international trade, so that virtual water can be transferred through trade, so as to overcome the problems of long-distance, high cost, and a long time in the process of importing physical water (Graham et al., 2020). Virtual water trade not only helps water-deficient countries save water resources but also contributes to the trade growth of virtual water exporting countries.

At present, there are some problems in China's water resources, such as uneven distribution, serious pollution, and a low recycling utilization rate (Wang & Hu, 2015; Guo et al., 2022). Virtual water trade provides a safe way for areas where water resources are scarce, which will not have serious consequences for the environment of virtual water input areas, and can alleviate the current situation of water shortage in water-poor areas and maintain the security of water resources. At the same time, some scholars summarized the virtual water strategy. The virtual water strategy refers that areas with water shortages that can reduce the use of local water resources by importing water-intensive products to alleviate the problem of water shortage in the areas. It encourages water resources lack countries or regions to import water-intensive products to other countries or regions through trade, to replace the part of water resources needed to participate in domestic production activities, and alleviate the pressure of domestic water resources.

In 1993, Allan (1993) first proposed the concept of virtual water. It provides a new idea for maintaining regional water resources security and realizing the sustainable development of water resources. Since then, the research on virtual water has developed continuously. At present, it mainly involves research on water footprint and the calculation method of virtual water (Lee, 2016; Qi et al., 2021; Peer & Chini, 2020).

The water footprint is an independent index to evaluate the sustainability of national water resources. It refers to the amount of water resources in all products and services consumed by a country or region within a certain period (Sun et al., 2021). The water footprint includes internal water footprint and external water footprint (Silva et al., 2017). The water footprint of a country or region is composed of domestic water consumption and virtual net water import (Brindha et al., 2020).

Scholars studied virtual water footprint from global scale (Hoekstra & Hung, 2005), national scale, such as India (Kumar & Jain, 2007), Malaysia (Hassan et al., 2017) and regional scale (Kotsovinos et al., 2011).

Seekell et al. (2011) studied the water footprint in global trade and found that virtual water use is highly unequal in countries, meanwhile because agricultural water occupies a dominant position in water demand, virtual water transfer alone is unlikely to increase equality. Park et al. (2020) introduced the detailed water footprint of South Korea's virtual water trade, including the international flow, water footprint, and virtual water trade of agricultural and animal husbandry products. Ali et al. (2019) studied Pakistan's virtual water footprint in the international trade of 15 major agricultural products between 1990 and 2016 and in 2030 and found that Pakistan has been conducting a large and increasing virtual water trade through agricultural products. Lamastra et al. (2017) studied the bilateral virtual water flow related to the top ten agricultural trade between Italy and China and found that the virtual water flows from Italy to China were greater than that in the opposite direction.

Based on the concepts of water footprint and virtual water, some scholars have calculated and analyzed the relationship between regional agricultural production and consumption by analyzing the virtual water flow and its corresponding water resources footprint in China. Ma et al. (2006) were the first to review and quantify the virtual water flow between regions in China. Deng et al. (2015) thought that on the whole, China is a net exporter of virtual water, but virtual water in agriculture, mining, and petrochemical sectors is net imported and suggests that China to adopt a virtual water trade strategy to alleviate the shortage of water resources. Xu et al. (2018) also found that China is a net exporter of virtual water, and the agricultural and food sectors are the largest imports and exports of virtual water. China mainly imports virtual water from the United States, India, and Brazil, and mainly exports virtual water to the United States, Japan, and Germany. Using the theory of comparative advantage, Zhao et al. (2019) quantitatively studies the water resources footprint in southern and northern China and believe that increasing the productivity of agricultural land in the southern region will help to alleviate the shortage of water resources in the northern and northeast plains. Lin et al. (2019) have studied the virtual water of the energy industry in various provinces or cities of China and found that there is a general flow of virtual energy water in the north-south direction and east-west direction of China. Starting from the regional economic level, Liu et al. (2021) analyzed the water resource footprint of different provinces or cities in China.

In a word, water footprint research is mainly aimed at the accounting of virtual water in agricultural sectors and agricultural products in various countries and regions. In recent years, the water footprint research within China has been increasing, and the research on the virtual water footprint in the agricultural sector and grain trade has also been the main focus. Scholars have found that China is a virtual water net exporter. However, there are few studies on the feasibility of implementing the virtual water strategy in China and in China's water-scarce regions. There is a lack of research on the possible negative effects of implementing the virtual water strategy and the correspondingly measures that can be taken.

The main measurement method of virtual water is the input-output method first proposed by Wassily Leontief in the 1930s. With the development of the method, the input-output method, which was originally used to study economic activities, has been widely used in the fields of resource utilization and environmental protection. The model has also evolved from the single-region input-output (SRIO) model to the multi-regional input-output model (MRIO) (Du et al., 2011). Based on the input-output analysis, combined with nighttime light data and population data sets, Zhao & Samson (2012) estimated the virtual water contained in international trade products. The results show that the existing research has a relatively large underestimation of virtual water volume in developed countries, and neither the lighting area nor urban population can be used to estimate net imported virtual water. Zhang & Anadon (2014) quantified the scale and structure of provincial-level virtual water trade and consumption-based water footprints in China based on a multi-regional input-output model.

Wang et al. (2019) proposed a linear optimization model considering opportunity cost from the perspective of the economic value of water resources to optimize the grain virtual water transaction flow. Kan and Huang (2020) used the Generalized Method of Moments to study the impact of urbanization on industrial water footprint. The results show that, on the whole, urbanization increases China's industrial water footprint, virtual water footprint, and grey water footprint. Li et al. (2021) used MRIO to analyze the model and spillover risk of inter-provincial virtual water trade in the Yellow River Economic Belt of China. It is found that the overall situation of the Yellow River Economic Belt is virtual water inflow, and the agriculture and water supply sectors as well as the power and hot water production sectors are the high-risk water use sectors. Zhang et al. (2021) proposed an input-output model based on a two-stage factor analysis, which quantified virtual water in Kyrgyzstan and found that the agriculture and animal husbandry sectors were the main water users.

With the continuous development and deepening of virtual water research, virtual water measurement methods continue to evolve. Scholars gradually began to combine input-output analysis with various methods to better measure virtual water. However, although there are many quantitative studies on virtual water trade, there are few studies on its impact on national or regional economic and social development.

Based on this, this paper aims to prove the effectiveness of virtual water trade, clarify the enforceability of virtual water strategy, and empirically analyze that virtual water strategy may achieve a good effect. First of all, the value-based input-output table is used to form the water resources input-output table. Secondly, take the pan-Beijing-Tianjin-Hebei region as an example for empirical analysis, calculate the relevant water consumption coefficient, virtual water trade volume, and inter-provincial and inter-industry virtual water transfer. Through select key water consumption sectors to fully understand the pan-Beijing-Tianjin-Hebei region virtual water trade pattern. Finally, clarify the virtual water connection relationship between various industries and put forward useful suggestions to promote the coordinated and sustainable development of the economy and ecology.

The rest of the article is structured as follows. The second chapter is the model construction, the third chapter is the empirical analysis, and the fourth chapter is the conclusions and suggestions.

2. Methods

Based on the input-output method, this paper constructs a water resource value-based input-output model to calculate and evaluate the water footprint and virtual water. The following equilibrium relationship is established: total output = total intermediate use + total final use + exports + others; total input = total intermediate input + import + added value; total input = total output.

$$x_i^r = \sum_j z_{ij}^{rr} + y_i^{rr} + \sum_{s(s \neq j)} z_{ij}^{rs} + \sum_{s(s \neq j)} y_i^{rs} \quad (r, s = 1, 2, \cdots, m; i, j = 1, 2, \cdots, n) \quad (1)$$

x_i^r represents the total output of sector *i* in region *r*, which includes the portion used in this region and the portion used in other regions. $\sum_j z_{ij}^{rr}$ represents the number of products from sector *i* in region *r* that are input to sector *j* in this region as an intermediate product. y_i^{rr} represents the output of sector *i* in region *r* as the final product input to the local. $\sum_{s(s \neq j)} z_{ij}^{rs}$ indicates that the product of sector *i* in region *r* is input to sector *j* in region *s* as an intermediate product. $\sum_{s(s \neq j)} y_i^{rs}$ indicates that the final product of sector *i* in region *r* is allocated to region *s*.

2.1. Direct and Complete Consumption Coefficient

The direct consumption coefficient can be represented by a_{ij}^{rs}, which represents the number of products in sector *i* in region *r* that needs to be consumed per unit of product produced in sector *j* in region *s*. The formula for calculating the direct consumption coefficient is:

$$a_{ij}^{rs} = \frac{z_{ij}^{rs}}{x_j^s} \quad (2)$$

$$x_i^r = \sum_s \sum_j a_{ij}^{rs} x_j^s + \sum_s y_i^{rs} \quad (3)$$

Written in matrix form:

$$\boldsymbol{X} = \boldsymbol{AX} + \boldsymbol{Y} \tag{4}$$

$$\boldsymbol{X} = \left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} \boldsymbol{Y} \tag{5}$$

In the above formula, $\boldsymbol{A}$ represents the direct consumption matrix. $\boldsymbol{I}$ is the unit matrix. Let $\boldsymbol{E} = \left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1}$. $\boldsymbol{E}$ is the complete consumption coefficient matrix of the input-output table between regions. E_{ij} represents the complete consumption coefficient, which refers to the number of products of department i that are directly and indirectly consumed per unit of product produced by department j. $\boldsymbol{Y}$ represents the final use matrix. Leontief inverse matrix reveals the relationship between product input of i sector in r area and j sector in s area and reflects the complete consumption of products and services of r area i sector when each additional unit is finally used, that is, the sum of direct consumption and indirect consumption.

2.2. Direct and Complete Water Use Coefficient

$\boldsymbol{Q}$ is the direct water consumption coefficient matrix. Q_i is the direct water consumption coefficient of the i sector. W_i is the direct water consumption of the i sector. X_i is the complete input of the i sector.

$$Q_i = \frac{W_i}{X_i} \tag{6}$$

Then the complete water use coefficient matrix $\boldsymbol{H}$ is:

$$H_i = Q_i \left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} \tag{7}$$

In formula (7): H_i represents the complete water consumption coefficient of the i sector. The complete water consumption coefficient includes the direct water consumption of this sector and the water consumption caused by other sectors when the intermediate inputs required to produce the products of this sector. So the indirect water consumption is a measure of the production process of the economic sector. Effective indicator of regional water resources environmental stress.

2.3. Pull Coefficient

The pull coefficient $\boldsymbol{L}$ is the ratio of the complete water consumption coefficient which represents the increase of the unit water consumption of a certain sector in an economic system to the increase of the overall water consumption. It shows that the production activities of the j economic sector affect the water consumption of the entire region driving the effect.

$$L_i = \frac{H_i}{Q_i} \tag{8}$$

2.4. Virtual Water Trade Volume

The virtual water trade volume $\boldsymbol{V}$ between sectors can be calculated by the product of the economic trade volume and the virtual water complete water consumption coefficient:

Virtual water import trade volume:

$$V^I = H_i T_i^I \tag{9}$$

Virtual water export trade volume:

$$V^E = H_i T_i^E \tag{10}$$

In the formula: V^I and V^E represent the virtual water import trade volume and virtual water export trade volume of the i sector. T_i^I and T_i^E represents the import trade volume and export trade volume of the i sector. To study the inter-provincial and inter-industrial virtual water transfer direction in the Beijing-Tianjin-Hebei region, the virtual water transfer matrix $\boldsymbol{TVW}$ was introduced, and the calculation formula is as follows:

$$\boldsymbol{VW} = \boldsymbol{QB}\left(\boldsymbol{I} - \boldsymbol{A}\right)^{-1} \tag{11}$$

$$\boldsymbol{TVW} = \boldsymbol{VW} - \left(\boldsymbol{VW}\right)^{-1} \tag{12}$$

In the formula, $\boldsymbol{VW}$ represents the complete water demand matrix, and $\boldsymbol{B}$ is the intermediate input matrix in the original input-output table. After the complete water demand matrix is obtained, the virtual water transfer matrix $\boldsymbol{TVW}$ can be obtained according to the complete water demand matrix, which is the final demand. It is the difference between the complete water demand matrix and its own transposed matrix. Positive and negative values indicate the virtual water transfer direction. Through calculation, we can find that the diagonal line of the matrix is zero, which means that the transfer amount of virtual water itself is zero, and the sum of each row of the matrix is the net transfer amount of virtual water in the i sector.

3. Empirical Analysis

3.1. Sample Selection

We take six regions of the Pan-Beijing-Tianjin-Hebei region: Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, and Shandong as study area for empirical analysis. Although the Pan-Beijing-Tianjin-Hebei region makes an outstanding contribution to China's GDP, the amount of water resources per capita there is lower than the national average. Water resources are relatively scarce, the population is large, and the amount of water resources needed for production activities and daily life is also increasing. By collecting the water consumption data of sectors in the six regions, we use the MRIO analysis method to calculate and analyze the water consumption and virtual water trade volume of sectors to describe the current situation of virtual water trade in the region, and reveal the pattern of regional virtual water trade.

3.2. Data Sources

This paper uses the input-output table of 30 sectors in 30 regions in China in

2010. The original table has 30 rows and 30 columns, that is, $i = j = 30$. Combined with the obtained industrial water consumption data and the attributes of each sector, we merged 30 sectors into seven industries, namely, agriculture (code 1), mining (code 2), manufacturing (code 3), electrical supply (code 4), water supply (code 5), construction (code 6), transportation and services (code 7).

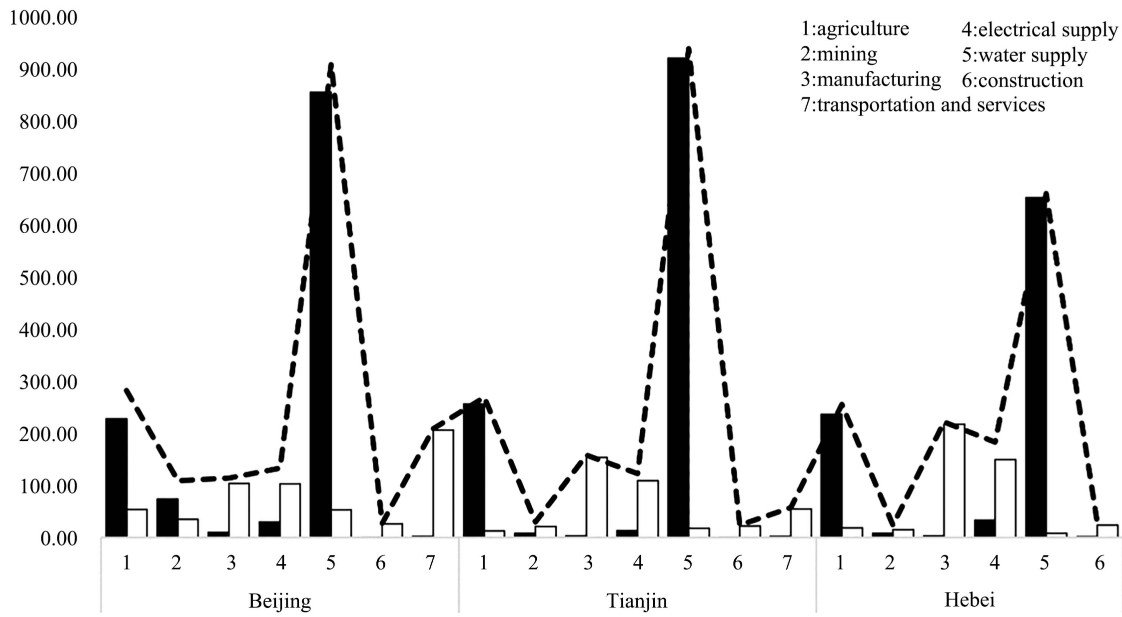
Among them, the agricultural water consumption data of the Pan-Beijing-Tianjin-Hebei region were obtained from the 2010 Water Resources Bulletin of the six regions. The water consumption data of the mining, manufacturing, and electrical supply industries in Hebei Province are from the 2010 Hebei Economic Yearbook. The water consumption data of the mining, manufacturing, and electrical supply industries in other regions are from the 2010 Water Resources Bulletin of each region. The water consumption of each industrial sector is distributed according to the proportion of the economic output value of each industrial sector in the statistical yearbook of each region. The water consumption data of the construction industry, water supply industry, and transportation and service industry cannot be obtained directly. Based on the strong positive correlation between water consumption of these three industries and economic growth, we adopt the indirect calculation method. Based on the 2011 water use data in the Bulletin, the economic growth rate in 2011 was regarded as the growth rate of water use.

3.3. Empirical and Result Analysis

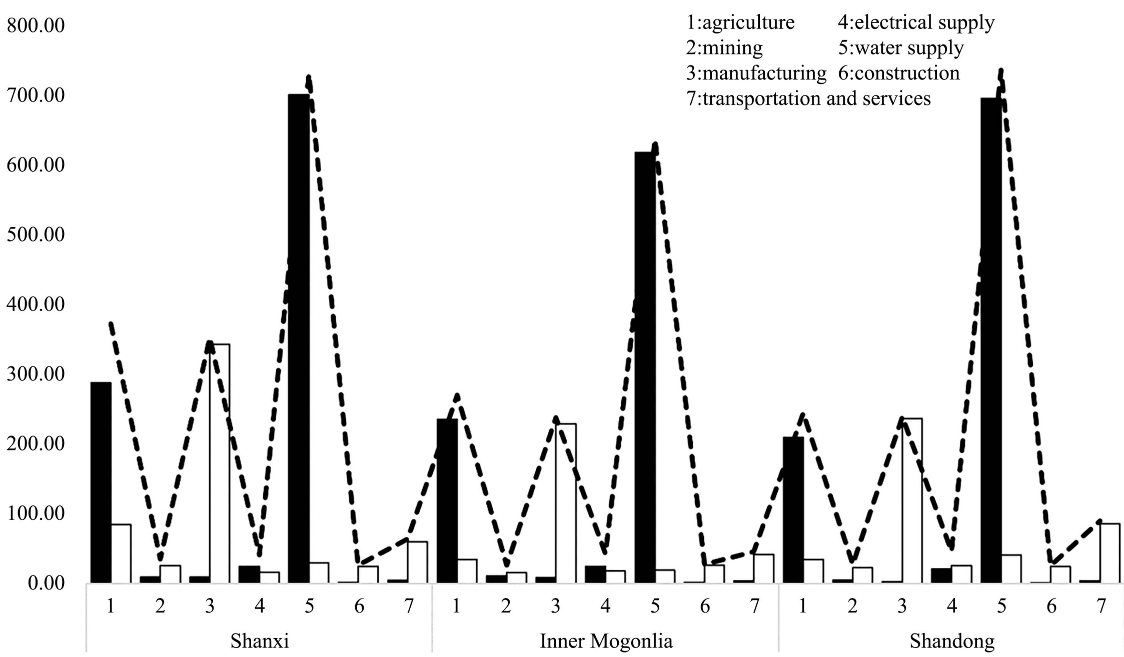
3.3.1. Water Use Coefficient Analysis

Figure 1(a), Figure 1(b) is the complete use coefficients of the water system numerical composition of seven industries in the Pan-Beijing-Tianjin-Hebei region. In terms of the proportion of direct water use coefficient and indirect water use coefficient, there are great differences among various industries. The direct water use coefficient of agriculture, mining and water supply in Beijing, agriculture and water supply in Tianjin and Hebei, agriculture, electrical supply, and water supply in Shanxi, agriculture and water supply in Inner Mongolia, and Shandong exceeds the indirect water use coefficient. The agricultural and water supply industries in the Pan-Beijing-Tianjin-Hebei region have high complete water use coefficients. Specifically, the average agricultural complete water use coefficient is more than 200 m^3 per ten thousand yuan. The average value of the complete water use coefficient in the water supply industry is more than 600 m^3 per ten thousand yuan. This shows that the agricultural and water supply industries consume a large amount of water resources per unit of product production, and the water use efficiency is low. In addition, the direct water use coefficient of these two industries accounted for more than 95%, indicating that these two industries are very large direct water consumption industries. To effectively reduce the use of water resources in the region, some measures should be taken to reduce direct water use.

From the view of the relationship between the production activities of various industries, the production activities of one industry will drive the consumption



(a)



(b)

Figure 1. Direct, indirect and complete water use coefficients in Pan-Beijing-Tianjin-Hebei region.

of water resources in other industries. The difference of pull coefficient determines that there are differences among industrial sectors. Generally speaking, due to the existence of resource endowment advantage in water-rich areas, industries with large water consumption can be vigorously developed, resulting in more direct consumption links and reducing indirect consumption links, so the closer the pull coefficient is to 1. On the contrary, the greater the pull coefficient will be. It can be seen from **Table 1** that the pull coefficients of agriculture, mining, and water supply industries in the Pan-Beijing-Tianjin-Hebei region are all close to 1. Since the products of these industries are used as basic products for the production activities of other industries, the direct water consumption in the production process is large, and the indirect consumption is small. When the direct water consumption is closer to the complete water consumption, the pulling coefficient will be closer to 1.

The average pull coefficient of the manufacturing industry, construction industry, and transportation and service industry in this region is higher than that of other industries. It indicates that there is a large gap between direct water consumption and complete water consumption in these three industries. It shows that there is a lot of indirect water consumption in these industries in the process of production.

From an industrial point of view, the difference between pull coefficients is mainly determined by the nature of the industry and the differences in basic products and production processes. From a regional point of view, the difference of pull coefficient mainly results from the difference of production structure and productivity level in different regions. In the formulation of water-saving policies, the policymakers should consider not only direct water use but also indirect water use. And policymakers also should proceed from the whole and comprehensively consider all aspects of the economic activities of these industries to achieve the goal of water saving in an all-around way.

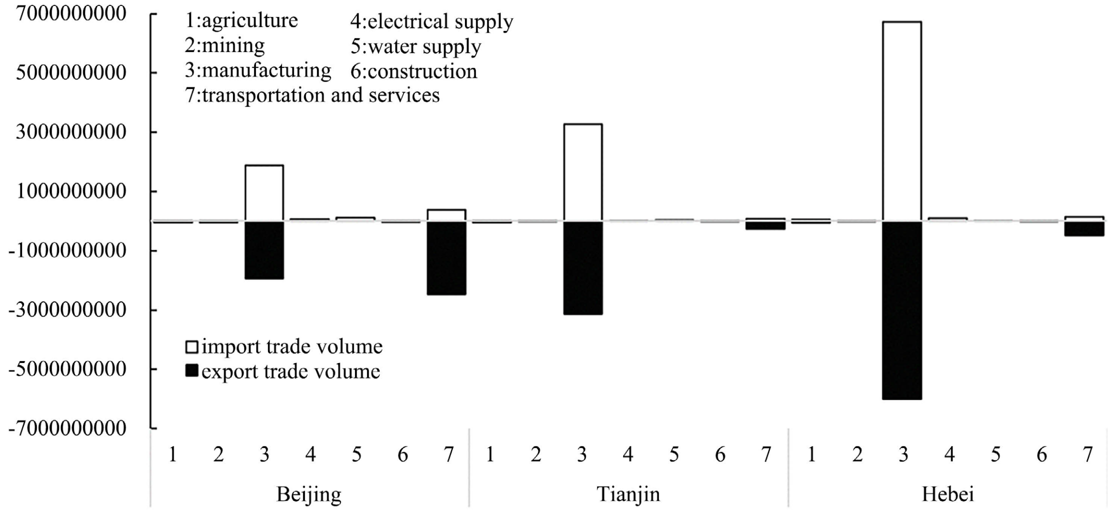
3.3.2. Virtual Water Import and Export Trade Volume Analysis

From the perspective of virtual water import and export trade volume, in 2010, the Pan-Beijing-Tianjin-Hebei region has a total virtual water input of 24.70 billion m^3, a total output of 25.05 billion m^3, and a total output of more than 350 million m^3. On the whole, the Pan-Beijing-Tianjin-Hebei region is a virtual net water export area. Specifically, Beijing and Tianjin are virtual net water import zones, while Hebei, Shanxi, Inner Mongolia, and Shandong are virtual net water export zones. The manufacturing industry has the largest input of virtual water, reaching 22.765 billion m^3, which is the main input industry of virtual water. At the same time, this industry is also the main virtual water output industry with a virtual water of 19.285 billion cubic meters. Therefore, improving the water use efficiency of this industry can effectively reduce the import and export trade volume of virtual water.

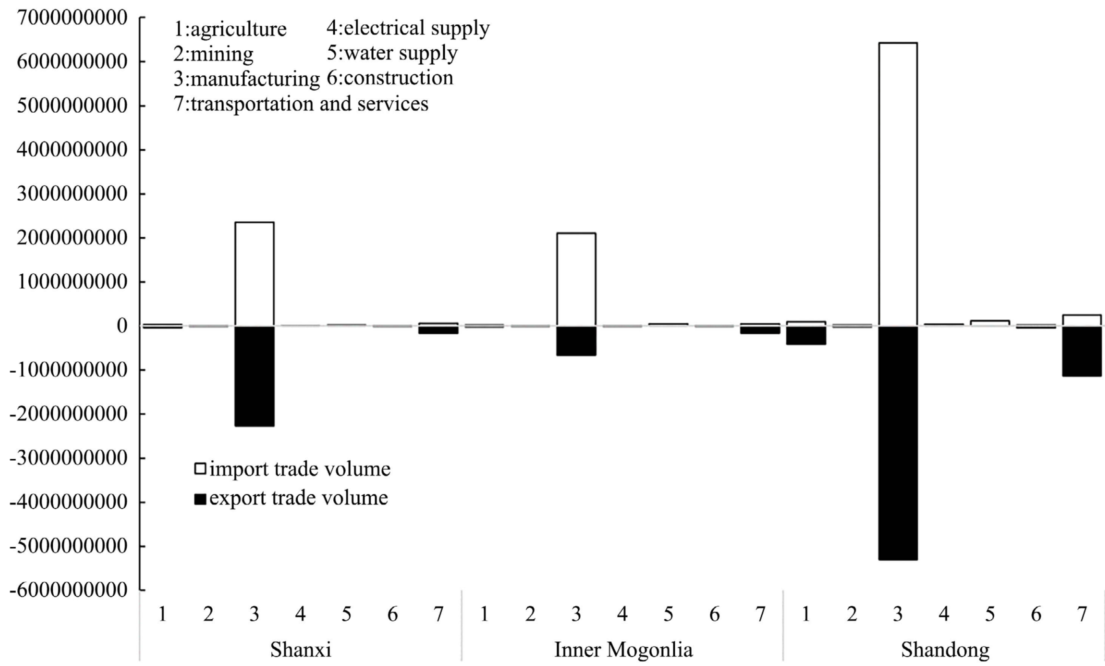
Figure 2(a), Figure 2(b) reflect the total amount of virtual water imports and exports of various industries in the Pan-Beijing-Tianjin-Hebei region. It can be seen from the figure that the industries produced most virtual water trade include manufacturing in six regions, transportation and service industries in Beijing and Shandong, and mining in Shanxi. These industries either input or export a large amount of virtual water, which are active in the virtual water trade. Among them, the virtual water net input industry is mainly the manufacturing industry in six regions. The manufacturing industry consumes a lot of virtual water in the production process and is an important consumer in the water

Table 1. Calculation results of the pull coefficient of each department in the six regions.

	agriculture	mining	manufacturing	electrical supply	water supply	construction	transportation and services
Beijing	1.24	1.48	11.00	4.44	1.06	26.41	91.31
Tianjin	1.05	3.63	43.47	9.08	1.02	21.52	23.35
Hebei	1.08	2.68	56.89	5.44	1.01	17.46	16.37
Shanxi	1.29	3.87	37.29	1.66	1.04	15.00	14.94
Inner Mogonlia	1.15	2.45	27.00	1.73	1.03	21.25	11.14
Shandong	1.16	5.78	94.69	2.23	1.06	21.19	24.20



(a)



(b)

Figure 2. Import and export volume of virtual water in Pan Beijing Tianjin Hebei region.

resource consumption system in this region. The net export industries are mainly the transportation and service industries in Hebei and Shandong and the mining industry in Shanxi, which means that these industries play the role of producers in the region's water consumption system.

3.3.3. Virtual Water Trade Flow Analysis

From the flow direction of virtual water trade in the Pan-Beijing-Tianjin-Hebei region, we can see that the agricultural industries of Hebei Province and Shandong Province have exported a large amount of virtual water for other industries in the Pan-Beijing-Tianjin-Hebei region. The main export targets are manufacturing, construction, transportation, and service industries. The industries with large virtual water imports are mainly manufacturing, water supply, and construction industries in Beijing. In Tianjin, it is manufacturing and construction industries . It can be seen that these industries are highly dependent on the output of virtual water in the Hebei and Shandong provinces.

From the perspective of virtual water export, Beijing agriculture, service, and transportation industry, Tianjin agriculture and water supply industry, Hebei agriculture, manufacturing industry, Shanxi agriculture, and electrical supply industry, and agriculture in Inner Mongolia and Shandong are relatively large and diversified compared with other local industries. Thus they are defined as the key industries of virtual water trade in themselves regions.

From the perspective of virtual water input, the manufacturing, transportation, and service industries of the six regions are the key industries of virtual water input, with large inflows and diverse sources. From the perspective of virtual water input, the manufacturing, transportation, and service industries of the six provinces or cities or cities are the key industries of virtual water input, with large inflows and diverse sources. These industries consume a large number of basic products from other industries in the production process, and the intermediate input is relatively large, so these industries with large virtual flow momentum need to focus on the regulation of virtual water trade.

Hebei and Inner Mongolia import a large amount of virtual water to various industries in Beijing and Tianjin, which is the main source of virtual water and provides a lot of water resources support for the development of Beijing and Tianjin. Shanxi's agricultural sector provides a large amount of virtual water for local construction and transportation and service industries. By judging the flow direction and path of these inter-provincial and inter-industry virtual water, we can identify the relevance of water resources between industries, and then take relevant countermeasures and suggestions according to local conditions.

As from **Table 2**, the virtual water transfer direction in Pan Beijing Tianjin Hebei region is: Tianjin-Beijing: 36,652,409 m^3; Hebei-Beijing: 3,294,581,594 m^3; Shanxi-Beijing: 158,438,379 m^3; Inner Mongolia-Beijing: 961,639,348 m^3; Shandong-Beijing: 1,763,817,907 m^3; Hebei-Tianjin: 2,094,346,446 m^3; Shanxi-Tianjin: 153,980,517 m^3; Inner Mongolia-Tianjin: 973,894,873 m^3; Shandong-Tianjin: 1,189,182,790 m^3; Hebei-Shanxi: 236,444,040 m^3; Hebei-Inner Mongolia:

Table 2. Virtual water trade volume between Pan-Beijing-Tianjin-Hebei regions.

Virtual water transfer	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Shandong
Beijing	0	−36,652,409	−3,294,581,594	−158,438,379	−961,639,348	−1,763,817,907
Tianjin	36,652,409	0	−2,094,346,446	−153,980,517	−973,894,873	−1,189,182,790
Hebei	3,294,581,594	2,094,346,446	0	236,444,040	330,246,384	3,524,468,541
Shanxi	158,438,379	153,980,517	−236,444,040	0	−198,832,580	−1,058,728,165
Inner Mongolia	961,639,348	973,894,873	−330,246,384	198,832,580	0	1,058,181,592
Shandong	1,763,817,907	1,189,182,790	−3,524,468,541	1,058,728,165	−1,058,181,592	0

330,246,384 m^3; Hebei-Shandong: 3,524,468,541 m^3; Inner Mongolia-Shanxi: 198,832,580 m^3; Shandong-Shanxi: 1,058,728,165 m^3; Inner Mongolia-Shandong: 10,581,592 m^3.

As a result, Hebei, and Shandong are the main export places of virtual water, with a total virtual water output of 12.342 billion m^3, accounting for 95.6% of the total virtual water output, mainly to Beijing, Tianjin and Shandong. Beijing, Tianjin, and Shanxi are the net input areas of virtual water, the virtual water of Beijing and Tianjin mainly comes from Hebei and Shandong, and the virtual water of Shanxi mainly comes from Shandong.

4. Conclusion and Suggestions

4.1. Conclusion

This paper calculates and analyzes the inter-provincial and inter-industrial virtual water flows in six provinces or cities and seven industries in the Pan-Beijing-Tianjin-Hebei region, draws relevant conclusions, and puts forward relevant suggestions for optimizing the virtual water trade structure and reducing regional water consumption. The situation of virtual water flow in the Pan-Beijing-Tianjin-Hebei region reflects the mutual allocation of water resources between regions to a certain extent. It can provide a reference for industrial policy and trade policy adjustment from the perspective of virtual water trade, and then give support for the introduction of virtual water strategy.

Industries vary in the characteristics of water use in production activities. From the perspective of industrial water use coefficients, both direct and complete water use coefficients are larger in agriculture and water supply industries, while only complete water use coefficients are larger in manufacturing. Some industries have less direct water consumption in the production process. But there are more indirect consumption links to increase a large amount of indirect water consumption, and the total consumption of water resources is larger. Government should focus on reducing its indirect water consumption. For the agriculture and water supply industries, direct water consumption is large, and indirect water consumption is small, due to the focus on reducing their direct water consumption. Therefore, considering the water use characteristics of different departments and starting from the difference between direct and indirect consumption, it is very essential to take targeted water-saving measures and implement water-saving policies.

The overall industrial structure of the Pan-Beijing-Tianjin-Hebei region will intensify its water resources pressure. Beijing, Tianjin, Shanxi, and Shandong are virtual net water input areas, while Hebei and Inner Mongolia are virtual net water export areas. Hebei and Inner Mongolia have virtual water output of 25.05 billion m^3 and input of 24.7 billion m^3. Therefore, the Pan-Beijing-Tianjin-Hebei region as a whole is a virtual net water export area. It is generally believed that importing virtual water will help to reduce the pressure on regional water resources, while blindly exporting virtual water will aggravate the pressure on water resources. Therefore, the industrial structure of Beijing, Tianjin, Shanxi, and Shandong is conducive to maintaining the safety and stability of water use, but Hebei and Inner Mongolia have to adjust the industrial structure and reduce the export of virtual water to ensure the sustainable development of regional water use. Although the virtual water output in the Pan-Beijing-Tianjin-Hebei region is slightly larger than the input, and the overall industrial structure is relatively balanced, the overall water resources pressure in the region shows a trend of aggregation. It is still necessary to regulate the relationship between trade and consumption and accelerate the transformation from a virtual water net output place to a virtual water net input place. In addition, the main import industries of virtual water are agriculture in Beijing and Tianjin and manufacturing in Inner Mongolia. The main industries of virtual water output are services and transportation in Beijing and Shandong and mining in Shanxi. The manufacturing and service industries should focus on adjusting the industrial structure to transform into water-saving industries.

Hebei and Inner Mongolia have exported a large amount of virtual water to the Pan-Beijing-Tianjin-Hebei region. In the virtual water trade flow in the Pan-Beijing-Tianjin-Hebei region, Hebei and Inner Mongolia provinces transport a large amount of virtual water for the region, providing strong water resources support for the economic and production activities of various departments. Therefore, the agricultural industries of Hebei and Shandong provinces are particularly important for the security and sustainable development of water use in the Pan-Beijing-Tianjin-Hebei region. The improvement of water use efficiency in these industries is the key to reducing the water consumption of the whole Pan-Beijing-Tianjin-Hebei region and promoting the transformation of the region to a virtual net water import area. From the perspective of water consumption of various industries, heavy industries such as chemical products, electric power, heat, gas, and water production and supply are the main industrial water use departments in Hebei Province. Hebei and Shandong provinces are populous agricultural provinces, rich in mineral resources, and the regional economy mainly depends on agriculture and heavy industry. This extensive development mode also makes heavy industry consume a lot of water resources.

4.2. Suggestions

China's Pan-Beijing-Tianjin-Hebei region is a virtual net water export area. If virtual water continues to be exported to other areas, the resulting economic growth will be based on a large number of water resources, which is not conducive to the healthy and sustainable economic development of the region. The application of a virtual water strategy can solve this problem.

The government should optimize the industrial structure and take measures according to the characteristics of departmental water use. The direct water consumption coefficient of agriculture and water supply industry in the Pan-Beijing-Tianjin-Hebei region is larger, while the indirect water consumption coefficient of the construction industry, manufacturing industry, and transportation and service industry is larger. In the virtual water trade structure of this region, the light industry is the virtual water export type, heavy industry is the virtual water import type. On the whole, it is still the net export type. Although the direct water consumption coefficient of some industries is not high, the value of the complete water consumption coefficient is very large in some industries because of the large indirect water consumption coefficient, which shows that a large number of water resources are consumed indirectly in the process of industrial production. Attention should be paid to reducing its indirect consumption, while departments with large direct consumption and small indirect consumption should devote themselves to reducing their direct consumption. Therefore, on the one hand, it is more scientific and reasonable that we should adjust the industrial structure and optimize the allocation of water resources. On the other hand, the government should identify the water use characteristics of various departments and take different water-saving measures.

The government should devote to improve water efficiency and reduce water consumption per unit product. The direct water consumption of agriculture and the water supply industry is large, improving the water use efficiency of these two departments can directly reduce water consumption. For the agricultural industry, water-saving technologies should be developed, such as circulating irrigation technology, rational use of a chemical water-retaining agent, and drought-resistant agent technology, to improve the utilization efficiency of water resources in agricultural production and reduce water consumption per unit product. When planting crops, it is necessary to adjust measures to local conditions. Planting and production of crops with a high direct water consumption coefficient should be avoided in water shortage areas. To improve the benefit and efficiency of water use, it is necessary to reduce the water consumption per unit product through scientific management and technological innovation, optimize the allocation of water resources, and rationally adjust the economic structure and industrial layout to achieve efficient use of water resources. With the development of the economy, industrial water consumption will be increasing. The Pan-Beijing-Tianjin-Hebei region is originally a region with high industrial development level, and the industrial sector is originally a sector with large water consumption. Improving the water use efficiency of the industrial sector and reducing the water consumption of industrial production and unit products are the most direct and effective ways.

The government also should guide consumption habits and investment direction. In the final use of the original input-output table, there are two main statistical indicators: the final consumption expenditure (i.e., consumption) and the total capital formation (i.e., investment), which are indispensable key indicators for calculating the volume of virtual water trade. Therefore, consumption and investment can be considered to optimize the structure of virtual water trade, thereby optimizing the economic structure. In terms of investment, a large amount of investment should be made in water-saving industries or low-consumption industries, and preferential policies should be given to promote the development of water-saving industries. This method is theoretically feasible, but it difficult. Because the ultimate goal of investment behavior is to pursue profits, profitable enterprises will have investment, whether it is a high water consumption industry or a low water consumption industry. Therefore, from the perspective of consumption, we can guide residents' water-saving consumption, cultivate residents' water-saving awareness, and fundamentally reduce water consumption.

4.3. Research Limitations

Due to the limitation of the applicability of the method and the accuracy of the data, our research only based on the Pan-Beijing-Tianjin-Hebei region. Meanwhile, we did not show the annual change in virtual water trade. Thus, future research should consider more year changes and regions to provide better support for government efforts to minimize virtual water trade negative impacts.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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