Assessing international virtual water trade of crops in Yellow River Basin, China

Rong Cai 1, Mengting Hu 1, Huiting Guo 1, Sinan Zhang 1, Xue Bai 1, Lijia Zhang 1*

1 Resource and Environmental Branch, China National Institute of Standardization, Haidian District, Beijing, 100191, China

*Corresponding author’s e-mail: zhanglij@cnis.gov.cn

Abstract. Faced with increasingly severe pressure on water resources, virtual water and virtual water trade theory provide a feasible solution to improve global water use efficiency for agricultural production and to alleviate the pressure on water resources in water-scarce countries or regions. The Yellow River, the second longest river in China, is facing increasing water scarcity. In this study we researched the crops international virtual water trade of 9 provinces and autonomous regions in Yellow River Basin in 2002 to 2010, to explore the effect on water resource of Yellow River Basin by crops international virtual water trade. The result shows that Yellow River Basin was the virtual water net import region in 2002 to 2010. Virtual water net import was increased from 7.5 billion tonnes to 52.4 billion tonnes from other countries in Yellow River Basin. Virtual water imports of Yellow River Basin relied mainly on the soybean import. Yellow River Basin exported virtual water by international trade of rice from 2002 to 2010. Yellow River Basin only exported virtual water by international trade of wheat in 2005 and imported virtual water in the other years. Also, Yellow River Basin imported virtual water by international trade of corn in 2002 to 2007 and exported virtual water in 2008 to 2010. The import and export of virtual water of rice, wheat and corn was very small compared to soybean. So crops international virtual water trade played a very important role in the water resources utilize of Yellow River Basin and will be increasingly important. This will to some extent alleviate the pressure of the water shortage in Yellow River Basin.

1. Introduction

Accessible fresh water is scarce, only 1% of the global water volume is accessible freshwater [1], and it is likely that this quantity will decrease in many regions under future climate change, e.g. through more frequent and more pronounced droughts and through reduced inflow from glaciers [2].

The idea of virtual water was derived from the concept of ‘embedded water’ applied to agriculture in Israel by Fishelson et al. [3]. Their study pointed out that exporting Israeli water embedded in water-intensive crops was not sustainable. Allan defines virtual water as the water used to produce food crops that are traded internationally [3]. He found that a few countries characterized as water-scarce have secured their agricultural products supply by importing water-intensive agricultural products, rather than producing all of their agricultural products supply with inadequate water resources. Limited water resources should be used efficiently by not allocating the majority of the water resources to the production of water-intensive products (e.g. crops, paper etc.) but rather water should be made available for other economic purposes that can contribute more to regional value added by consuming less water [4-6]. Chapagain and Hoekstra computed virtual water content (water use per harvested biomass) [7].
Several studies have quantified global virtual water imports and exports using various statistical analyses and models. The commodities used in these estimates have been expanded to include fibre products [8], livestock products [9], and industrial products [6]. Hoekstra and Hung estimated the global virtual water exports related to international trade in crops from 1995 to 1999 by multiplying the international crop trade flow (tonne yr\(^{-1}\)) and the associated virtual water content (VWC, m\(^3\) tonne\(^{-1}\)) [10]. They showed that there was 695 billion of virtual water flow of the world in 1995-1999. According to estimation, about 5.4 trillion m\(^3\) of water was used by the world crop growth. This shows that 13% of the agricultural water exported in the form of virtual water. In various food crops trade, virtual water flow caused by exported of wheat, soybeans and rice respectively was 30%, 17% and 15% [11, 12]. In addition, the Wholesale World Congress (WWC) and the Food and Agriculture Organization of the United Nations (FAO) also made an in-depth analysis of the virtual water flow on the global scale, the estimated results was 1.34 trillion m\(^3\) of the virtual water flow, of which agriculture and animal products trade accounted for 60%, marine fish products trade accounted for 14%, and industrial products trade accounted for only 10% [13]. Oki and Kanae [14] and Yang et al. [15] produced similar estimates using different approaches. The above studies estimated the total global virtual water exports of crops at 556–979 km\(^3\) yr\(^{-1}\). The wide range of the estimates is not surprising, as they depend on the period and number of commodities used in the calculations. Oki et al. [16] calculated the global virtual water flow, respectively for 680 billion m\(^3\) and 1.14 trillion m\(^3\) from the two angles of producers and consumers. For further information on previous studies, Yang and Zehnder [17] provide a critical review of major research issues and results in the virtual water literature.

Based on the traditional point of view of virtual water strategy, water-scarce countries or regions imported agricultural products through the trade of agricultural from water-rich countries or regions, not only alleviate the water shortage situation, and guarantee the safety of the food. Cao et al. calculated virtual water trade of food crops in China for nearly 40 years. In 1992 to 2001, average annual net import virtual water was 31 billion m\(^3\), accounting for 8% of the whole agricultural water use [18]. Liu et al. studied that average annual net import virtual water of China was about 40 billion m\(^3\). This was equivalent 100% - 133% to the amount of water resources shortage in our country every year [19]. These studies have shown that agricultural products virtual water import and export is advantageous to our country water resources.

The Yellow River, the second longest river in China, is facing increasing water scarcity. In this study we researched the crops international virtual water trade of 9 provinces and autonomous regions in Yellow River Basin in 2002 to 2010, to explore the effect on water resource of Yellow River Basin by crops international virtual water trade.

2. Methodology and data

2.1. Study area
Yellow river is originated in Bayan Har Mountains in Plateau at an altitude of about 4500m, flows through Qinghai, Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, Shandong and other nine provinces (autonomous regions), into the Bohai Sea. The length of yellow river is about 5464 km. The average annual natural runoff of whole river for many years is about 58 billion m\(^3\), account for only 2% of total runoff of China. The per capita water of the basin is 593 m\(^3\), for 25% of the national per capita water. Arable land per acre of water is 324 m\(^3\), only 17% of the national farmland water per acre.

2.2. Methodology and data
Agricultural products mainly include two categories of products of food crops and cash crops. The acquisition of domestic inter-district economic crop products trade flows data is difficult, therefore, in this article the major food crops (rice, wheat, corn, soybeans) are used as the object of this study.
The gross volume of virtual water import (GVWI) to a region is the sum of crop imports (CI) multiplied by their associated crop virtual water content (VWC) in that region:

$$GVWI = \sum_c(CI \times VWC)_c$$

Similarly, the gross volume of virtual water export (GVWE) from a country is the sum of crop exports (CE) multiplied by their associated crop virtual water content (VWC) in that region:

$$GVWE = \sum_c(CE \times VWC)_c$$

The net virtual water trade of a country (NVWT) can be calculated as:

$$NVWT = GVWI - GVWE$$

Equations for estimating the total basin virtual water import (TBVWI) and total basin virtual water export (TBVWE) are expressed as:

$$TBVWI = \sum_{n=1}^{n} \sum_{c=1}^{c} GVWI_{n,c}$$

$$TBVWE = \sum_{n=1}^{n} \sum_{c=1}^{c} GVWE_{n,c}$$

Where n is the number of countries, and c is the number of crops. Water saving/loss generated from the total net virtual water trade (TNVWT) can be calculated as:

$$TNVWT = TBVWI - TBVWE$$

3. Results

3.1. International net virtual water trade volume of rice

Yellow River Basin exported virtual water by international trade of rice from 2002 to 2010. In 2004, Yellow River Basin exported the least virtual water – 2.0 million tonnes - by international trade of rice; and exported the most virtual water – 24.9 million tonnes - in 2007 (Figure 1).

![Figure 1. The net virtual water trade by international rice trade in Yellow River Basin from 2002-2010](image)

3.2. International net virtual water trade volume of wheat

Yellow River Basin only exported virtual water by international trade of wheat in 2005 and imported virtual water in the other years. In 2005 Yellow River Basin exported 7.1 million tonnes virtual water and imported the most virtual water of 58.7 million tonnes by international trade of wheat in 2002 (Figure 2).
3.3. International net virtual water trade volume of corn

Yellow River Basin exported virtual water by international trade of corn in 2002 to 2007 and imported virtual water in 2008 to 2010. In 2003 Yellow River Basin exported the most virtual water of 2.1 billion tonnes and imported the most virtual water of 58.7 million tonnes by international trade of wheat in 2010 (Figure 3).

3.4. International net virtual water trade volume of Soybean

Virtual water imported of Yellow River Basin relied mainly on the soybean imported in 2002 to 2010. The imported virtual water by international soybean trade was increased from 9.0 billion tonnes to 52.2 billion tonnes from 2002 to 2010 (Figure 4).
3.5. International net virtual water trade volume of crops

Yellow River Basin was the virtual water net import region in 2002 to 2010. The international virtual water net import was increased from 7.5 billion tonnes to 52.4 billion tonnes (Figure 5).

Table 1. The international net virtual water trade in Yellow River Basin from 2002-2010 (million tonnes)

| Region    | 2002  | 2003  | 2004  | 2005  | 2006  | 2007  | 2008  | 2009  | 2010  |
|-----------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Qinghai   | 0     | -0.5  | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| Sichuan   | -1.2  | 482.3 | 393.7 | 1125.6| 185.3 | 322.4 | 342.4 | 403.6 | 540.5 |
| Gansu     | -0.2  | -0.2  | -0.1  | 0     | 0.01  | -0.01 | -0.01 | -0.03 | -0.04 |
| Ningxia   | -0.5  | -1.2  | -0.7  | -0.6  | -0.3  | 0     | 0     | 0     | 0     |
| Inner Mongolia | -1383.0 | -1536.5 | -231.9 | -38.8 | -289.8 | -657.2 | -28.1 | -21.6 | -16.3 |
| Shaanxi   | -0.9  | -0.5  | -0.08 | -2.2  | 6.0   | -53.7 | -47.5 | -7.1  | 218.7 |
| Shanxi    | -337.8| -576.6| -48.1 | -0.3  | -82.5 | -9.6  | -0.09 | 4.8   | 2.9   |
| Henan     | 2394.1| 3647.3| 2975.8| 3096.0| 3347.3| 2978.5| 4076.6| 3969.5| 4885.6|
| Shandong  | 6836.1| 13211.5| 13587.1| 11147.1| 13964.3| 19409.0| 23892.9| 29629.0| 46724.7|

Figure 4. The net virtual water trade by international soybean trade in Yellow River Basin from 2002-2010

Figure 5. The international net virtual water trade in Yellow River Basin from 2002-2010

The number of the net virtual water import regions was 2 in 2002; and the number of the net virtual water import regions was added to 5 in 2010 (Table 1).
The imported and exported of virtual water of rice, wheat and corn was very small compared to soybean (Figure 6).

Figure 6. The net virtual water trade by four crops trade in Yellow River Basin from 2002-2010

4. Discussion and Conclusions
Soybean was the virtual water net import crops every year from 2002 to 2010. Virtual water imports of Yellow River Basin relied mainly on the soybean import. Soybean virtual water import average account for 104.4% of virtual water import of Yellow River Basin in 2002 to 2010. The imported virtual water by international soybean trade was increased from 9.0 billion tonnes to 52.2 billion tonnes from 2002 to 2010. Soybean virtual water imports were growing at the rate of 24.6% per annum. International wheat net virtual water export only appeared in 2005. In 2005 Yellow River Basin exported 7.1 million tonnes virtual water and imported the most virtual water of 58.7 million tonnes by international trade of wheat in 2002. Corn began to realize virtual water net import from 2008. In 2003 Yellow River Basin exported the most virtual water of 2078.6 million tonnes and imported the most virtual water of 58.7 million tonnes by international trade of wheat in 2010. However, rice was the virtual water net exported crop every year from 2002 to 2010. In 2004, Yellow River Basin exported the least virtual water – 2.0 million tonnes - by international trade of rice and exported the most virtual water – 24.9 million tonnes - in 2007.

The import of virtual water by the international trade of crops of Yellow River Basin was in dominant position and Yellow River Basin was the virtual water net import region in 2002 to 2010. Yellow River Basin respectively imported 7.5 billion tonnes, 15.2 billion tonnes, 16.7 billion tonnes, 15.3 billion tonnes, 17.1 billion tonnes, 22.0 billion tonnes, 28.2 billion tonnes, 34.0 billion tonnes and 52.4 billion tonnes virtual water from other counties in 2002 to 2010. Virtual water imports under an increasing trend of 27% per annum. Crops virtual water international import played a very important role in the water resources utilize of Yellow River Basin and will be more and more important. This will to some extent alleviate the shortage of water resources in Yellow River Basin and at the same time help to ensure the food safety of Yellow River Basin.

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