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# Virtual water flows in the international trade of agricultural products of China

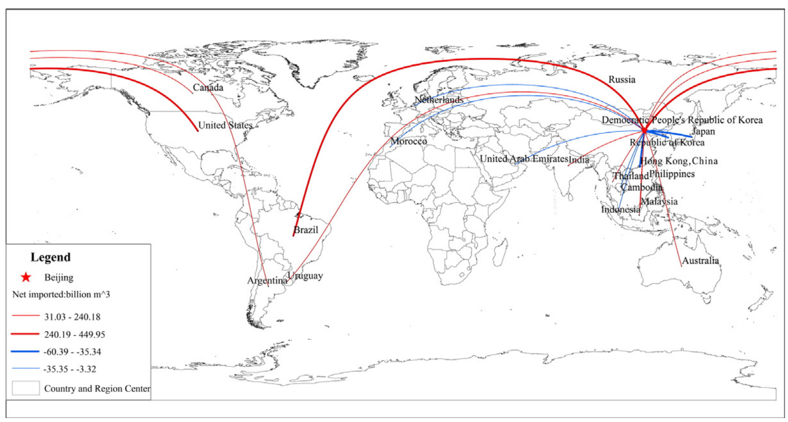
Yu Zhang, Jinhe Zhang *, Guorong Tang, Min Chen, Lachun Wang

*School of Geographic and Oceanographic Sciences, Nanjing University, Nanjing 210023, China*

## HIGHLIGHTS

- A comprehensive analysis was conducted on China's international virtual water trade of agricultural products.
- Giving full consideration to each partner's actual virtual water coefficient
- Four types of trade partners: mutual benefit countries, unilateral benefit countries, supported countries, and double pressure countries
- China was in trade surplus in relation to the international virtual water trade of agricultural products.
- The structure of virtual water trade was highly concentrated on several trade partners and agricultural products.

## GRAPHICAL ABSTRACT

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## ABSTRACT

With the rapid development of the economy and population, water scarcity and poor water quality caused by water pollution have become increasingly severe in China. Virtual water trade is a useful tool to alleviate water shortage. This paper focuses on a comprehensive study of China's international virtual water flows from agricultural products trade and completes a diachronic analysis from 2001 to 2013. The results show that China was in trade surplus in relation to the virtual water trade of agricultural products. The exported virtual water amounted to 29.94 billion $m^3$/ /yr. while 155.55 billion $m^3$/yr. was embedded in imported products. The trend that China exported virtual water per year was on the decline while the imported was on a rising trend. Virtual water trade of China was highly concentrated. Not all of the exported products had comparative advantages in virtual water content. Imported products were excessively concentrated on water intensive agricultural products such as soya beans, cotton, and palm oil. The exported virtual water mainly flowed to the Republic of Korea, Hong Kong of China and Japan, while the imported mainly flowed from the United States of America, Brazil and Argentina. From the ethical point of view, the trade partners were classified into four types in terms of "net import" and "water abundance": mutual benefit countries, such as Australia and Canada; unilateral benefit countries, such as Mongolia and Norway; supported countries, such as Egypt and Singapore; and double pressure countries, such as India and Pakistan. Virtual water strategy refers to water resources, agricultural products and human beings. The findings are beneficial for innovating water resources management system, adjusting trade structure, ensuring food security in China, and promoting the construction of national ecological security system.



* Corresponding author.
*E-mail address:* zhangjinhe@nju.edu.cn (J. Zhang).

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## 1. Introduction

Water plays a key role in sustaining our daily life and natural ecosystems, and it underpins the development of any societies. Some argue that the world will face two crises in the 21st century: a water crisis and an energy crisis (Brown, 1998; Feffer, 2008; Flavin, 1999). The United Nations estimated that about 2–7 billion people may face water scarcity by the year 2050, and per capita water resources may shrink by one third during the next two decades (United Nations, 2003). Virtual water as well as water footprint shine a completely new light on water consumption, water scarcity and the management of water resources, also reflect virtual water flows through trade among different regions (Dong et al., 2014; Novo et al., 2009). Water scarce countries or regions can save water through import of water-intensive products or make use of their relative water abundance to produce water-intensive commodities for export (Allan, 1999; Hoekstra, 2003). Considering the large share of water withdrawal for food production, a growing number of literature about virtual water flows of agricultural products can be currently available (Chen and Chen, 2013), from the global aspect (Chapagain et al., 2006; Hoekstra and Hung, 2005; Mekonnen and Hoekstra, 2010a, 2010b, 2011), national and regional level scenarios, such as Nile Basin (Zeitoun et al., 2010), EU river basins (Vanham, 2013), Spain (Novo et al., 2009), and Libya (Wheida and Verhoeven, 2007).

Since the 1980s, China has been facing water scarcity due to the increasing water demands from urban industries, domestic consumption, and the irrigated agriculture (The Word Bank, 2002). In addition, China enjoys the first agricultural production power, together with the agricultural products trading power in the world (Ministry of Commerce of the People's Republic of China, 2015), posing great influence on the world market and resources. Furthermore, agriculture represents the largest water-consuming sector in China, accounting for approximately 55% of the total water use of the whole society (Dalin et al., 2015; Ministry of Agriculture of the People's Republic of China, 2015b). Therefore, virtual water of agricultural products of China has become a focus of many studies. The literatures mainly concentrated on the calculation of special agricultural products, water footprints of different regions, and virtual water flows at regional and national levels.

The first hot topic was the calculation of virtual water content or water footprint of agricultural products and the influential factors. There were significant differences for the water footprint among different crops in the same area or among different areas for the same crop. In China, rice had the highest water footprint at 1.39 $m^3$/kg, while corn had the lowest at 0.91 $m^3$/kg among the main grain crops (Wang et al., 2014a). From south to north along the latitude, there was a high-low-high distribution trend of the aggregated virtual water content of the crops (Zhao et al., 2014b). The annual average water footprint of integrated-crop production in Hetao irrigation district was 3.91 $m^3$/kg, mainly relied on blue water, accounting for 91% (Sun et al., 2013). In addition, the water footprints of four major crops were calculated in five provinces along China's South–North Water Transfer Project (Wei et al., 2016). As China's dairy consumption grows, water footprints of milk and milk products produced in Heilongjiang were calculated. The water footprints of milk products (cradle to factory gate) produced in Heilongjiang were much lower than those imported from California, but higher than those from New Zealand (Huang et al., 2014). As for the influential factors, crop patterns, agricultural management and climate change may had an important impact on virtual water content of grain products (Sun et al., 2013; Wang et al., 2014a; Zhao et al., 2014b).

Other studies have also been conducted on water footprint of China or a particular region that faced severe water scarcity. From the national aspect, agriculture was the most water-consuming sector in the country (Dong et al., 2014). Based on an extended STIRPAT model, water footprint of agricultural sector increased from 549.68 billion $m^3$ in 1990 to 1016.64 billion $m^3$ in 2009 (Zhao et al., 2014a). As for grain cultivation, national water use was approximately 689.04 billion $m^3$, blue and green water accounted for 42.26% and 57.74% respectively (Cao et al., 2015). With respect to water footprint of family members of Chinese households, the average person wasted (consumed) 16 (415) kg of food at home annually equivalent to 18 (673) $m^3$ water footprint (Song et al., 2015). Per capita water requirement for food has increased from 255 $m^3$ in 1961 to 860 $m^3$ in 2003, largely due to the great increase in animal product consumption (Liu and Savenije, 2008). Furthermore, there were studies on special regions, such as Beijing, Liaoning province and Heihe River Basin. Owing to the rapid urbanization, water footprint of crop production in Beijing experienced a decrease of 35.1% from 1978 to 2012, and blue water footprint was the dominant (Xu et al., 2015). From the perspective of different sectors in Beijing, the agricultural water footprint showed a trend of decline (Wang et al., 2013). In more details, the total water footprint of Beijing in 2009 was 2.37 billion $m^3$ with regard to the consumption of crop products produced locally in Beijing. Gray water was greater than the green and blue ones (Huang et al., 2012). Another case was Liaoning province, the total water footprint of Liaoning was 7.30 billion $m^3$ in 2007. The agriculture industrial sector had the highest water footprint with a figure of 2.87 billion $m^3$, accounting for about 39.26% (Dong et al., 2013). The water footprint within the Heihe River Basin was 1768 million $m^3$/yr. over 2004–2006. Agricultural production accounted for 96% of the total water footprint (Zeng et al., 2012).

A growing body of literature has focused on virtual water flows of agricultural products at regional and national levels. From the regional level, virtual water usually flows from water-poor regions to water-rich regions and from regions with high water use efficiency for grain production to regions with low water use efficiency in China (Wang et al., 2014b). Between the north and the south, water resources in China presented the reverse flow of virtual form and real form between the north and the south. Namely, on the one hand, water resources in real form flowed from the rich area to the poor area (South-to-North Water Diversion Project). On the other hand, water resources in virtual form flowed from the poor area to the rich area (North-to-South Grain Dispatching) (Han and Sun, 2013; Ma et al., 2006). Water-scarce north China predominantly produced and exported water-intensive products but imported non-water intensive commodities (Guan and Hubacek, 2007). North China annually exported about 52 billion $m^3$ virtual water to south China (Ma et al., 2006). Moreover, the most developed and water scarce areas such as Shanghai and Beijing intended to import virtual water, while Xinjiang, Inner Mongolia and Guangxi were the main water import regions (Dong et al., 2014). There were also studies on special districts and river basins, such as Hetao irrigation district and Yellow River Basin. More than 90% of the virtual water flows in the Hetao irrigation district originated from counties with lower water stress and was transferred to those with higher water stress. The export of virtual water fluctuated but tended to increase in the Hetao irrigation district (Liu et al., 2015a, 2015b). In respect to virtual water flows between the three reaches of the Yellow River Basin and the rest of China, all three reaches were net virtual water exporter (Feng et al., 2012). Referring to international trade, overall, China was the net importer of virtual water related to agricultural products and the product structure was single (Ji, 2008; Liu and Wu, 2005; Ma et al., 2011), and a significant share of international virtual water flows was soya beans (93%) (Dalin et al., 2014). While considering all departments, including agriculture, industry and service, China was a net exporter (Mekonnen and Hoekstra, 2011; Zhao et al., 2009; Zhu and Gao, 2009). Considering future food trade patterns of China and associated water transfers, foreign virtual water imports will increase from about 49 $km^3$ in 2005 to 137 $km^3$ in 2030 (Dalin et al., 2015). Nevertheless, the trade status was different among special countries and regions. In 2005, China was a net importer in virtual water trade with ASEAN (Yang et al., 2008). The virtual water trade of agricultural products between China and Russia in 2012 indicated that China was a net exporter (Ma, 2016).