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Optimization of virtual water flow via grain trade within China

Zongzhi Wang[a,*], Lingling Zhang[b,*], Qing Zhang[b], Yi-Ming Wei[c,*], Jin-Wei Wang[c], Xueli Ding[b], Zhifu Mi[d,*]

[a] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Nanjing Hydraulic Research Institute, Nanjing 210029, China
[b] School of Public Administration, Hohai University, Nanjing 210098, China
[c] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing 100081, China
[d] The Bartlett School of Construction and Project Management, University College London, London WC1E 7HB, UK

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ABSTRACT

The irrational virtual water flow caused by grain trade makes water use efficiency low and further threatens grain security in China. However, optimizing the grain virtual water trade flow from the perspective of the economic value of water resources has rarely been carried out in current research. This paper proposes a linear optimization model considering opportunity cost to fill this gap. The current situation of grain virtual water trade is analyzed and we find an irrational trade mode which quantity and direction of grain virtual water trade in some provinces are not consistent with actual demand. Then, opportunity cost is added to the linear optimization model to adjust grain virtual water trade which shows several advantages compared to general linear optimization model. Results show that huge virtual flow is generated, up to 1179.24 billion cubic meters of water. And the economic value generated by grain virtual water trade can not only cover the transportation cost but can also eventually generate economic benefits of 7410 billion yuan. Finally, the relevant conclusions and implications of adjusting China's grain virtual water trade are obtained.

1. Introduction

Problems related to water is considered the grimmest challenges in China due to the low availability of per capita volume. China's average water availability is 2300 m^3/year, only accounting for 1/3 of the average of world. What's worse is that North China supports more than half of the total population with merely 20% of the total water resources and approximately 1/8 of the national level in terms of per capita water availability. Flourishing trade activities on both domestic and international levels are expected to contribute to the ever increasing levels of water consumption (Guan and Hubacek, 2007). As a production link with high water consumption and low economic returns, grain production plays an important role in water utilization, economic development and social stability. The virtual water strategy constructs a bridge between water resource management and food security by changing the traditional thinking of relying on engineering and technological means to solve the problem of water shortage. Virtual water has been recognized as a potentially useful concept for redistributing water from water-rich to water-poor regions (Feng et al., 2012), that is, the indirect allocation of water resources by economic ties.

However, from the perspective of virtual water, China's grain trade shows the pattern of "the north water moves to the south" (Hoekstra and Hung, 2002). The virtual water flow from north to south from 2004 to 2013 was approximately 42.6 billion m^3/year and the irrigation water was accounts for approximately 10% of the water consumption for crop production in the North (Jiang et al., 2017). For China, this transfer, along with scarce water resources and uneven distribution, is a serious threat to the sustainable development of agriculture. This pattern is the result of comprehensive factors, such as water and soil resource matching, economic development, population size and so on (Jiang et al., 2015). Therefore, remolding the water trade relationship is an important supplementary tool in solving water shortage (Zhang and Anadon, 2014).

And trade is a means of transferring water resources between regions. The virtual water trade is a powerful accounting tool mapping the linkages between trade activities and anthropogenic water use (Chen and Li, 2015). Thus, evaluating the virtual water flow via China's inter-provincial grain trade has significant policy implications. However, to the best knowledge of the authors, there are few studies on optimizing the grain virtual water trade flow from the perspective of the economic value of water resources. Many researches have

* Corresponding authors.
E-mail addresses: wangzz77@163.com (Z. Wang), llzhang007@163.com (L. Zhang), wei@bit.edu.cn (Y.-M. Wei), z.mi@ucl.ac.uk (Z. Mi).

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advocated virtual water as a strategy due to the comparative advantage of water resources, to be specific, that is a water-scarce country can aim at importing water-intensive products and exporting water-extensive products (Hoekstra and Hung, 2005). Therefore, existing researches only emphasize the endowment conditions of the water resources but ignore the other factors when applied virtual water strategy. And the comparative advantages of virtual water strategy are only gained from the perspective of water resources endowment resulting that the choice of virtual water trade in this situation lacks overall consideration.

The water embodied in virtual water trade can also be used in other purposes such as economic development and environment requirement. Thus, it is necessary to take the opportunity cost factor into consideration in weighing the pros and cons of the virtual water trade. The so-called opportunity cost is, when a decision is made, the loss of the potential benefit of giving up another scheme is caused by the choice of a better scheme. Since this potential benefit is a possible choice, the decision-makers cannot only consider the resources of sacrifice when measuring the benefits of a particular scheme (the actual cost) but they also compare the loss of the benefit (opportunity cost) resulting from the other suboptimal schemes. Therefore, the opportunity cost is the related cost of decision making and is of great significance to decision-making. Finally, we choose the economic value of water resources as the opportunity cost. To this end, this paper, based on the current situation of grain production and consumption of virtual water, quantifies and adjusts the grain virtual water trade structure from the perspective of the economic value of water resources to fill gap in this area.

This paper attempts to address three issues:

(1) What is the current situation of grain virtual water trade?
(2) How can grain virtual water trade be optimized?
(3) What are the advantages of the optimized method of grain virtual water trade other than the general optimization?

2. Literature review

2.1. Virtual water trade

Professor Allan (1993, 1994) first proposed the concept of virtual water and defined the amount of water consumed for production goods and services as "virtual water". Hoekstra and Hung (2005) put forward the concept of the "water footprint" based on the virtual water used to measure and calculate the water consumption of a certain area after the virtual water flow.

Many virtual water trade studies have been conducted on multiple levels with many meaningful results. At the global level, the virtual water flows related to international rice trade 31 km^3/year (Chapagain and Hoekstra, 2011). Global virtual water trade was estimated and 450 km^3/year is virtually saved by global trade resulting from the comparative advantage of water use efficiency in import and output countries (Chapagain and Hoekstra, 2003). Given the importance of non-food product in global trade, another study was done and results show that 57% of the international virtual water flows is embodied in non-food trade (Chen and Chen, 2013). At national level, El-Sadek (2010) found that Egypt's net virtual water import as a percentage of water resources has mounted to be 23.55% and discussed the applicability of virtual water concept in the national water resources strategy of Egypt. Abu-Sharar et al. (2012) analyzed the optimization role of virtual water in water resources management in the Jordanian region and noted that continued importation of food crops will become an effective way to balance food production and save water resources. Allan and Olmsted (2003) calculated the import and export volumes of virtual water in recent years in some countries in the Middle East and North Africa and noted that virtual water trade played an important role in guaranteeing food security. Ma et al. (2006) quantified the volumes of virtual water flows between regions in China and the results shown that the export volume of virtual water from north China to south China was 52 Gm^3/year. At the provincial and basin level, Zhang et al. (2011) found that Beijing import 51% of virtual water from other provinces. Feng et al. (2012) assessed the regional virtual water flows between the Yellow River Basin and the rest of China, and results shown that all three reaches of that are net virtual water exporter.

2.2. Optimization of virtual water trade

Research focused on virtual water trade pattern in China and the characteristics of virtual water trade shown from north to south and from arid regions to wet regions (Dalin et al., 2014). Ansink (2010) explained the phenomenon and claimed the arable land has played more decisive role in grain production than water. The paradox that arid regions transfer virtual water to wet regions is contributing to more unsustainable and uneven economic and environmental development (Chen et al., 2017). Based on previous studies, some literatures had put forward policy recommendations such as optimizing trade structures (Zhang et al., 2017). Virtual water provides an innovative application of virtual water trade in the traditional allocation of physical water resources in water scarce regions (Ye et al., 2018). Cheng (2006) introduced the concept of virtual water to China and noted that it is of great significance to optimize the trade structure of water-intensive agricultural products. Some unexpected challenges occurs to the governments when they wishing to implement a virtual water strategy aiming to encourage farmers to select low-valued, water-intensive crops rather than higher-valued, tradable crops (Wichelns, 2001).

In the study of inter-regional grain virtual water trade in China, Zou et al. (2010a) explored the current situation of domestic grain virtual water balance and put forward the ideal layout mode of China's grain production under the background of virtual water. The direction of regional grain production adjustment is given (Zou et al., 2010b). Wang et al. (2014) studied the impact of inter-regional food virtual water flow on the regional economy and water resources in China and noted that improving the efficiency of agricultural water use, implementing virtual water compensation and optimizing crop planting structure are the key measures to solve the negative effects of regional virtual water flow. Virtual water trade's rational foothold should be the coordination of economic development goals and water resource issues. Therefore, virtual water trade has both water-saving effects and economic values (Xu et al., 2010). Hoekstra and Hung (2002) argued that not only pricing and technology can be means to increase local water use efficiency and reallocating water, but also virtual water trade between nations can be an instrument to increase water use efficiency.

Linear programming is the most important method of system optimization in operational research, and it is an applied mathematical method for the rational utilization and allocation of resources. Its basic idea is to meet certain constraints and make the target reach the optimal. The wide application of linear programming, in addition to its own practical characteristics, is still simple in its structure and easy to master. This method has been applied by researchers in the field of virtual water trade, such as Dalin et al. (2015), who estimated China's future food trade patterns and water transfers and measured the influences of targeted irrigated land reductions on water consumption and food self-sufficiency. Li et al. (2018) used the interval linear multi-objective programming (ILMP) model for irrigation water allocation through considering conflicting objectives and uncertainties and indicated that the ILMP model provided effective linkages between revenue/output promotion and water saving. Domestic scholars (Dong, 2016) use the linear programming method to study the Xinjiang virtual water trade structure optimization by adjusting the sector net outflow/net export trade on the premise of ensuring the economic, environmental and social benefits. However, at present, the research on the quantitative adjustment of the grain virtual water trade pattern from the point of view of its economic value has not been carried out.