Agricultural Water Management 208 (2018) 204–213

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

The virtual Water flow of crops between intraregional and interregional in mainland China

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ARTICLE INFO

Keywords:
Virtual water
Virtual water flow
Virtual water trade
China

ABSTRACT

Agriculture is the main consumer of freshwater in the world. The paper described the process of virtual water content and flow in crops. Differences in climatic conditions of different regions in China result in large differences in water consumption during crop growth. The virtual water trade in crops connects water flows within and between regions, linking the actual water consumption with the invisible water trade as a whole. The objective of the paper was supplying the agricultural products virtual water trade evaluation system, determining quantitatively the virtual water flow within the region & regional. Using meteorological and agricultural data from 2003 to 2010, a comprehensive analysis of China's domestic & international virtual water trade of agricultural products has been undertaken. The virtual water for the three primary crops and virtual water trade are discussed. The virtual water content of grain crops in northern & southern China was 1293 m^3/t & 942 m^3/t, respectively; the national average value was 1117 m^3/t; and the regional differences in virtual water content for each crop were significant. China's inter-regional agricultural products virtual water trade was not consistent with water resource endowment expectations. The transfer of crops from northern to southern regions would have a significant impact on the sustainable utilization of water resources and would exacerbate water resources shortages in northern regions. China had a trade surplus in global virtual water trade of agricultural products. The exported agricultural products virtual water amounted to 31.5 billion m^3/yr., and the imported amount was 145 billion m^3/yr. The net import of virtual water embedded in agricultural products increased from 44 billion m^3/yr. in 2003 to 178 billion m^3/yr. in 2010. It is further concluded that the trend for agricultural products total virtual water, green water, and blue water is that China is increasing its imports year on year. A large increase in imports of agricultural products has led to a decline in the rate of self-sufficiency in domestic agricultural production. The paper provided the basis for the comprehensive evaluation of crop planting structure adjustment, grain import & export, and the potential of regional water resources development and utilization.

1. Introduction

The populations of most nations consume products of both domestic and foreign origin, importing together with the products the water which is expended abroad for their production (termed ‘virtual water’) (Allan, 1994). The scholar Tony Allan (1997) first proposed the concept of virtual water, which was further extended by Hoekstra (2003a,b,c) to the currently recognized concept of virtual water, the quantity of water needed to produce goods and services. The related theory of virtual water has provided new ideas for solving the problem of water resources in China. Agricultural virtual water refers to the water consumed during the production of agricultural products (including crops and livestock products). The virtual water, as non-real water yield congealed in products and services, is internalized in product in the form of "virtual", i.e. "embedded water" or "exogenous water". The virtual water is derived with the development of merchandise trade based on resource flow, resource substitution, and comparative advantage theory. Since the Israeli economists stated the diseconomy to the development of high-water-consumption agriculture in water-shortage countries/regions in the 1980s, the decision-making guidance role of "virtual water" as countries/regions to alleviate water resource shortages has been highlighted. With the increasing globalization of commodity exchange trading, Hoekstra further expanded virtual water as the amount of water resources needed to produce commodities and services (Hoekstra and Hung, 2002). Since 2002, the theories of virtual water have been internationally expanded, while the quantitative calculation system has been gradually elaborated. Therefore, for a region, the smaller the total amount of virtual water for agricultural products

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https://doi.org/10.1016/j.agwat.2018.06.023
Received 3 April 2018; Received in revised form 18 June 2018; Accepted 19 June 2018
0378-3774/

means that the smaller the amount of agricultural water consumed, the more water resources that can be used in other industries will be conducive to the increase of regional economic output value. To understand the development trend of the total amount of virtual water for agricultural products in a region, it is particularly important to find out the drivers of the change in the total amount of virtual water in agricultural products in mainland China. Research on virtual water and related theories at home and abroad is mainly focused on the issue of agricultural products (especially food). Scholars from various countries have conducted in-depth discussions on the driving factors of virtual water trade (flow) from the actual conditions of their own countries (Ma et al., 2006; Wang et al., 2015; Kumar and Singh, 2005; Hoekstra, 2003a,b,c).

The proposition of the concept of virtual water causes the diversion of the study on water resource issues from "water entity" to "generalized water", which promotes the system innovation of water resources and makes a second configuration of water resources come true. And in the meantime, it broadens the research field of water resources and lays a solid foundation for solving of regional water resource issues by employing the concept and method of "macro-water resources development" system and has remarkably practical significance on the studies of rational allocation, carrying capacity and efficient use of water resources in China. Virtual water flow represents the volume of water that is embedded in traded commodities (Chouchane et al., 2018). Water traded in this way is referred to as ‘virtual water’ and constitutes a significant portion of global water consumption (Hoekstra and Mekonnen, 2012). The “flows of virtual water” should be considered when designing national strategies regarding water and agriculture, and when evaluating guidelines pertaining to international trade (Duarte et al., 2014; Shi et al., 2014; Zoumides et al., 2014). Virtual water trade in mainly agricultural products can be considered as a substitute for trade in freshwater, or non-virtual water. The theory of comparative advantage suggests that if two countries have relative differences in production processes, expressed as differences in opportunity costs, there will be scope for trade that will benefit both countries (Wichelns, 2010). The virtual water trade process may prove significant for improving global water use efficiency and alleviating pressure on local water resources (Goswami and Nishad, 2015). The development process of global virtual water trade is shown in Fig. 1, while the globalization of food trading and the digitization of metering system as the signs of the development of new water resources have greatly propelled the process of virtual water trade.

The concept of water footprint is similar to the concept of virtual water. In many cases, the water footprint of product and the virtual water contained in the product can be exchanged. People often used the concept of water footprint when investigating the consumption of water resources by production and consumption activities in the region. The concept of virtual water was often used when studying the consumption of water resources in cross-regional consumption and trade (Lenzen, 2009; Mekonnen and Hoekstra, 2012). When product is exported, its water footprint becomes virtual water trade or transfer. To realize the water balance among different countries, Aldaya et al. (2012) suggested water footprint should instead of virtual water for a product. The concept of water footprint is defined for a product “volume of freshwater appropriated to produce the product, considering the volumes of water consumed and polluted in the different steps of the supply chain”. Therefore, we can determine the amount of water necessary to produce a series of products (Table 1). Several authors began calculating the “water foot prints” of goods and services a few years after the notion of virtual water was introduced, with the goal of describing the direct and indirect water use by consumers and producers (Hoekstra et al., 2011; Ercin and Hoekstra, 2014; Brindha, 2017). The water footprint of virtual water consumption and trades are interrelated relationship, which is illustrated in Fig. 2 (Hoekstra and Mekonnen, 2012). The water footprint relates virtual water with the actual water consumption of human beings, truly reflecting the demand for and occupancy of water resources by the population and the degree of human pressures on water resources systems. In the field of water footprint assessment, with most studies carried out at the watershed, national and global level, application at the urban level is at its infancy. Yu et al. (2010) developed a regional input-output model to assess domestic water footprint for various consumption categories for the southeast and the northeast of England. Paterson et al. (2015) provide the first review of research on the water footprint of cities, and a range of methods for estimating the water footprint of consumption is being used. Rushforth and Ruddell (2015) quantify the water footprint of the Phoenix Metropolitan Area in Arizona, contributing methodologically by calculating intra-metropolitan areavirtual water flows using commodity and labor flows. De Miguel et al. (2015a) considers water footprint at the river basin level by considering the sustainability of the water footprint of crop production in the Duero River Basin in Spain.

The various countries in the world are not entirely equal in virtual water trading. The virtual water strategy refers to the purchase of water-intensive products from the water-enriched countries (regions) by the water-shortage countries (regions) by way of trade, which is to guarantee water and food security. Water withdrawals for irrigation are limited by water scarcity in major river basins from Mexico to North Africa, West Asia, Central Asia and North China (Brown et al., 2009). It is widely agreed that virtual water trade as a strategy is likely to play a more prominent role in the future in global food production. Measuring

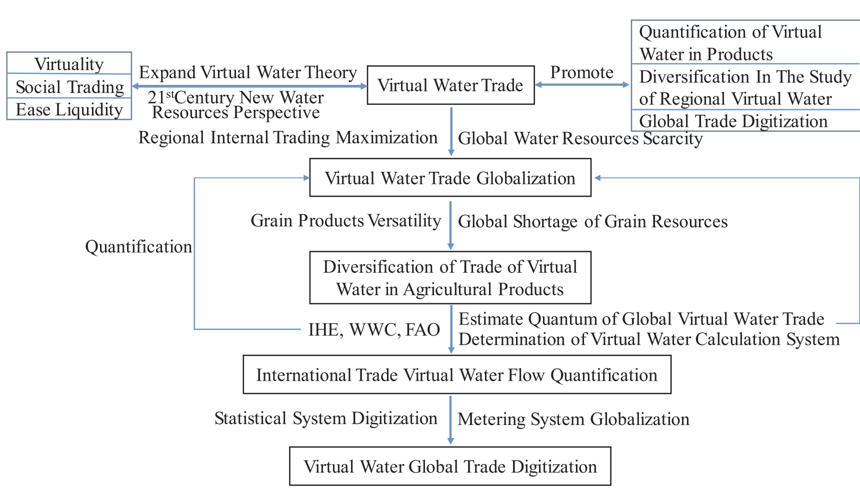

Fig. 1. The development process of global virtual water trade. In the figure, the IHE, WWC and FAO is the abbreviation of International Health Evaluation Association, World Water Council, and Food and Agriculture Organization.