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A Review of Virtual Water Research

Chao Liu, Yifan Wang, and Yaozong Zhang*
North China University of Science and Technology, Tangshan, China

Abstract

A comprehensive and objective understanding of the amount of water resources occupied by human activities is an important way to improve the existing water resources management. The theory of virtual water is a brand-new concept proposed at the end of the 20th century to solve the problems of water resource shortage and water resource security. Based on a brief analysis of virtual water and its related concepts, this paper introduces the research status of related theories at home and abroad, discusses from the perspectives of water footprint, virtual water quantitative calculation, virtual water trade, virtual water strategy, etc., and points out that virtual water plays a vital role in maintaining regional peace. Stabilizing and promoting regional economic development is of great significance. It also examines the imperfections in the existing theories of virtual water and looks forward to the future research directions of virtual water.

Keywords

Virtual Water; Water Footprint; Virtual Water Quantitative Calculation; Virtual Water Trade; Virtual Water Strategy.

1. Introduction

At present, with the continuous growth of global population and rapid economic development, more than 40 countries around the world are suffering from water resource crisis, and about 3 billion people are facing water shortage. [1].

The problem of water resources is one of the important factors restricting the economic development of the world today. Therefore, effectively responding to water resource security issues and rationally allocating water resources have become hot topics for achieving sustainable development. Virtual water provides a new perspective for solving the problem of water resource security, and the research content surrounding this concept is increasing. This paper summarizes the research on virtual water and points out the future research trends.

2. Virtual Water Theory

2.1. Development

According to the evaluation index of virtual water theory research results and important events, the development stage of virtual water can be divided into starting stage, rising stage and mature stage.

2.1.1. Initial Stage

As early as the 1980s, some scholars in the Middle East proposed importing food to reduce domestic water consumption and then make up for the agricultural water consumed in domestic food production. This idea was a "virtual" idea proposed by British scholar Allan. The predecessor of "water strategy", and when it was first proposed, it did not attract the attention of many scholars. Research on "virtual water" in my country started relatively late. In 2003, Guodong Cheng, an academician of the Chinese Academy of Sciences, introduced the concept of

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"virtual water" from abroad for the first time in order to explore how to achieve the relationship between efficient utilization of water resources and sustainable development in the arid regions of northwest China [2].

2.1.2. Rising Stage

After Professor Allan proposed “virtual water”, related theories continued to improve, and the concept of virtual water trade was subsequently proposed. Virtual water trade is the amount of water hidden behind inter-regional product trade [3], which realizes the circulation of sufficient water resource products from water-rich areas to water-scarce areas, and meets the demand for industrial and agricultural products in water-scarce areas. In 2000, the second World Water Forum was held in The Hague, Netherlands. The forum released "Water Security in the 21st Century --- The Hague Ministerial Conference Declaration", and water security has become an important strategy for the sustainable development of all countries. In this declaration, sharing water resources becomes an important issue: promoting peaceful cooperation and developing coordination among different water users at all levels; for projects in the same basin or across basins, through sustainable basin management or other appropriate To carry out cooperation between countries [4]. The virtual water concept and virtual water strategy[5] provide a new perspective for solving water security and water resource sharing. After Academician Guodong Cheng introduced related concepts, Guicai Dong[6] found through research that regulating water prices and developing water-saving technologies can effectively improve the water resources allocation rate. Mei Guo[7] and others achieved virtual water strategic security in my country or some areas of my country by evaluating water resource security measurement indicators, water resource security rating indicators and other factors Jiao . Zhou[8] and others studied virtual water trade and pointed out that my country needs to accelerate the construction of a regional virtual water strategy. Lingling Zhou[9] and others provide reference for my country's water security strategy by studying the water footprint theory.

2.1.3. Mature Stage

After 2015, the golden period of virtual water-related research development, and the number of relevant articles at home and abroad showed a rapid growth. In 2022, the 9th World Water Forum will be held in Dakar, Senegal, "Virtual Water" is One of the important topics of this forum. The theme of this forum is "Ensuring Water Security for All Countries, Promoting Peace and Development", which to some extent shows that the establishment of a universal virtual water mechanism is of great significance to maintaining regional peace and stability. Relevant international exchanges have become increasingly frequent, and many scholars have shifted their research focus to water quantity accounting. For example, Caizhi Sun et al studied the virtual water flow of agricultural products trade along the "Belt and Road"; Lu Wang[10] studied the forest virtual water accounting of Benxi City and pointed out that improving the export structure of forest products could improve the efficiency of water resources utilization; Ning Zhang [11] et al. pointed out that optimizing the water trade structure could alleviate the pressure of water resources in the region by studying the virtual water trade accounting of the Yangtze River Delta. Shuangshuang Xu[12] et al. studied the water footprint and virtual water accounting in Liaoning Province and analyzed the maximum net virtual water output of different industries.

2.2. Definition of Concept Virtual Water

Virtual water refers to the amount of water resources required for production or service, and virtual water is proposed to solve the problem of international food security. From the perspective of producers, virtual water can be considered as the amount of water resources consumed in the production of a product. From the consumer's point of view, virtual water can be thought of as the amount of water condensed by the consumer goods used. Due to the

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different evaluation standards of the quantity of water resources in the producing area and the consuming place, the quantity of virtual water of products is different in different regions or countries.

2.3. Virtual Water Trade

Virtual water trade refers to the flow of virtual water resources from countries with higher productivity to countries with lower productivity. The theoretical basis of virtual water trade is Ricardo's theory of comparative advantage, which indicates that a country or region can import products or services without its own advantages through international trade, and export products or services with its own comparative advantages, so as to bring more benefits to the country in the process of international trade. Chengxiang Xia [13] et al. pointed out that in the international virtual water trade, virtual water mainly flows from North America, Oceania and South America to Central and East Asia and Africa. In many studies on virtual water, the main analysis is the allocation and utilization of water resources by the first industry such as grain, and the unique phenomenon in China is "grain from the north to the south", where food crops flow from the north where water resources are relatively poor to the south where water resources are relatively abundant. In this regard, the author believes that the phenomenon can not deny the understanding of international virtual water trade, but caused by the special development of our country, with the prelude of reform and opening up, the industrial development of southeast coastal areas of our country to the second and third industries, the industrial structure has undergone great changes. The production activities have shifted from the primary industry with high water consumption to the secondary and tertiary industries with low water consumption, and the economic benefits have been greatly improved. Affected by the policy and geographical position, the vast northern region bears the burden of food production in our country. The study of virtual water trade can not be made by burning a boat, but should be adapted to local conditions and The Times to rationally and smoothly allocate water resources utilization.

2.4. Virtual Water Strategy

The virtual water strategy is similar to the definition of virtual water trade, except that the virtual water strategy needs to measure the impact of water resources on people's livelihood from the perspective of national security. For example, the domestic unrest caused by food shortage in some African countries has not been well solved. If the flow of food crops from water-rich to water-poor countries could be fully realized, the international development landscape would be greatly improved. From the perspective of the distribution of global freshwater resources and China's freshwater resources, both show the characteristics of uneven distribution of water resources in time and space. The global freshwater resources are mainly concentrated in America and Oceania, while the available water resources in parts of Africa, Asia and Europe are less, and the available freshwater resources in China are mainly concentrated in the Yangtze River basin and the south region. Traditionally, people choose to solve the problem of water shortage in the problem area, but the virtual water strategy thinks out of the box and chooses the problem area in the place where the problem does not occur. For example, water-poor countries can import water resources indirectly by importing commodities, which can meet their own commodity demand and save domestic water resources to the greatest extent, while exporting countries can import commodities in shortage or generate foreign exchange income through commodity exports. Achieving win-win results is of great significance to regional peace and stability.

2.5. Water Footprint

The concept of water footprint was first adopted by Hoekstra as the concept of ecological footprintEF. The connotation of water footprint refers to the amount of water resources

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required by all products and services consumed by a certain research individual or country or region in a certain period of time, covering all water consumption of primary, secondary and tertiary industries. Figuratively speaking, it is the footprint of water in the process of production and consumption [14]. A country's water footprint consists of two parts: the amount of water consumed in the production and provision of goods and services for domestic production and consumption is the internal water footprint; The footprint generated by the consumption of imported goods is the external water footprint[14]. Water footprint can be used to evaluate regional water resources carrying capacity and external dependence[15] and accurately describe regional water resources security. Water footprint and virtual water permeate each other. Only by combining the two concepts can we accurately describe the water resources security of different countries or regions and lay a theoretical foundation for ensuring global water security.

3. Virtual Water Theory Calculation Method

3.1. Virtual Water Calculation

The above part only analyzes and expounds the virtual water theory from the perspective of macro concept, and does not analyze the virtual water theory by micro-quantitative method. The following part will evaluate the virtual water theory quantitatively from different angles.

3.1.1. Calculation of Virtual Water for Agricultural Products

Today, agricultural water consumption accounts for 80% of the world's total water consumption, so it is particularly important to analyze the virtual water content of agricultural products. At present, there are two kinds of calculation methods for virtual water. One is the method proposed by Chapagain and Hoekstra to study the production tree of different products . The other is a calculation by Zimmer and Renault based on distinguishing between different product types[16]. According to the Cropwat and Climwat databases designed by the Food and Agriculture Organization of the United Nations (FAO), the virtual water content of a single product can be measured. The calculation formula is as follows:

$$SWD_{[a,b]} = \frac{CWR_{[a,b]}}{CY_{[a,b]}}$$

Where SWD[a,b] is the virtual water content (m3/kg) per unit weight of crops in region a, CWR[a,b] is the water requirement per unit area of crops in region a (m3/hm2), and CY[a,b] is the yield per unit area of crops in region a (kg/hm2).

Although the above formula is a direct calculation formula, the equivalent CWR is not easy to be directly measured, and the evaporation amount ET[a,b] of the entire growing period of the crop needs to be accumulated. The calculation formula is as follows:

$$ET_{[a,b]} = K_{[a,b]} \cdot ET_{0[a,b]}$$

In the formula, ET[a,b] is the evaporation of crop b in region a (mm/d), ET0[a,b] is the reference evaporation of crop b in region a (mm/d), which can be calculated according to the Penman formula proposed by FAO, and K[a,b] is the crop coefficient, reflecting the difference between the physical and physiological characteristics of the reference crop and the calculated crop.

The total virtual water output of Region a crop in year b is:

$$TVW_{[a,b]} = SWD_{[a,b]} \cdot TCY_{[a,b]}$$

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In the formula, TVW[a,b] is the total virtual water production of crops in region a in year b (t), and TCY[a,b] is the annual production of crops in region a in year b (kg/a).

3.1.2. Virtual Water for Live Animals and Derivatives

The virtual water content of a live animal is expressed as the amount of water consumed throughout its life cycle from birth to death. Including virtual water contained in feed, drinking water, animal feeding house clean water, etc. Virtual water in feed consumption includes two parts: virtual water contained in feed crops and physical water required by mixed feed crops. The virtual water content of different component crops in feed crops is calculated using the method described above, and then weighted according to the weight ratio in feed crops to obtain the virtual water content of feed crops. Drinking water for animals needs to be calculated for the entire life of the animal[16]. The calculation of virtual water content of animal products should be considered from the aspects of live animals, production and processing, distribution times, etc., but there is no calculation criterion for virtual water output of animal products in the industry so far.

3.1.3. Virtual Water Content Calculation of Industrial Products

Compared with the virtual water content calculation of agricultural and livestock industry, the virtual water content calculation of industrial products is more complicated. Virtual water the main source of the content is industrial production and processing. Xiang Xuemin[17]et al. and Li yanyan[18] et al. calculated the formula of virtual water content of industrial products by using the concept of physical water. However, this formula is not completely consistent with the idea of solving the problem of physical water resource security when the concept of virtual water was proposed. It is still necessary for scholars to work out a unified formula.

3.2. Calculation of Water Footprint

According to the definition of water footprint, it can be divided into internal water footprint and external water footprint. Internal water footprint refers to the virtual water resources used to meet the living and production of water-rich countries or regions minus the virtual water resources finally exported, while external water footprint can be understood as the virtual water resources obtained through trade imports by water-poor countries or regions minus the virtual water resources not fully utilized. It can be expressed by mathematical formula as:

$$\mathrm{WFP} = \mathrm{IWFP} + \mathrm{EWFP}$$

In the formula, WFP stands for water footprint, IWFP stands for internal water footprint, and EWFP stands for external water footprint. A high value of water footprint indicates that the country or region has sufficient total tradable water resources, good resilience and great potential for economic development.

4. Virtual Water Outlook

This year (2023) marks the 30th anniversary of the concept of virtual water proposed by Professor Allan. It is of great significance to summarize the research achievements of virtual water in the past 30 years. Reviewing the research process of virtual water theory, it is not difficult to find that theoretical research is mainly concentrated in agricultural production, especially in ensuring food production security, while the progress is slow in industry and service industry. Therefore, we should vigorously promote the world to speed up the theoretical research in industry and service industry, and gradually promote the theoretical achievements in agricultural production to life. In addition, virtual water theory has not yet

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moved to the ecological environment, which is one of the future research directions of virtual water theory.

As far as China is concerned, the study of virtual water theory and the implementation of virtual water strategy can solve the dilemma of uneven distribution of water resources in the direction of east and west and north and south, transport a lot of grain from the north to the south, and exchange industrial and service products from the south to the north, which is of milestone significance for the construction of China's domestic economic cycle and the realization of exchanges between different nationalities. In terms of China's contribution to the world's development, this move can demonstrate China's responsibility as a major country and contribute Eastern strength to advocating the building of a community with a shared future for mankind.

As far as other countries and regions are concerned, the implementation of virtual water strategy is a necessary move to promote regional economic development and a proper measure to achieve regional peace and stability. It can not only promote economic and trade exchanges between relevant countries and regions, but also build a civilized and harmonious regional environment.

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