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Review

Virtual water and water self-sufficiency in agricultural and livestock products in Brazil

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A B S T R A C T

Virtual water trade is often considered a solution for restricted water availability in many regions of the world. Brazil is the world leader in the production and export of various agricultural and livestock products. The country is either a strong net importer or a strong net exporter of these products. The objective of this study is to determine the volume of virtual water contained in agricultural and livestock products imported/exported by Brazil from 1997 to 2012, and to define the water self-sufficiency index of agricultural and livestock products in Brazil. The indexes of water scarcity (WSI), water dependency (WDI) and water self-sufficiency (WSSI) were calculated for each Brazilian state. These indexes and the virtual water balance were calculated following the methodology developed by Chapagain and Hoekstra (2008) and Hoekstra and Hung (2005). The total water exports and imports embedded in agricultural and livestock products were 5.28×10^{10} and 1.22×10^{10} $Gm^3\ yr^{-1}$, respectively, which results in positive virtual water balance of 4.05×10^{10} $Gm^3\ yr^{-1}$. Brazil is either a strong net importer or a strong net exporter of agricultural and livestock products among the Mercosur countries. Brazil has a positive virtual water balance of 1.85×10^{10} $Gm^3\ yr^{-1}$. The indexes used in this study reveal that Brazil is self-sufficient in food production, except for a few products such as wheat and rice. Horticultural products (tomato, onion, potato, cassava and garlic) make up a unique product group with negative virtual water balance in Brazil.

Contents

1. Introduction

Water is one of the world's most important natural resources. Water is responsible for the planet's biological, hydrological, geological and chemical sustainability. The world's overall economy

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depends on water availability. However, water scarcity has been a serious problem for food producers in most parts of the world. Water consumption has increased dramatically because of the world ever growing farming activities (Liu et al., 2015). The agriculture sector alone is responsible for 73% of the total water consumption in the world. According to the 2012 official estimates of the United Nations, the world population for 2050 has been estimated at 9 billion people. Population growth will inevitably lead to increasing scarcity of freshwater worldwide. This represents, in the near future, a major environmental problem which calls for the implementation of technical and managerial actions aiming at establishing rational and sustainable water policies (Hoekstra and Chapagain, 2008). One possible alternative is to develop, in collaboration with other nations in the world, virtual water flow regulations focused on the trade of commodities and livestock products. The implementation of virtual water trading policies at small and localized scales may contribute to alleviating water scarcity and improving local water management (Liu et al., 2015). Consequently, considering water withdrawal for food production, virtual water studies have been focused primarily on water resources for food production (Ming and Chen, 2013).

Virtual water trade is often considered a viable solution for the problem caused by limited water availability because of its importance in promoting global food security. Moreover, global trade can also be translated into a correspondingly virtual water trade situation. Water trade would permit the quantification of import and export fluxes. In most countries, the consumption of products of domestic and foreign origin includes water costs as well (Orlowsky et al., 2014). According to Italy's virtual water balance, the country's dependence on imports has increased over the last decades. This has overpowered Italy's internal production since the year 2000 (Tamea et al., 2013). Orlowsky et al. (2014) have also reported that water consumption will inevitably lead to the effects of some potentially reduced water availability concerning both domestic water resources and virtual water trade. The transfer of huge volumes of virtual water from a water-rich country to a water-poor country must be treated with considerable care.

The concept of virtual water (VW) was introduced by the geographer Tony Allan (Allan, 1993), followed by the water footprint concept which was introduced by Arjen Hoekstra in 2002. The purpose of these concepts was to regulate the use of water in order to create products and services (Hoekstra, 2003). These concepts have been currently applied by many researchers in studies on water resources used in both agriculture and livestock worldwide (Yu et al., 2010; Mao and Yang, 2012; Silva et al., 2013, 2015; Zhuo et al., 2016). The analysis of virtual water content embedded in agricultural products at different scales is most central in alleviating water scarcity and promoting water use efficiency (Dabrowski et al. (2009).

Though 73% of all fresh water available in Brazil is located in the Amazon basin, the total of inhabitants in this area represents less than 5% of the entire Brazilian population. On the other hand, the Brazilian semiarid suffers from severe water scarcity which originates basically from a combination of recurrent droughts and environmental degradation (Silva et al., 2010). Brazil is world leader in the production and export of agro-livestock goods. The environmental impacts caused by the water resources transfer embedded in all agricultural and livestock products that flow from Brazil to other countries are still unknown. This has made other countries control the amount of water imported and exported, establishing, in this way, a net virtual water balance (Chapagain and Hoekstra, 2008; Zeitoun et al., 2010; Verma et al., 2009; Wichelns, 2010; Vanham, 2013; Ming and Chen, 2013; Orlowsky et al., 2014). To meet such demands, the present study aims to determine the virtual water content embedded in all agricultural and livestock products imported/exported by Brazil. The study also seeks to define a water self-sufficiency index for these products.

2. Material and methods

The data used in this study represent the Brazilian total export and import of agricultural and livestock products. The national production data were provided by the Brazilian Institute of Geography and Statistics − IBGE in Portuguese (http://www.ibge.gov.br/english/). The data based on exports and imports were provided by the Foreign Trade Secretariat of the Ministry of Development, Industry and Commerce (http://www.investexportbrasil.gov.br/mdic-1?l=en). The analysis includes the average annual values for the period 1997−2012. The average specific water demand per crop type was calculated from the data on crop yields of the countries investigated. The crop yield data for Brazil are provided by IBGE while for other countries they were provided by the Food and Agriculture Organization (FAO). Information on crop water requirements was assessed using a methodology developed by the FAO (Allen et al., 1998) and made available on FAO's website. Twenty-two types of agricultural and livestock products were included in this study: maize, wheat, coffee, rice, bean, rye, barley, banana, orange, apple, grape, pear, tomato, onion, potato, cassava, garlic, beef, pork, chicken, milk and chicken eggs. The analysis included all Mercosur country members (Argentina, Brazil, Paraguay, Uruguay and Venezuela). It also included Brazil's top import/export partners (USA, Algeria, Iran, Germany, Senegal, India, Saudi Arabia, Netherlands, Italy, Ecuador, United Kingdom, Spain, Russia and Canada). FAO crop yield.

Virtual water trade (VWT) is based on the crop specific water demand required by the exporting country where the crop is produced. The VWT is calculated as follows:

$$VWT[n_e, n_i, c, t] = CT[n_e, n_i, c, t] x \ SWD[n_e, c] \quad (1)$$

where:

VWT − virtual water trade ($m^3\ yr^{-1}$);
n_e − exporting country;
n_i − importing country;
t − year;
c − result of crop trade;
CT − crop trade (ton yr^{-1});
SWD − the crop specific water demand (m^3 ton^{-1}) in the exporting country.

The average water demand defined by type of crop was calculated separately for each country, and based on FAO data on crop water requirements and crop yields:

$$SWD[n, c] = \frac{CWR[n, c]}{CY[n, c]} \quad (2)$$

where:

SWD − specific water demand (ton yr^{-1}) of crop c in country n
CWR − crop water requirement (m^3 ha^{-1})
CY − crop yield (ton ha^{-1})
The CWR is deduced from crop evapotranspiration ET_c (mm d^{-1}) during growth period.

The ET_c can be obtained by multiplying the evapotranspiration reference ET_o by the crop coefficient K_c. The only factors affecting ET_o are the climatic parameters. The reference crop evapotranspiration ET_o is calculated by the FAO Penman-Monteith equation

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