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Relationships between regional economic sectors and water use in a water-scarce area in China: A quantitative analysis

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SUMMARY

Northern China has been facing severe water scarcity as a result of vigorous economic growth, population expansion and changing lifestyles. A typical case is Shandong province whose water resources per capita is approximately only a sixth of the national average and a twentieth of the global average. It is useful to assess the implications of the province's growth and trade patterns for water use and water conservation strategies. This study quantitatively analyses relationships between regional economic sectors and water use in Shandong using an input–output model for virtual water resources. The changes in key indicators for 1997–2007 are tracked and the effects of water-saving policies on these changes are examined. The results highlight the benefits of applying a virtual water trade analysis on a water-scarce region where water resources exhibit highly heterogeneous temporal and geographical distributions. The net export of virtual water in Shandong was initially large, but this declined over the years and the province has recently become a net importer. Between 1997 and 2002, water use in most sectors increased due to rapid urbanisation and industrialisation. Since then, water use in all Shandong economic sectors exhibit a downward trend despite continued increases in goods and services net exports, a trend which can be attributed to the vigorous implementation of water-saving policies and measures, especially water use quotas. Economic sectors consume water directly and indirectly and understanding the pattern of virtual water trade implied by sectoral relationships is important for managing water scarcity problems. This study fills the knowledge gap in the existing literature created by the lack of case studies that dynamically assess virtual water trade and analyse the effects of water-saving policies and measures. The study draws policy recommendations that are relevant for future water planning in Shandong and other regions in northern China.

1. Introduction

China has been experiencing astonishing economic growth since its economic reforms in 1978. However, the northern part of China has been facing a fast growing water demand as a result of vigorous economic growth, population expansion, and changing lifestyles. Shandong province is especially plagued by water problems and its further socio-economic development is strongly affected by water scarcity (Kutzner et al., 2006). The province is located in the lower reaches of the Yellow River, borders the Bohai Sea to the north and the Yellow Sea to the southeast, as shown in Fig. 1. Located in the Asian warm temperate monsoon climate zone, Shandong has an area of 156.7 thousand square kilometres. The average annual total fresh water resources in this province amount to 30.6 billion cubic metres, and about a third (or 9.6 billion cubic metres) of these are groundwater resources (Water Resources Department of Shandong Province, 2003–2013). The provinces' endowments account for only 1% of the total national water resources (China Ministry of Water Resources, 2003–2013). But the province is home to 7.07% of the country's population. Per capita water resources in Shandong amount to only 344 m^3/year. This figure is only a six of the national average and a twentieth of the world's average, and below the internationally recognised limit for extreme water shortage areas (500 m^3/capita/year). Meanwhile, the water resources in Shandong have the characteristics of highly heterogeneous geographical distribution, showing a decreasing trend from the southeast to the northwest. Consecutive

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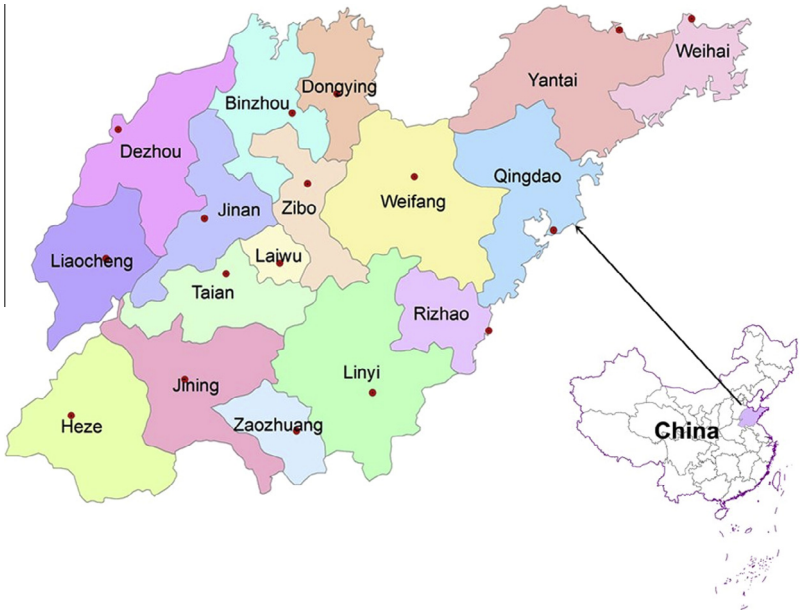

Fig. 1. Map of Shandong province and its location in China.

dry years and wet years alternate and the distribution of annual precipitation is mainly concentrated in the period from June to September.

With the accelerated process of urbanisation and industrialisation, the gap between water demand and supply has been increasing. Shandong is one of the richest provinces of China. With a GDP (gross domestic product) of 4.5 trillion Yuan or US$ 711 billion (2011 figures), the province ranks third in the country. Shandong ranks first among the provinces in big industrial production and diversity of products in China. The province is important in energy and water use.

To deal with its water scarcity problems, Shandong needs to take some measures, such as enhancing water supply, curbing water demand, and raising water use and allocation efficiency. For example, the eastern route of the south-to-north water diversion project is currently under construction and is regarded as one of the significant measures aimed at solving the shortage of water resources in Shandong. Once the project is completed, water diverted to Shandong would be nearly 3.6 billion m^3 and could greatly relieve the pressure on local water resources. In particular, the diversion could generate ecological benefits, replacing part of the overexploited groundwater and fixing groundwater aquifers that have been overused. But these measures may not be enough with fast growing water demand.

For Shandong, another avenue for dealing with water scarcity is importing virtual water. The term "virtual water" was first proposed by Allan (1993, 1998) and refers to the fresh water required in the production process (Chapagain and Hoekstra, 2008; Dietzenbacher and Velázquez, 2007; Hoekstra and Hung, 2005; Hoekstra and Mekonnen, 2012). Importing goods and services from other regions virtually equals to importing water that was used to produce the imports. A closely related term in the literature is water footprint, which is the volume of fresh water consumed during the production process, measured over the full production chain (Feng et al., 2012; Zhang et al., 2012). This method is helpful to understand water use structure, water connections with the outside world through trade, and the driving forces of change (Zhang et al., 2012). Analysis of trade in virtual water could shed light on structuring needs for the primary, secondary and tertiary industries in Shandong to resolve the fundamental conflict between socio-economic development goals and water shortage constraints.

There is a substantial literature on virtual water assessment (e.g., Chen and Chen, 2013; Dietzenbacher and Velázquez, 2007; Faramarzi et al., 2010; Feng et al., 2011; Guan and Hubacek, 2007; Hoekstra and Hung, 2005; Velázquez, 2006; Wang and Wang, 2009; Zhang et al., 2011; Zhao et al., 2009). Studies have applied input–output (I–O) models (Leontief, 1936) to quantitatively analyse the dependences of economic sectors on water use and the interconnection among economic activities linked by virtual water use. This has been done at regional, national and global levels.

However, the current literature suffers from two key shortcomings. First, the existing studies have mostly focused on data covering only single periods (a year), and thus failed to paint a dynamic picture of virtual water assessment results. This is primarily due to data constraints. Studies making a dynamic assessment remain very limited. Dalin et al. (2012) and Konar et al. (2012) analysed temporal dynamics of virtual water content and trade at the global scale. Liu et al. (2007) investigated historical trends of China's international virtual water trade and Zhang et al. (2012) did an investigation on temporal changes in Beijing's water footprint. Although some of these studies attempted to determine the factors contributing to change at different times, the effects of government-led water-saving policies and measures were not explored, which is the other shortcoming in existing literature. For example, during the period 1997–2007, Shandong experienced fast economic growth and rapid industrial transformation. In 2003, a water-saving society was advocated and many measures were implemented to reduce fresh water use (Shandong Provincial Government, 2003b; Shandong Provincial Water Conservation Office, 2006). The following year, Shandong province issued water use quotas for provincial agriculture irrigation (Water Resources Department of Shandong Province, 2004b) and for Shandong provincial power, paper-making, metallurgy, chemicals and textile (silk) industries (Water Resources Department of Shandong Province, 2004c). Further water use quotas were promulgated for coal mining, wine production, medicine production, and machinery (Water Resources Department of Shandong Province, 2007). Simultaneously, advanced production processes were pursued in