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# An inquiry into water transfer network of the Yangtze River Economic Belt in China

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ABSTRACT

As a typical region moving forward on green development demonstration belt, Yangtze River Economic Belt (YREB) is sensitive to profound conflict between coordination development and unbalanced water allocation. Uncovering water transfer network can help improving water resource coordination development from the perspective of water-trade nexus. An integrated framework by uniting the inter-regional input-output (IRIO) analysis and social network analysis (SNA) in this study can estimate not only the scale and structure of water trade pattern, but also the topological characteristic of water transfer network of YREB. Results show that the rank of production-based virtual water volume was roughly in the order of middle, lower and upper reaches except Jiangsu, while the rank of consumption-based virtual water volume was in the order of lower, middle and upper reaches. The provincial virtual water external dependence in YREB was not well consistent with the water resource endowment. Water transfer network was constructed on basis of the inter-provincial virtual water transfers between every two provinces inside YREB. Furthermore, the water transfer network assessment results illustrated the network structural form and revealed the network property and characteristics. Inside YREB, Shanghai, Jiangsu, Zhejiang, Anhui and Jiangxi were predominant in the water transfer network (from degree centrality), while Jiangxi, Hubei, Hunan and Anhui acted as the important medium and bridge (from betweenness centrality). The AFAF sector (Agriculture, Forestry, Animal husbandry and Fishery) and Industry sector of Jiangxi, and the Industry sector of Hubei and Jiangsu were the critical exporters in the network. Jiangsu received large amounts of virtual water from many good hubs and also transferred much to many good authorities when acted as bagmen in the network. Some provinces received large virtual water flow but provided few to others, such as Shanghai, and the AFAF sectors of most provinces transferred much to others. Thus, the research results would help understand the regional responsibility transfer in the hidden network linkages of interprovincial and intersectoral virtual water flows.



## 1. Introduction

In our epoch, as it continues along the path of rapid industrialization and urbanization, the sheer quantity of water resources consumed by the world economy is recognized as the overarching threat to planetary health (Oki and Kanae, 2006). The dual-stresses of ever-increasing freshwater scarcity and water demand will place a heavy burden on future development (Lambooy, 2011; Murray et al., 2012; Hubacek et al., 2009). In terms of China, the interregional water-trade nexus shows a complex and multi-threaded network pattern rather than the nearest neighborhood relationship (Dong et al., 2013; Chen et al., 2017). China's water transfers expresses as a complex scene due to its continuous advances of the marketization process and water conservation projects in recent years (Cai, 2008). Specifically, due to the spatial peculiarity of water resources and the interregional trades of goods and services, their supply and demand distributions have the potential to evolve as a picture of complex interactive information covering interprovincial and intersectoral water flows (Burkhard et al., 2012). In this study, water transfer network is exactly manifested as a network form of the aggregated interactive information, and it is the interactive information that can well reflect the impact on water flows from the interregional trades.

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The water policy relevant to the solutions to water scarcity is often regional or river basin issues (Zhao et al., 2010), which is characterized by a mismatch between water resources distributions, economic development and other primary factors of production and consumption (Zhang and Anadon, 2014). Each region bears some degree of responsibility to water conservation and sustainable utilization (Chapagain and Hoekstra, 2008; Zhang et al., 2017). Yangtze River Economic Belt (YREB), China's emerging economic belt relied on the gold channel of Yangtze River, is another important growth engine after Yangtze River Delta, Pearl River Delta and Bohai Rim (Zhang et al., 2015). As a typical region moving forward on green development demonstration belt, YREB is a valuable subject to assess the water transfer network due to the profound conflict between coordination development and unbalanced water allocation. However, the full picture of inter-provincial and inter-sectoral virtual water transfer of YREB is still missing, especially the detailed structure characteristics from the network perspective. Thereby, water transfer network analysis should be one of significant complementary tools to help address the issues of water responsibility transfer in YREB.

Tracking inter-regional virtual water flows is the first necessary step for constructing water transfer network. A reliable approach should be virtual water accounting (Allan, 1993; Hoekstra and Chapagain, 2007a; Zhang and Anadon, 2014), which can not only reveal the water consumption scale but also reflect the virtual water flows embedded in the interregional trades (Jiang et al., 2015; Zhang et al., 2017). Currently, a growing body of literature has catalogued valuable results related to virtual water accounting, and various research frameworks have been used in previous studies (Feng et al., 2011; Zhang et al., 2017). From methods point of view, a strand of researches relied on the bottom-up (e.g., product tree) framework, and the effects are calculated through arithmetic representations of all products and services and their corresponding virtual water consumption (Antonelli et al., 2012; Vanham and Bidoglio, 2013). Its shortcomings are mainly expressed in neglecting the association and dependency among different economic sectors for each region and giving a difficult practice on the secondary and tertiary industries (Hoekstra and Chapagain, 2007b; Chen et al., 2017). Another strand of researches concentrated on the top-down framework, such as the input-output model (Munksgaard et al., 2005; Zhao et al., 2009), which is capable of tracking the virtual water concealed in sectors nexus and distinguishing production-based virtual water from consumption-based virtual water (Feng et al., 2014). The related researches prevailingly focused on the sectoral level (Zhao and Chen, 2014; Zhang and Anadon, 2014; Zhuo et al., 2016), provincial and basin level (Feng et al., 2012; Zhang et al., 2012; Wang et al., 2013; Dong et al., 2013) and national level (Guan and Hubacek, 2007; Wang et al., 2014; Chen et al., 2017), as well as some researchers focused on a global level (Ercin and Hoekstra, 2014; Lutter et al., 2016).

Existing studies have enlarged the research fields related to virtual water trades. Among them, most results realized that water-deficient regions were always driven by the consumption from water-abundant regions in China, leading to a more unsustainable direction (Jiang et al., 2015). The outline of YREB's development program requires this region must develop the comparative advantages of the upper, middle and lower reaches to achieve a coordinated development belt, although it has obvious interprovincial development differences from the aspects of resources, environment, transportation and industry basis (Chen et al., 2017). Reshaping the regional water-trade nexus from the perspective of water responsibility transfer is helpful for improving water resource coordination development. To understand water responsibility transfer, however, it should be more informative to offer a scientific inquiry into the whole water transfer network of YREB than to only investigate the interregional virtual water flows (Wichelns, 2010). In the light of water transfer network construction, the gravity model and vector auto-regression model often contribute to determine whether there is a link between any two locations or sectors (nodes), like in the existing cases of economic development network and energy network analysis (Li et al., 2014; Liu et al., 2015), as well as the ecological network analysis (Zhang et al., 2014; Chen and Chen, 2016). But it is with regret that both the estimation methods, which usually acts as the first necessary step of network construction in prior studies, have weak objectivity relative to the input-output analysis that can present more direct quantitative relations.

Given these considerations, understanding the complex water transfer network of YREB is vital for reshaping and reallocating the water resource allowance across different areas. That should be helpful for environmental regulations on trans-regional water resources management system, providing the scientific evidence of optimal distribution of limited water resources. It is also of paramount importance to conduct a complete research framework through uniting the inter-regional input-output (IRIO) analysis and social network analysis (SNA), which can estimate not only the scale and structure of water trade pattern, but also the topological characteristic of water transfer network of YREB.

Summarizing the extant literature, the contributions of this study are reflected in two ways. Firstly, it focuses on estimating the water trade pattern through understanding the provincial water trade with the area both inside and outside YREB, which seems to be more informative for water management. Secondly, compared with the interregional virtual water accounting in the prior studies, the topological characteristic of water transfer network structure inside YREB were assessed, which can help identify the relative importance of each province (sector) in the whole interprovincial (inter-industrial) water network and the interactions between different provinces (sectors). The coupled research framework makes the simulations of the whole process from water-trade intervention to water transfer network analysis. Overall, the research outcomes can help giving the practical policy implications on responding YREB's water crisis by considering water-trade nexus, as well as providing a theory framework for identifying water transfer responsibility. The rest of the article is structured as follows. In the following sections, after a short introduction of study area and data source, the research methodology is described. This is followed by detailed explanations of the specific methods and techniques. A detailed case study of YREB is presented in the next section. Finally, the fourth section summarizes the main findings and conclusions from this research.

## 2. Study area and data description

### 2.1. Study area

The Yangtze River Economic Belt has developed to be one of regions who harbor the greatest comprehensive strength and the biggest strategic support in China since the reform and opening-up. YREB has a surface area of 2.05 million square kilometers, covers 11 provincial areas including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan and Guizhou from east to west, and contributes over 40% of both the population and GDP of China. As the related guidance suggests, it is well known that the YREB should be built into a “green ecological corridor” as a demonstration zone for achieving ecological civilization in China. Although the whole economic belt moves forward into the common goal, there are obvious interprovincial development differences from the aspects of resources, environment, transportation and industry basis. In particular, spatial arrangements are the