ARTICLE IN PRESS

Resources, Conservation & Recycling xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

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

Full length article

Identification of the critical transmission sectors and typology of industrial water use for supply-chain water pressure mitigation

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ARTICLE INFO

Keywords:
Water consumption
Betweenness-based method
Input–output table
Industrial transformation
Structural path analysis

ABSTRACT

The industrial system produces pressure on water resources by directly consuming the water needed for industrial production and by indirectly consuming water through intermediate inputs. To date, identifying the critical transmission sectors for supply-chain water resources pressure mitigation has been under-examined. To fill this gap in knowledge, we use a betweenness-based method in combination with the standard input–output table extended with water-resource sector accounts to identify the key transmission sectors using Zhangye City in the Heihe River Basin, China as an example. The results show that the sectors with low rankings of the production-based indicator do not consume large amounts of water resources to directly generate products, which demonstrates that these sectors have limited scope for reducing water-resource consumption. The results also indicate that those sectors having higher betweenness-based water use but lower consumption-based and production-based water use merit close attention because these sectors transmit relatively large amounts of water resources embodied in their intermediate inputs from water-intensive upstream industrial sectors. Consequently, improving production efficiency in these sectors has an indirect effect by lowering the consumption of upstream water resources. This study also shows that the betweenness-based indicator is able to provide additional information beyond that given by the usual metrics derived from the production and demand sides. Moreover, the typology of water use that we innovatively generate is able to inform corresponding and targeted sector-specific policies and strategies for mitigating water resources pressure.

1. Introduction

Water resources pressure induced by the imbalance between water availability and water demand has become one of the world's most pressing and challenging issues (Godfray et al., 2010; Peterson and Schoengold, 2008). Rapidly expanding demand, combined with increasing competition for limited water resources among industrial development, economic growth, anthropogenic activities, and ecosystem protection, has led to increasing levels of water scarcity (Dalin et al., 2014; Oki and Kanae, 2006; Rockström et al., 2009).

The industrial system, as the primary factor affecting the utilization and allocation of water resources, contributes to the generation of water resources pressures directly by consuming the water resources needed for industrial production and indirectly by influencing water resources through intermediate inputs, namely, the upstream and downstream industrial sectors (Feng et al., 2014; Lenzen et al., 2013; Wang et al., 2013; Zhang and Anadon, 2014). These sectors play a significant role in mitigating water resources pressure as key transmission centers. The betweenness-based method and structural path analysis provide a way of recognizing these transmission sectors (Liang et al., 2016, 2015).

Previous studies have attempted to identify the critical sectors that affect water resources consumption from both the production and consumption sides (Ewing et al., 2012; Hubacek et al., 2009; Oki and Kanae, 2006; Wiedmann, 2009; Zhang et al., 2011; Zhao et al., 2015, 2009). However, to date, identifying the key transmission sectors for the purpose of supply-chain water resources pressure mitigation has been underexplored. Most of the studies using the betweenness-based

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https://doi.org/10.1016/j.resconrec.2017.10.024
Received 12 May 2017; Received in revised form 13 October 2017; Accepted 20 October 2017
0921-3449/

method have investigated the critical transmission sectors for mitigating environmental pressure, especially with respect to CO_2 emission reduction (Liang et al., 2015). The betweenness-based method is dependent on the input–output table as the data source, although the basic input–output table extended with a sector-based water resources account is not easy to compile (Deng et al., 2014). This difficulty has hindered the wider application of the betweenness-based method to tackling resource issues such as water and land resources pressure mitigation. This context leads to the key research questions addressed in this study: (i) What are the critical transmission sectors of water consumption beyond the traditional analysis of the production and consumption sides? (ii) Does the betweenness-based method provide additional information for mitigating water resources pressure above that provided by traditional analysis? And (iii) What sector-specific policies or strategies can be put forward according to the results of the betweenness-based, production-based, consumption-based, and income-based water use indicators? As one of the first attempts to answer these questions, the present study aims to identify the critical transmission sectors for supply-chain water resources pressure mitigation. This, in turn, will advance the existing literature by extending the betweenness-based method to a new application field. Moreover, to develop sector-specific policies and strategies, we generate a typology of water uses through clustering the sectors with similar characteristics represented by four indicators. For a particular category, the policies might be similar because they have similar characteristics whether derived from the production, consumption, or transmission sides. Exploring the typology of water use can therefore help develop targeted policies and strategies for each category of water use. This is another novel and practical outcome of this study.

The overall objective of this study is to identify critical transmission sectors for supply-chain water resources pressure mitigation, using Zhangye City, situated in the Heihe River Basin, as an example. The rest of the paper is structured as follows. First, the study area is described in Section 2. The data (the input–output table extended with the sector-based water resources account) and core methodology are presented in Section 3. The calculation results of four types of water use indicators from the production, consumption, and intermediate sides are presented and discussed in detail in Section 4, and the conclusion is presented in Section 5.

2. Study area

Zhangye City, a prefecture-level city in Gansu Province in northwestern China, is located in the middle reaches of the Heihe River Basin and in the middle part of the Hexi Corridor (Fig. 1). Zhangye City dominates the social economy output of the Heihe River Basin (Liu et al., 2017; Sun et al., 2016; Zhang et al., 2015). Specifically, Zhangye City accounts for over 90% of the basin’s population, economic outputs, and agricultural water consumption. As a critical nodal city proposed in the “Belt and Road Initiative”, Zhangye City will play an increasingly important role in regional development in the future (Liu et al., 2017; Sun et al., 2016; Zhang et al., 2015).

Zhangye City encompasses six counties or districts, namely, Ganzhou district, Linze county, Gaotai county, Shandan county, Minle county, and Sunan county. Although all of these geographic units are located in an inland arid region, they are considered as desert oases and as the “southern frontier” (in Chinese, *saishang jiangnan*). In recent years, water resources have faced increasing pressure due to the implementation of the national water allocation strategy. The contradiction of water consumption between productive and ecological usage is distinct, and this has impeded regional socio-economic development to an extent. Zhangye City had a total population of over 1.3 million in 2015, with 42.2% being urban dwellers. Zhangye’s economy is relatively weak compared with eastern cities, and the average annual income of urban residents is approximate 19,700 Chinese Yuan (2015), which is 1.82 times the per capita income of rural residents.

Agriculture is the dominant industrial sector of the economic system in Zhangye City. Correspondingly, agricultural water usage occupies the largest percentage of total water consumption. This agriculture-dominated water usage pattern has remained unchanged for several decades (Cheng et al., 2014; Feng et al., 2017). In 2015, the area of cultivated land reached 3.88 million mu,[1] and grain sown area reached 3.95 million mu, accounting for 10% of the area of the middle reaches of the river basin. The food production of the city reached 1.36 million tons in 2015, and the city’s grain production accounted for 11.6% of grain production in Gansu Province. However, the level of agricultural industrialization is low, and the market mechanism is not well developed in this region. The cultivated irrigation area in 2015 was 2.65 million mu in Zhangye City, of which the seeded corn planting area was about 1.1 million mu, making corn the region's major agricultural crop. However, the area of corn in recent years has been greatly affected by market fluctuations. During this period of transformation, Zhangye City has adopted the ecological economy as a primary development channel to promote socio-economic development, including performing ecological construction, facilitating the construction of the Silk Road economic belt, and accelerating the movement towards a modern agricultural pattern of development.

The gross domestic product (GDP) of Zhangye City was approximate 37.35 billion Chinese Yuan in 2015, 4.84 times greater than that in 2000, giving an annual growth rate of ~7.5%. The main change in industrial structure has been the increase in the proportion of the service and manufacturing sectors. Specifically, the relative contribution of the manufacturing and service industries to GDP reached 29.4% and 45.2% in 2015, respectively, whereas the percentage of agriculture declined to 25.4%. The leading manufacturing sectors of Zhangye City are power generation, mining, ferroalloy processing, and food processing. The industrial added value was about 10.98 billion Chinese Yuan in 2015, with an annual growth rate of around 6.1%, which indicates that although the manufacturing base of this region is not strong, it has had dramatic recent year-on-year growth. The service sector output reached around 16.9 billion Chinese Yuan in 2015, surpassing that of manufacturing. In recent years, the tourism industry, which is the major sector of the service/tertiary sector, has shown rapid growth in recent years and now accounts for 20.3% of the total GDP (2015).

3. Data and methodology

3.1. Data

The basic data source used in this study is the input–output table extended with a water-resource account of Zhangye City for 2012. This extended table contains 48 industrial sectors (Table 1), of which 41 industrial sectors are inherited from the standard input–output table published by China's National Bureau of Statistics, and the remaining 7 of which are produced by disaggregating the agricultural sector into 7 sectors (wheat, corn, oilseed, cotton, fruit, vegetables, and other agriculture) according to the dominant agricultural activities in Zhangye City (Deng et al., 2014). We applied a hybrid method by using both survey and non-survey approaches with the aid of statistical data from the Zhangye Statistical Yearbook and import and export volume data acquired by investigation when compiling the input–output table extended with the water-resource account for the study area. The specific procedure for compiling this input–output table extended with the water-resource account for a prefectural city is documented in detail in Deng et al. (2014). Our table matches with the national standard input–output table seamlessly, which is a superior approach compared with using an incomplete input–output table that concentrated only on specific and limited sectors to analyze targeted water issues in this region.

[1] “mu” is a frequently-used Chinese unit of area measurement, 1 mu = 0.067 ha.