ARTICLE IN PRESS

Journal of Cleaner Production xxx (2015) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

The driving force of water footprint under the rapid urbanization process: a structural decomposition analysis for Zhangye city in China

Le Feng [a], Bin Chen [a, b, *], Tasawar Hayat [b, c], Ahmed Alsaedi [b], Bashir Ahmad [b]

[a] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing, 100875, China
[b] NAAM Group, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia
[c] Department of Mathematics, Quaid-i-Azam University, 45320, Islamabad, Pakistan

A R T I C L E I N F O

Article history:
Received 14 May 2015
Received in revised form
26 July 2015
Accepted 13 September 2015
Available online xxx

Keywords:
Input–output analysis
Semi-arid area
Water footprint
Structural decomposition analysis

A B S T R A C T

Located in a typical semi-arid area in China, Zhangye city has been experiencing increasing water shortage during the rapid urbanization process over the past decades. This paper conducted an input–output analysis (IOA) and structural decomposition analysis (SDA) to explore the water footprint (WF) of Zhangye city and its driving factors during 2001–2011. Particularly, the urbanization level was incorporated into the SDA to depict the relationship between urbanization and WF. The results showed that the WF of Zhangye city decreased from 1.01 billion m^3 in 2001 to 0.997 billion m^3 in 2011. The principal contributor to the slight reduction of the WF of Zhangye was the technological effect stemmed from the growth on the water consumption intensity and partly offset by the structural effect induced by the change of final demand structure. From the final demand perspective, structural effect as the principle driving factor contributed to the increment of both urban and rural household WFs by 206.3%, 136.3%, while urbanization rate 17.7% and −14.6%, respectively. Meanwhile, the growth of urban and rural household WFs were offset by technological effect and per capita scale effect, respectively. From the sectoral categories scale perspective, agriculture, forestry, animal husbandry, transportation communication and electronic equipment sectors are responsible for the variation of total WF and household WF. Technological innovation and final demand structure adjustment are also suggested to be the priorities for Zhangye to reduce the WF.

1. Introduction

Water scarcity is the hinder strength for social and economic development of cities, especially in the semi-arid areas (Aguilera, 1994; Pfister et al., 2009; Cazcarro et al., 2012; White et al., 2015). Moreover, the economic development and urbanization process leave deep marks on the water resource availability and quality. A comprehensive exploration into water consumption as well as its driving forces is therefore significant for obtaining a better understanding of the water resource challenge faced by cities located in semi-arid areas.

The perspective of virtual water (VW) and water footprint (WF) are particularly useful for resolving water scarcity issues. VW was put forward by Allan (1998) and applied to illustrate the total amount of the water embodied in the crop and suggested importing water-intensive product in the water deficient areas. Many researchers have analyzed the pattern of the product and the relevant water flow with VW (e.g., Dietzenbacher and Velazquez, 2007; Hoekstra et al., 2009). The closely related concept is WF, which refers to the total virtual water content consumed by the individual, city and nation along the consumption of products (Chapagain and Orr, 2009). WF as the consumption-based indicator was propsoed by Hoekstra and Hung (2002) in analogy with 'ecological footprint' and applied under the background of the consumer or the producers of the products (Zhao et al., 2009; Zeitoun et al., 2010), concerning the water uses beyond the regional and sectoral scales (Allan, 1993; Oki and Kanae, 2004; Hoekstra and Hung, 2005; Lenzen, 2009).

Meanwhile, we need to explore the driving forces behind the changes of WF. SDA has been used as a powerful approach to analyze social economic factors influencing water resources over time (Yang and Zehnder, 2007), which formulates an explained variable (e.g., WF) as a sum or product of explanatory determinants, such as utilization efficiency, technological effect, per-capita consumption and population. There have been some studies

* Corresponding author. No 19, Xinjiekouwai Street, Beijing, 100875, China. Tel./fax: +86 10 58807368.
E-mail address: chenb@bnu.edu.cn (B. Chen).

http://dx.doi.org/10.1016/j.jclepro.2015.09.047
0959-6526/

Please cite this article in press as: Feng, L., et al., The driving force of water footprint under the rapid urbanization process: a structural decomposition analysis for Zhangye city in China, Journal of Cleaner Production (2015), http://dx.doi.org/10.1016/j.jclepro.2015.09.047

investigating the driving factors of water resources in social-economic systems. To examine the factors underlying economic growth-technology, process of input substitution and changes in final demand, Cazcarro et al. (2012) used SDA to explore the main changes in water consumption embodied in final demand in Spain. Based on the input–output analysis (IOA), Zhi et al. (2013) combined SDA with the Generating Regional IO Tables (GRIT) for the Haihe River Basin. Generally, these studies focused on exploring the contributors of water consumption at the national or river basin scale, of which ity is an independent geographical unit of the river basin and nation, and also an important carrier of human activities with a relatively integrated eco-hydrological pattern (Zhao et al., 2010; Chen et al., 2011; Mao and Yang, 2012). Thus, investigating the driving forces of water utilization in cities is the basis for large-scale complex system analysis, especially those in semi-arid areas under rapid urbanization and industrialization with intense competition for limited water resources. Thus, driving force analysis may provide valuable experiences for cities that have similar economic patterns or challenges. For example, Zhang et al. (2012) conducted a quasi-dynamic IOA to distinguish the time series contribution of WF in Beijing, demonstrating that the technological effect is the principal contributor to the offset of WF increase, and the structural effect stemming from the shift of product demand toward the tertiary industry also contributes to its reduction during 1997–2007.

As the significant agricultural base in China, Zhangye city in Heihe River Basin is born a trading connection with other regions on the product and the service trade due to the large amount of VW outflow via export crop, which can be chosen as a typical case to investigate the fluctuation of WF under urbanization. Several studies have been conducted with traditional SDA for Zhangye. Zhang (2011) elaborated the contributions from the intermediate demand, technological effect and the final demand effect to the change of water consumption in Ganzhou district of Zhangye during 2002–2010. Wang (2013) adopted the same decomposition factors and illustrated the underlying contributions to the change of water use for Zhangye during 2002–2007.

Meanwhile, with the implementation of the 12th Five-Year Socio-Economic Development Plan (2011–2015) in Zhangye, both the planting structure and proportion of tertiary industry in the socio-economic system have changed, resulting in the modified allocation of water resources among socio-economic system. Limited by the acquisition of the IO table for the research area, 5-year was often chosen as the time space in previous studies. However, period-wise decomposition is sensitive to the selection of the baseline year and the final year in SDA, thus the contribution of each year is difficult to be identified.

This paper established a hybrid IO table for Zhangye during 2001–2011 to explore the underlying contribution factors for WF by SDA. The driving forces for the urban and rural household WF over time were also elaborated. The reminder of this paper is organized as follows. In the following section, we present the methodological aspects of the IOA and SDA approach. Then, data source and foundation of the IOA are provided. Section 3 is devoted to presenting the decomposition results, of which the key factors and final demand components for the change of WF of Zhangye are discussed. Section 4 concludes this research.

2. Materials and methods

2.1. Study site

Zhangye city, located in Gansu province, is one of the national modern agriculture demonstration areas in China that includes Ganzhou, Linze, Minle, Shandan and Gaotai country, as shown in Fig. 1. The annual average precipitation in Zhangye city is approximately 200 mm, most of which is concentrated in the summer season. The available water resource is 1.7×10^9 m^3 with 1250 m^3/person (Gansu Statistic Office, 2007; Zhangye Statistical Yearbook, 2011). Although water consumption of the agriculture sector accounts for 87.6% of the total water consumption in Zhangye, the sector's output only accounts for 37.8% of the local GDP (Gansu Water Resources Bulletin, 2013).

2.2. Framework of IOA

In this paper, blue water including surface and ground water resources is considered as the component of WF. Because the agriculture and other raw material providers not only use blue water but also green water, the inclusion of green water or soil moisture on the proportion of water allocated to the agricultural sector would lead to deviation in addressing the water consumption across different sectors (Zhao et al., 2010). Moreover, the grey water is excluded due to the limitation on the data acquisition of the nature of pollutants and the pollution load from each sector, which follows the similar estimation of previous studies (Hoekstra et al., 2011; Zhang et al., 2011; Shao and Chen, 2013, 2015; Shao et al., 2014).

The contribution effects of variation of WF for Zhangye during the 11 years are decomposed into technological, economic system efficiency, structural and scale effects. Technological effect refers to the influence of technological change on the volume of water use for one monetary unit of output. Technological improvement can significantly reduce water consumption for a given product. Economic system efficiency effect denotes the effect of inter-dependence between sectors based on the supply and demand in the economic system. This inter-dependence could be captured by the variation in the Leontief inverse matrix on the water consumption in Zhangye. Scale effect represents the effect of changes in the total volume of the sectoral final demand on its water consumption. Finally, structural effect depicts the role of variation in the sectoral distribution of the final demand.

IOA is a useful approach to quantify sectoral WF, which is based on Leontief model and gives full consideration to multiple inter-sectoral relationships. According to Guan and Hubacek (2007), Weber et al. (2007) and Feng et al. (2012), the basic model for sectoral WF can be expressed as:

$$\boldsymbol{w} = \boldsymbol{F}(\boldsymbol{I} - \mathbf{A})^{-1}\boldsymbol{y} = \boldsymbol{FLy} \tag{1}$$

where, $\boldsymbol{w}$ is the vector of sectoral WF that captures all the water flows consumed in the economic system directly or indirectly; $\boldsymbol{F}$ is the vector of water use intensity representing the volume of WF per unit of output; $\boldsymbol{I}$ is the identity matrix; $\mathbf{A} = (a_{ij})$ is the coefficient matrix, in which a_{ij} represents the input demands of the ith sector to produce per unit of output in the jth sector; $\boldsymbol{L} = (\boldsymbol{I}-\mathbf{A})^{-\mathbf{1}}$ is the Leontief inverse, with element in the matrix (b_{ij}) representing the amount of output generated in the ith sector per unit of final demand for the sector's output; and $\boldsymbol{y}$ is the column of sectoral final demand.

According to Miller and Blair (2009), different final demand categories can be represented by $\boldsymbol{y}$ from the input–output table (IOT), which includes categories such as rural and urban household consumption, government consumption, investment, export and import activity. Given that import activities data is unavailable in official IOTs, the domestic water use intensity ($\boldsymbol{F}$) for domestic technology assumption is adopted when calculating the import WF.