Full length article

Water footprint and scenario analysis in the transformation of Chongming into an international eco-island

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A B S T R A C T

Chongming Island is a distinct developing area in Shanghai and is currently being transformed as an international eco-island. The area is located in the Yangtze River estuary and secures the crop supply in Shanghai because of its unique geographical position and abundant water resource. Chongming is an agriculture-dominated district in an industrial city and is characterized by balanced utilization and natural preservation. In this study, the water footprint in Chongming Island from 2011 to 2014 was calculated and the water shortage was analyzed using virtual water as a criterion. Result shows that agricultural water footprint accounted for a major proportion of the total water footprint in Chongming Island. Water footprint from the manufacture of consumer products or services for residents was within the local water resource capacity, indicating that the self-sufficiency rate of water resource in Chongming Island was high. Nevertheless, this rate had been decreasing because of large imports that transfer water burden to other areas to optimize sustainable water consumption. However, Chongming Island had a higher water scarcity than other cities near Shanghai. Agricultural water footprint was categorized to assess the water utilization structure in Chongming’s agriculture. On the basis of the data from 2005 to 2014, four different scenarios were analyzed to predict the water footprint by 2040. The influence of the agricultural structure adjustment on the water resources of Chongming Island was assessed. Water consumption could be obviously reduced by 11.5% when the agricultural structure was changed. This situation should not be ignored by policy makers.

1. Introduction

The rapid economic growth over the past four decades has brought severe environmental challenges to China, such as worsening urban air quality and widespread water pollution (Liu and Xia 2004; Jing et al., 2010). China should therefore quickly transition to a path of sustainable development that balances economic prosperity and environmental and human health. Ecological civilization and circular economy concepts have been introduced and become popular in China; however, effectuating these concepts and achieving the goals of sustainable development is still faced with practical challenges. Chongming Island is the ecological backyard of Shanghai, a relatively un-urbanized region, and is a special case that provides exploratory and illustrative importance for China’s path toward sustainability.

Chongming Island in Shanghai is the third largest island in China and covers an area of approximately 1200 km\textsuperscript{2} with 3.94 × 10\textsuperscript{9} m\textsuperscript{3} water resource in 2014 (Chongming Statistic Yearbook, 2014). Chongming Island has been strategically positioned by the Shanghai Overall Planning Office to be developed into a world-class eco-island (Chu et al., 2015). Its development has received great attention and cooperation and involvement from international organizations, such as the United Nations Environmental Programs. Investments in various aspects of development in Chongming, including natural resource conservation, circular economy, pollution control, and public service, amounted to approximately 20 billion dollars between 2010 and 2012(Chu et al., 2015). The administrative position of Chongming Island is recently promoted from a county to a district of Shanghai. This promotion will strengthen the relationship between Shanghai and Chongming.

However, compared with other districts, Chongming Island is mainly an agricultural area with the lowest GDP in Shanghai and thus suffers the conflict between urbanization and natural protection.
Agriculture is water intensive in general and accounts for 70% of the global freshwater resource (Vörösmarty et al., 2010). Thus, regions of intensive agricultural practices and dense settlement may result in high water risks (Calzadilla et al., 2010). Chongming Island is already a breadbasket of Shanghai and has provided the city with various agricultural products for a long time. Thus, other economic and social changes in Shanghai, such as dietary change, will influence the water environment in Chongming Island.

The status quo of Chongming’s environment should be examined from a historical perspective because of its positioning as an eco-island. The future environment of Chongming should also be evaluated in consideration of the internal pressure of economic development and the new external relationship with Shanghai. The current study aimed to explore these tasks by use of the increasingly applied water footprint. Specifically, this study systematically and comprehensively evaluated water resources, analyzed virtual water trade of Chongming Island, and investigated the impacts of policy on water resources. Detailed agricultural water footprints were studied to assess the water utilization structure in Chongming’s agriculture. Four different scenarios regarding agriculture were examined to assess the water footprint by 2040 with the assumption of the same trend from 2005 to 2014. This study used water footprint as a tool for the sustainable water resource management in Chongming Island, and the findings could serve as a reference for policy makers who are interested in developing an eco-island. In the following section, the study area, Chongming Island, is first introduced, followed by a brief review of the water footprint methodology and a detailed description of the specific method used to calculate regional water footprint and of scenario analysis.

2. Materials and method

2.1. Study area

Chongming Island is a typical estuarine alluvial sand island, surrounded by the Yangtze River with one side along the coast. It covers an area of about 1200 km² and has an independent complete drainage. It is located in east longitude 121°09′00″~121°54′00″, north latitude 31°27′00″~31°51′15″. Its geographical position is shown in Fig. 1. Chongming Island is mild and humid in climate and has abundant rain, which makes it rich in water resources. And all the calculation of water footprint is based on the boundary of Chongming Island.

2.2. Overview of water footprint

Total demand or consumption of water resource and water supply capacity should be considered in maintaining water resource development and utilization within the scope of sustainability. Evaluation methods and indexes of freshwater resource usage are continuously improving (Diamond and Melesse 2016; Sun et al., 2016). Evaluation of water usage in a certain area usually adopts indexes, such as agricultural water consumption and industrial water consumption. However, these indexes ignore the influence of moisture in agricultural production soil and the impacts of inter-regional commodity flows on water resources (Ge et al., 2011). The virtual water concept was first introduced in the late 1990s (Allan 1998). In the process of agricultural and industrial production, the amount of water contained in the product is called “virtual water.” Water-deficient areas can purchase water intensive agricultural products (especially food) from water-rich area for water and food security. On the basis of the research on virtual water, Hoekstra further proposed the “water footprint” concept in 2002. This concept describes the impacts of human consumption on water resource systems (Hoekstra 2002).

Water footprint refers to the water consumption of all products and services of any known population (national, regional, or individual) in a certain period. Life cycle Assessment methodologies have been incorporated into water footprint research for comprehensive assessments (Jefferyes et al., 2012; Liang et al., 2013; Manzardo et al., 2016). Water footprint has been used to evaluate various aspects, such as industrial products (Berger et al., 2012; Van Oel and Hoekstra 2012), agricultural products (Chapagain and Hoekstra, 2007; Chapagain and Hoekstra, 2011; Mekonnen and Hoekstra, 2012a, 2012b; Zhuo et al., 2016a, 2016b), and energy (Gerbens-Leenes et al., 2009; Mekonnen and Hoekstra 2012a, 2012b). In the past decades, research based on virtual water trade has been extensively studied in water footprint (Zhao et al., 2010; Feng et al., 2012; Zhuo et al., 2016a, 2016b). Water footprint is an effective tool for measuring the utilization of regional water resources. Most studies in China focus on the water footprint of cities, provinces, river basins, and even multi-region or entire country levels (Zhang and Anadon 2014). The object region of the present study is a micro-region dominated by agricultural productions and is located in a major industrial province.

2.3. Regional water footprint calculation and assessment

The approach used for regional water footprint calculation in this study is based on early research (Hoekstra and Chapagain 2007). In our research, we considered the application of LCA, covering all aspects of the life cycle including transport and, processing of materials. LCA is a tool to discuss the water stress during the process of a product (Jefferyes et al., 2012). However, in our study, seven agricultural products were investigated and the detailed data were unavailable for LCA analysis in Chongming Island, which is a rural area in a developing country. More importantly, for food systems and for a society in general, water for agriculture is the predominate source of water footprint (Yang et al., 2012; Yang and Suh, 2015), especially in rural areas like Chongming Island. This means that other aspects like transport would not significantly affect our results. Water footprint of country or area equals the sum of 1) total quantity of water resources demanded in producing all products and services consumed by residents in the country or area, and 2) quantity of the water footprint of a country or an area. The basic form is expressed as

\[ WFP = IWFP + EWFP \]  (1)

where \( WFP \) is the footprint of water resources in a country or area. \( IWFP \) is the total quantity of water resources demanded in producing all products and services consumed by residents in the country or area, that is, internal water footprint. \( EWFP \) is the imported virtual water, that is, external water footprint. Furthermore,

\[ IWFP = AWU + IWW + DWW + EWW - VWE_{DOM} \]  (2)

where \( AWU \) is the quantity of water demanded by agricultural production (excluding the portion of water loss caused by agricultural irrigation). \( IWW \) is the quantity of water demanded by industrial production. \( DWW \) is the domestic water usage. \( EWW \) is the water demand for local ecological environment. \( VWE_{DOM} \) is the export of virtual water. Moreover,

\[ EWFP = VWI - VWE_{RE-EXPORT} \]  (3)

where \( VWI \) is the import of virtual water from other countries or regions, and \( VWE_{RE-EXPORT} \) is the total virtual water of re-export of imported products.

Personal water footprint is calculated by

\[ WFP_{PC} = \frac{WFP}{TotalPopulation} \]  (4)

The degree of water shortage (WS) in a country or area is equal to the ratio of water footprint (WFP) to available natural water resources (WA). WS is helpful to measure the water risk in a country or an area and to raise the attention of relative governments. The basic form is expressed as
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