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Decoupling analysis of economic growth from water use in City: A case study of Beijing, Shanghai, and Guangzhou of China

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ABSTRACT

Water scarcity is one of the biggest challenges in urban development in many countries, especially China. Better understanding the decoupling between economic growth and water usage in cities can facilitate and promote economic growth without increasing water usage. This study developed a water resource decoupling model and a water environment decoupling model to quantify the relationship between urban economic growth and water usage. China's top three megacities (Beijing, Shanghai, and Guangzhou) were studied to provide a case study analysis. The results show the best decoupling status between the urban economic output and water usage is Guangzhou, followed by Shanghai and Beijing. The waste resource decoupling status in industry sector was better than that in agriculture sector. The best decoupling status between the urban economic output and total waste water discharge was also Guangzhou, followed by Shanghai and Beijing.

1. Introduction

Water is a strategic natural resource and plays an important role in maintaining ecological balance and promoting economic development (Rosegrant et al., 2009). Significant population growth and a driving momentum towards socio-economic development have caused global water use to be largely unsustainable (Nazemi and Madani 2018), especially in urban regions (Kontokosta and Jain 2015). As the world's second-largest economy, China is the most populous country in the world, accounting for 21% of the world's population. However, its water resources make up only 6% of the world's water resources (Gu et al., 2017). China is one of the 13 water-scarce countries in the world and has been facing a growing water scarcity crisis for a long time (Zhao et al., 2017). Water resource shortages and the deterioration of the water environment are the two main problems restricting water resource use in China. These problems are restricting China's sustainable development. The optimal relationship between the economy and water resources environment is when the economy grows without a growth in water usage and without deteriorating the water environment. This means there is a decoupling between economic growth and the water resources environment. Therefore, research on the coordinated development of urban economic growth and the water resource environment is important to address the contradiction between China's sustained economic development and the water resources crisis.

2. Literature review

Water is one of the most prominent elements on earth and is very important to human life and development (Nazemi and Madani 2018, Wang and Chen 2015). Water is particularly important in urban regions because these regions are the most densely populated areas and the most economically active areas in the world (Nazemi and Madani 2017, Richter et al. 2018, Rojas et al., 2015). Therefore, may scholars have engaged in urban water research (Fraga et al., 2016, House-Peters and Chang 2011, Kingsborough et al., 2016, Noiva et al., 2016, Wilcox et al. 2016, Wang and Li 2016, Wang and Li et al., 2017a). Li et al. (2017) studied the estimated residential total water use and consumptive water use in the state of Nebraska in the United States in 2010; this provided a feasible and effective method for water managers to estimate residential water consumption (Li et al. 2017). Alireza et al. (2017) built a dynamic modeling method to simulate urban water supply dynamics, applying an agent-based modeling framework (Ali, Shafiee and Berglund 2017). S. Alireza et al. (2016) developed a new multiple regression model to predict urban water consumption. This provided a useful tool for policymakers to manage water usage by adjusting water prices and policies (Eslamian, Li and Haghighat 2016). Therefore, this study investigated mainland China's top 3 developed cities with the greatest economic strength: Beijing, Shanghai, and Guangzhou.

Economic development can't be separated from water utilization. Rapid economic growth is accompanied by water resource shortages

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and water environment deterioration. Many scholars have explored the relationship between water and the economy, using many approaches. Ke et al. (2016) built a comprehensive multi-objective optimization model and conducted an input-output analysis to study the trade-off between economic growth, water use, and environmental protection in Ordos. The study then proposed effective industrial restructuring programs and water supply plans (Ke et al. 2016). Bao and Chen (2015) proposed a complete decomposition model to investigate driving factors, particularly urbanization, on water consumption and the economy at the provincial-level in China. The results show that urbanization can lead to a water crisis in urban areas or in urban agglomerations (Bao and Chen 2015).

Zhao et al. (2017) investigated the relationship between water consumption and economic output in China using province-level panel data. The results show that China's water use is expected to rise in the next few years and reach the inflection point by 2021 (Zhao et al. 2017). Jaramillo and Nazemi (2017) applied downscaled climate simulations to assess the impact of climate change on water security in Montreal, Canada (Jaramillo and Nazemi 2017). Chao Bao (2015) used a cointegration test and the vector error correction model Granger causality test to analyze the causal relationship between total water consumption, economic output, and urbanization level (Bao and He 2015).

Decoupling theory was first proposed by Weizsäcker in 1990 (Weizsäcker 1990). Zhang et al. (2014) studied the decoupling relationship between water consumption and the impact on the water environment from crop production in Heilongjiang using the water footprint method. The results show that the decoupling state between water consumption and crop production was mainly concentrated in strong decoupling; the decoupling state between the water environment and crop production was mainly concentrated in the weak decoupling (Zhang and Yang 2014).

Zhu et al. (2013) used a decoupling model to analyze the relationship between water use and the economic output of Yunnan and Guizhou in China. The results show that the decoupling state of both provinces are all highly undesirable; this outcome is due to slow economic growth, and a low efficiency and unreasonable structure of water consumption (Zhu et al. 2013). Dan (2014) constructed a decoupling tense analysis model to analyze economic development and water resources utilization in China from 1953 to 2010 (Dan 2014). This literature review shows that when analyzing the relationship between economic growth and water resources, decoupling theory is widely used.

The concept of decoupling reflects the non-synchronous changes between economic growth and environmental damage (Weizsäcker 1990). The Organization for Economic Co-operation and Development (OECD) proposed its own decoupling model, dividing "decoupling" into two types: absolute decoupling and relative decoupling (OECD 2002). Based on the OECD decoupling model, Vehmas expanded the decoupling state from two types to six types, including: strong and weak decoupling; and strong, weak, expansive, and recessive coupling (Vehmas, Kaivo-Oja, & Luukkanen, 2018). In 2005, Tapio introduced decoupling elasticity into the decoupling model, resulting in eight decoupling state categories (weak, strong, weak negative, strong negative, expansive negative and recessive decoupling; expansive and recessive coupling) (Tapio 2005).

In the field of resources and the environment, the Tapio decoupling model has been mostly used to explore the decoupling relationship between economic growth and carbon emissions (Jiang and Li et al., 2017; Zhang and Da, 2015; Wang et al., 2016; Andreoni and Galmarini, 2012; Li and Jiang, 2017; Lu et al. 2015; Su, Jiang, & Li, 2017; Wang, Jiang, & Li, 2017) many scholars have also used it to study the decoupling relationship between economic growth and the energy consumption (Dong et al. 2016, Kan and Lianju 2017, Chen et al. 2017, Zhang and Da 2015, Niu et al. 2015, Ouyang et al., 2013, Liu et al., 2011, Wang and Li et al., 2017b). In addition, the Tapio decoupling model has been found to be the best approach to characterize the relationship between economic growth and water use (Gilmont 2015, Wang et al. 2015, Zhang et al. 2016). Therefore, the Tapio decoupling model was used to explore the coordinated development of the water resource environment and urban economic growth in China.

For this study, water research was subdivided into water resources and water environment research. Water consumption changes were used to represent changes in water resources; wastewater discharge changes were used to represent the change in the water environment change. Therefore, the water resource decoupling model and the water environment decoupling model were constructed to analyze the relationship between the water resource environment and urban economic growth in Beijing, Shanghai, and Guangzhou. Furthermore, based on the industrial structure and water consumption structure, the decoupling relationship between economic growth and the two major water use sectors: agriculture and industry were studied separately.

3. Methodologies and data sources

3.1. Methodologies

3.1.1. The water resource decoupling model

Urban economic growth was measured using the percent change in gross domestic product (GDP). The percent change of water consumption represents the water resources (WR). The water resource decoupling model is expressed as follows:

$$e_{ij}^{r} = \frac{\Delta WR_{ij}/WR_{ij}}{\Delta GDP_{ij}/GDP_{ij}} \quad (1)$$

In this expression,

i = 1,2, 3 denotes Beijing, Shanghai, and Guangzhou, respectively;

j = 1,2, 3 denotes the whole city, Agriculture sector, and Industry sector, respectively;

e_{ij}^{r} denotes the decoupling elasticity value of the water consumption and economic growth;

WR_{ij} denotes the water consumption;

GDP_{ij} denotes the economic output value;

3.1.2. The water environment decoupling model

Urban economic growth is measured using the percent change of GDP. The percent change in wastewater discharge represents the water environment (WE). The water environment decoupling model is expressed as follows:

$$e_{i}^{e} = \frac{\Delta WE_{i}/WE_{i}}{\Delta GDP_{i}/GDP_{i}} \quad (2)$$

e_{i}^{e} denotes the decoupling elasticity value of the waste water and economic growth;

WE_{i} denotes the total discharge of waste water;

GDP_{i} denotes the economic output value;

Using the Tapio decoupling model, eight logical possibilities can be defined according to the decoupling elasticity value. The eight options include strong decoupling, weak decoupling, expansive coupling, expansive negative decoupling, strong negative decoupling, weak negative decoupling, recessive coupling, and recessive decoupling. Table 1 provides the standards for dividing the eight logical possibilities. Table 2 shows the meaning of the decoupling status with respect to water resources and the water environment decoupling model.

3.2. Data source

Based on data availability, this study period for this research began in 2005 and ended in 2015. The gross domestic product and gross domestic product indices (previous year = 100) of Beijing and Shanghai were collected from the China Statistical Yearbook (NBS 2017). The water consumption for Beijing and Shanghai were collected from the