

# Decomposing the decoupling of water consumption and economic growth in Jiangxi, China

Mianhao Hu, Yunlin Hu, Juhong Yuan and Fucai Lu

## ABSTRACT

Current population growth coupled with industrial growth has caused water supply to be outstripped by human demand. Understanding water consumption (WC) decoupling patterns and the factors affecting the decoupling status are essential for balancing economic growth and WC. This study determines the decoupling relationship between WC and economic growth in Jiangxi Province, China, and the driving factors were determined by the Tapio decoupling model and the logarithmic mean Divisia index method. Results showed that changes in the industrial structure in Jiangxi Province resulted in corresponding changes in WC structure. Analysis of the decoupling relationship showed that the decoupling state between WC and economic growth for primary industry was very unstable and largely volatile from 1999 to 2015, but showed a good decoupling status for secondary and tertiary industries. The largest cumulative effects on WC were economic development and technology, which were positive and negative drivers of WC changes, contributing 1,406.14% and -902.96% to the total effect of WC, respectively. The findings can help Jiangxi government identify the key factors influencing the decoupling effect, and formulate effective policies to reduce WC, which will benefit the harmonious development of economy, society and water resources in Jiangxi Province.

**Key words** | decomposition, decoupling, economic growth, Jiangxi, water consumption

**Mianhao Hu** (corresponding author)

**Yunlin Hu**

**Fucai Lu**

Institute of Ecological Economics,  
Jiangxi University of Finance & Economics,  
Nanchang 330032,  
China

E-mail: yankeu1@163.com

**Juhong Yuan**

Institute of Environment and Plant Science,  
Jiangxi University of Finance and Economics,  
Nanchang 330032,  
China

## INTRODUCTION

Water resources are indispensable for healthy human societies, the preservation of natural environments and ecosystem services, and population and socioeconomic development. However, with rapid economic development, population growth, urbanization and climate change, problems related to water resources have posed a great threat to human security, and hindered sustainable economic development (Wu *et al.* 2016). The frequency and severity of water resource issues are both increasing, which has aroused concern among researchers worldwide (Murray *et al.* 2014; Ren *et al.* 2016). Many different methods have been proposed to understand water resources and their consumption, for

example, the link between supply and demand, conflict for water resources (Böhmelt *et al.* 2014; Xiong *et al.* 2015), water footprint and water consumption in the Nile Basin (Sallam 2014), in Heilongjiang, China (Zhang & Yang 2014), and in China (Li *et al.* 2017a), water consumption and climate change (Dawadi & Ahmad 2015; Palazzoli *et al.* 2015), the relationship between water consumption and economic growth with structural decomposition analysis (Cazcarro *et al.* 2013), panel dataset analysis (Tir *et al.* 2014), the environmental Kuznets curve (Katz 2015; Shan 2016), and the transcendental logarithmic (translog) production model (Ngoran *et al.* 2016). These studies have shown that water consumption has a determining role in both increasing and decreasing economic growth. Although water availability is potentially able to promote economic growth, long-term economic growth can only be assured if an increase in

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water supply provision is identified on a sustainable basis. Consequently, there is a need for more robust approaches to investigate water consumption and its relationship with sustainable economic growth.

Decoupling analysis is widely used and has attracted great attention in studies of economic growth in association with environmental pressures (OECD 2002). Decoupling refers to breaking the linkages between 'economic goods' and 'environmental bads'. Determining the decoupling relationship between the economy and the environment is a key step in achieving green economic development, which is one of the main objectives of human development as proposed by the Organisation for Economic Co-operation and Development (OECD 2001). Decoupling can be accomplished by compelling people to rethink the connections among resource utilization, environmental quality, and economic growth (Zhang et al. 2016a, 2016b). Considerable research has been conducted to establish the decoupling relationship between economic growth and water consumption. For example, Zhu et al. (2013) studied the decoupling relationship between water use and economic development for two provinces in China (Yunnan and Guizhou), and found that the decoupling state was far from ideal. Zhang & Yang (2014) used the water footprint method to study the decoupling relationship among water consumption, water environmental pressure, and crop production, and showed that strong decoupling occurs more often between water consumption and crop production. Gilmont (2014) found that decoupling comprises two types in Israel: one type occurs when the economy ceases to be water self-sufficient, and the other type occurs when the economy has the capacity to remedy its over-exploitation of natural water. Wang et al. (2015) introduced decoupling indices to examine the decoupling relationship between environmental pressure (including water resources) and economic growth, and obtain the corresponding decoupling state in Tianjin, China. Li et al. (2017b) used the decoupling model to examine the relationship between water consumption and economic growth in China, and showed a decoupling trend occurred during 2001–2014, but a steady stage of decoupling had not yet been achieved. However, research on the decoupling of economic growth and water consumption is still limited for industrial water consumption, and many regions and nations. In addition, current research

universally consents to this idea and analysis of the decoupling state, but cannot fulfill further decomposition to consider the driving factors of water consumption.

Jiangxi Province in China has rich water resources, but the distribution of the water resources varies largely in both time and space. Furthermore, with accelerated development of a relatively dense population and town, a relatively backward production mode, and prominent structural contradictions, as well as rapid industrial aggregation, the disparity between supply and demand of water resources in Jiangxi has become increasingly prominent, which has seriously constrained sustainable socioeconomic and regional development. On the basis of this consideration, we investigated the relationship between water consumption and economic growth in Jiangxi Province by decoupling methodology and then analyzed the driving factors of the relationship by the logarithmic mean Divisia index (LMDI), to provide a reference for the management and optimization of water resources utilization among different industries, and coordinating the relationship between economic development and water consumption. The study shows that changes in the industrial structure of Jiangxi Province resulted in corresponding changes in the water consumption structure and that economic development and technology were the main drivers of water consumption changes.

## MATERIALS AND METHODS

### Research area

Jiangxi Province is located in southeastern China. It borders Zhejiang and Fujian in the east, Guangdong to the south, Hunan to the west, and Hubei and Anhui to the north (Figure 1). It is a common hinterland of the Yangtze River delta, the Pearl River delta and the Hercynian economic zone. In addition, China's largest freshwater lake, Poyang Lake, is located in northern Jiangxi Province and is connected to the Yangtze River.

Jiangxi Province covers an area of 166,900 km<sup>2</sup> and ranges from 24° 29' 14" to 30° 04' 41" N and from 113° 34' 36" to 118° 28' 58" E. With the rapid development of the Poyang Lake ecological economic zone in recent years, Jiangxi has become the most economically active area in South China.

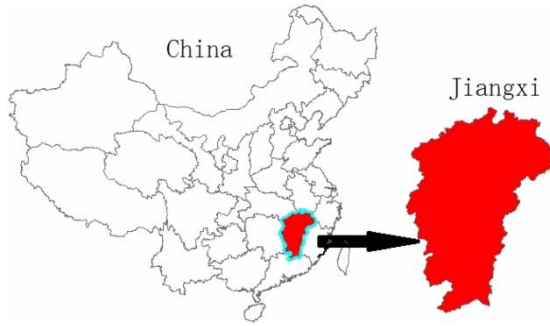


Figure 1 | Location of Jiangxi Province in China.

In particular, the Poyang Lake ecological economic zone was included in the national strategy in 2009, which has further accelerated the economic development of Jiangxi.

### Tapio decoupling model

In the early 2000s, decoupling theory was introduced to social economics to study the relationships between economic growth and environmental pressures. Tapio's decoupling elasticity method (Tapio 2005) is used universally to describe the direction and degree of decoupling. In decoupling studies of water consumption and economic growth, the decoupling elasticity coefficient is defined as the ratio between the change rate of water consumption or environmental pressure and the change rate of economic conditions over a certain period of time. The decoupling elasticity coefficient of water consumption and economic growth is calculated by the following equation:

$$D(wc, g) = \frac{\Delta WC / WC_{t-1}}{\Delta GDP / GDP_{t-1}} = \frac{(WC_t - WC_{t-1}) / WC_{t-1}}{(GDP_t - GDP_{t-1}) / GDP_{t-1}} \quad (1)$$

where  $WC$  is water consumption,  $WC_i$  is defined as the  $WC$  of the  $i$  industry in year  $t$ , and  $WC_{t-1}$  is defined as the  $WC$  of the  $i$  industry in year  $t - 1$ .  $GDP$  is gross domestic product,  $\Delta WC$  is the change of  $WC$ , and  $\Delta GDP$  is the change of  $GDP$ .  $\Delta WC$  and  $\Delta GDP$  are obtained by calculating the corresponding data at two time points: year  $t$  and year  $t - 1$ . The type and state of decoupling is defined by the range of decoupling elasticity coefficient values, the situation of economic growth, and the pressure state of resources and the environment. Eight logical possibilities are yielded and are shown in

Figure 2. These possibilities include expansive negative decoupling, strong negative decoupling, weak negative decoupling, weak decoupling, strong decoupling, recessive decoupling, expansive coupling, and recessive coupling. Strong decoupling is the ideal state of decoupling, that is, a decline in water consumption with economic growth. Strong negative decoupling is the worst situation, that is, simultaneous recession and increased water consumption.

### LMDI decomposition model

The index decomposition analysis (IDA) method is widely used to analyze the factors affecting energy consumption and pollutant emissions (Ang 2005; Olanrewaju et al. 2012; Xu & Ang 2013; Nie & Kemp 2014; Kim & Heo 2016; Lyu et al. 2016), and is also used in studies of water resources (Kondo 2005; Sun & Wang 2010; Cosmo et al. 2014; Shang et al. 2016; Kang et al. 2017; Li et al. 2017a, 2017b). The IDA method is divided into many types of model (Ang 2004), but the LMDI is the optimal method (Ang & Zhang 2000; Ang 2004). Thus, the LMDI model is applied in this study. Water consumption can be calculated as:

$$WC = \sum_i WC_i = \sum_i \frac{GDP}{P} \times \frac{GDP_i}{GDP} \times \frac{WC_i}{GDP_i} \times P = \sum_i g \times S_i \times I_i \times P \quad (2)$$

where  $WC_i$  is the  $WC$  of  $i$  industry,  $GDP/P$  is the proportion of  $GDP$  to total population ( $P$ ), representing the  $GDP$  per capita ( $g$ ),  $GDP_i$  is the  $GDP$  of  $i$  industry (in millions),  $GDP_i/GDP$  is the proportion of the  $GDP$  of  $i$  industry to the total gross domestic product, which represents the structural effect of the  $i$  industry ( $S_i$ ), and  $WC_i/GDP_i$  is the  $WC$  intensity which means the  $WC$  consumed per unit of production value of  $i$  industry, and it represents the technology effect of the  $i$  industry ( $I_i$ ). The decomposition of  $WC$  change ( $\Delta WC$ ) between base year  $t - 1$  and target year  $t$  according to the LMDI method (Ang 2005) can be broken down into the following formula:

$$\Delta WC = \Delta WC_P + \Delta WC_g + \Delta WC_{S_i} + \Delta WC_{I_i} \quad (3)$$

where  $\Delta WC_P$  is the contribution of total population to the annual change in  $WC$ ,  $\Delta WC_g$  is the contribution of regional economic development to the annual change in  $WC$ ,

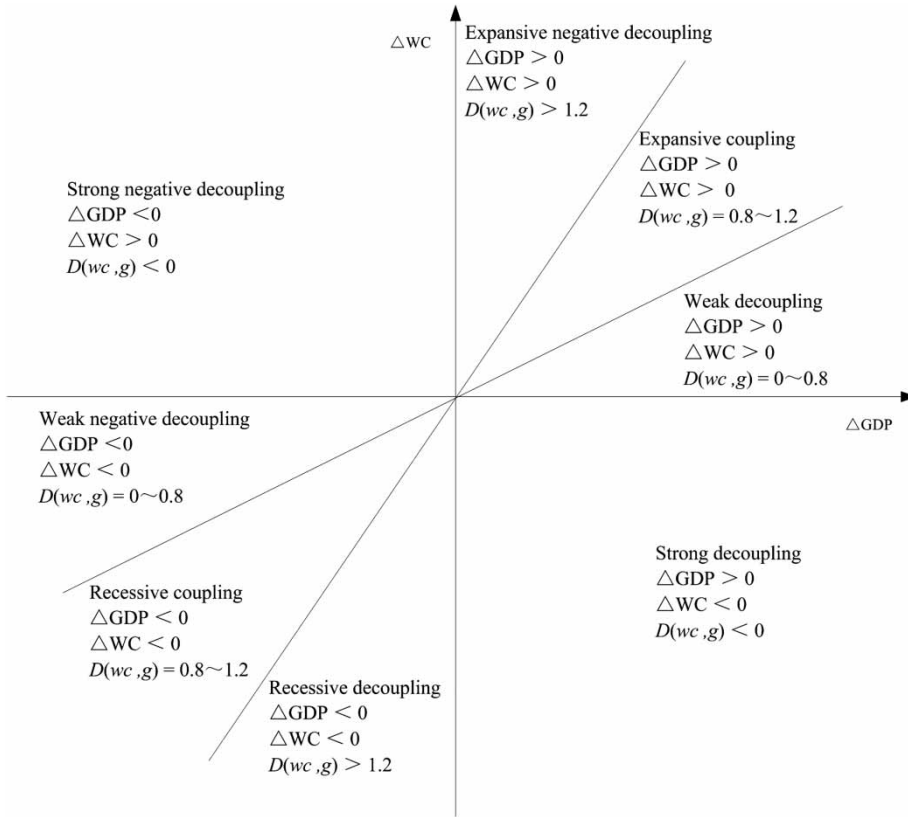


Figure 2 | Degrees of coupling and decoupling between water consumption growth (ΔWC) and economic growth (ΔGDP) (modified from Tapio (2005)).

$\Delta WC_{S_i}$  is the contribution of industrial structure to the annual change in WC, and  $\Delta WC_{T_i}$  is the contribution of technology to annual change in WC. The remaining terms  $\Delta WC$ ,  $\Delta WC_P$ ,  $\Delta WC_g$ ,  $\Delta WC_{S_i}$ , and  $\Delta WC_{T_i}$  represent the difference in WC between year  $t$  and year  $t - 1$ , for total effect, population effect, economic development effect, industrial structure effect and technology effect, respectively. The contribution of each factor based on the LMDI decomposition method (Ang 2005) can be expressed by the following formulas:

$$\Delta WC_P = \sum_i \frac{WC_i^t - WC_i^{t-1}}{\ln WC_i^t - \ln WC_i^{t-1}} \times \ln \frac{P^t}{P^{t-1}} \tag{4}$$

$$\Delta WC_g = \sum_i \frac{WC_i^t - WC_i^{t-1}}{\ln WC_i^t - \ln WC_i^{t-1}} \times \ln \frac{g^t}{g^{t-1}} \tag{5}$$

$$\Delta WC_{S_i} = \sum_i \frac{WC_i^t - WC_i^{t-1}}{\ln WC_i^t - \ln WC_i^{t-1}} \times \ln \frac{S_i^t}{S_i^{t-1}} \tag{6}$$

$$\Delta WC_{T_i} = \sum_i \frac{WC_i^t - WC_i^{t-1}}{\ln WC_i^t - \ln WC_i^{t-1}} \times \ln \frac{I_i^t}{I_i^{t-1}} \tag{7}$$

Data source and processing

Data for 1999 to 2015 were collected from issues of the *Jiangxi Statistical Yearbook* and *Jiangxi Water Resources Bulletin*. The whole economy of Jiangxi has been divided into primary, secondary, and tertiary industries (Zhang et al. 2015). To eliminate the effect of price changes and ensure the accuracy of comparison, the GDP of the three industries was converted according to the 1999 constant prices by using the indices of GDP (IGDP, preceding year = 100). The sum of the adjusted GDPs for the three industries is equal to the total GDP of Jiangxi. Total population refers to Jiangxi's permanent population. The WC of farmland irrigation, forest, livestock, and fishery are classified as the WC of primary industry (Zhang et al. 2016a, 2016b), industrial water consumption is designated as the WC of secondary

industry (Zhang *et al.* 2016a, 2016b), and the domestic water consumption is classified as the WC of tertiary industry (Yun *et al.* 2008; Sun & Xie 2011). The sum of adjusted WCs for the three industries was equal to the total WC of Jiangxi.

## RESULTS AND DISCUSSION

### Changes in the industry structure and WC structure

The industry structure in Jiangxi exhibited a tertiary–secondary–primary structure from 1999 to 2002 and a secondary–tertiary–primary structure from 2003 to 2015. From 1999 to 2015, the proportion of output value of secondary industry to GDP showed an increasing trend, the proportion of output value of tertiary industry to GDP presented a downward then a slow upward trend, and the proportion of output value of the primary industry to GDP showed a gradual downward trend (Figure 3(a)). In 1999, the total WC of Jiangxi reached 21.708 billion

m<sup>3</sup>, and the proportion of WC of primary, secondary and tertiary industries relative to total WC was 70.42%, 20.73%, and 8.85%, respectively (Figure 3(b)). In 2015, the total WC of Jiangxi reached 24.581 billion m<sup>3</sup>, and showed a downward–upward trend over the study period. However, the proportion of WC of primary industry relative to total WC maintained a downward trend, and decreased by 63.25%; the WC of secondary and tertiary industries increased each year, and the proportions relative to total WC reached 25.29% and 11.46%, respectively (Figure 3(b)). The results indicate that industry structure is closely related to the water consumption structure, and that changes in industrial structure result in corresponding changes in the water consumption structure. This finding is consistent with most of the previous studies mentioned in this paper (Gu *et al.* 2013; Wu *et al.* 2014). However, research on the textile industry found that industrial scale plays an important role in water consumption increases in the three sub-sectors, while the influence of the industry structure is not particularly significant (Li *et al.* 2017b).

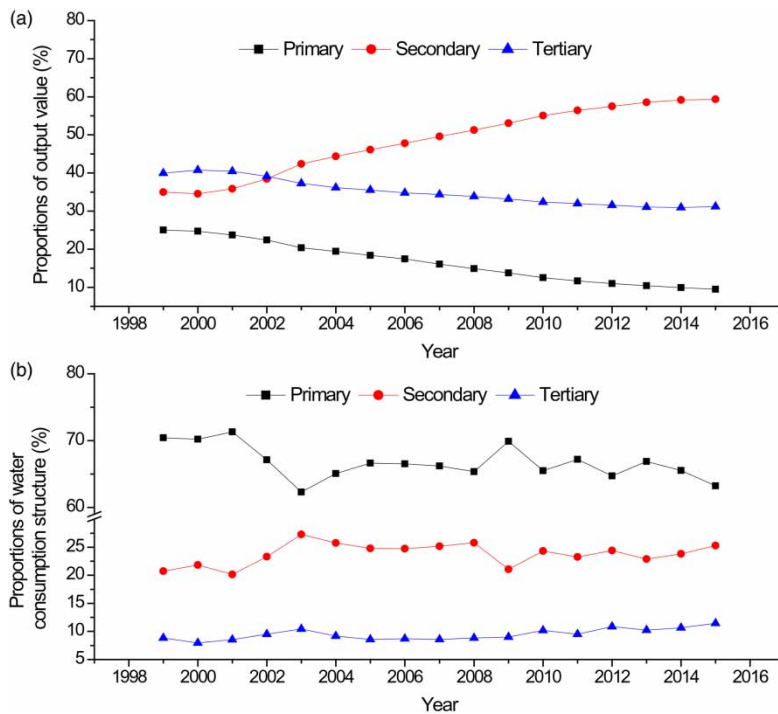


Figure 3 | Changes in the (a) industry structure and (b) water consumption structure in Jiangxi Province from 1999 to 2015.

## Analysis of the decoupling relationship between WC and economic growth

### Decoupling analysis of total WC and total economic growth

Table 1 shows the decoupling relationship between total WC and total economic growth in Jiangxi from 2000 to 2015. As is reported in Table 1, Jiangxi experienced expansive negative decoupling in 2004, expansive coupling in 2007, 2011, and 2013, weak decoupling in 2000, 2005, and 2009, and strong decoupling in the remaining years (2001, 2002, 2003, 2006, 2008, 2010, 2012, 2014, and 2015). However, for the strong decoupling, nearly all the absolute  $D(wc, g)$  values were smaller than 1, except for the value in 2003 ( $-1.071$ ). This indicates that the economic growth of Jiangxi is not significantly strongly decoupled from WC, which means further improvement is still needed. During 2000, 2005, and 2009, there were weak decoupling states, with  $D(wc, g)$  values ranging from 0.17 to 0.659, which manifest as desirable decoupling states. Expansive negative decoupling occurred

**Table 1** | Decoupling trend between total water consumption and total economic growth in Jiangxi Province (2000–2015)

Year	% $\Delta$ GDP	% $\Delta$ WC	$D(wc, g)$	Degree decoupling/coupling
2000	8.203	4.249	0.518	Weak decoupling
2001	8.711	-3.088	-0.354	Strong decoupling
2002	10.466	-5.770	-0.551	Strong decoupling
2003	12.846	-13.756	-1.071	Strong decoupling
2004	13.160	18.068	1.373	Expansive negative decoupling
2005	12.760	2.164	0.170	Weak decoupling
2006	12.226	-1.170	-0.096	Strong decoupling
2007	13.050	13.952	1.069	Expansive coupling
2008	13.150	-0.283	-0.022	Strong decoupling
2009	13.058	8.609	0.659	Weak decoupling
2010	13.926	-6.472	-0.465	Strong decoupling
2011	12.492	10.574	0.846	Expansive coupling
2012	10.961	-7.788	-0.710	Strong decoupling
2013	10.042	9.231	0.919	Expansive coupling
2014	9.695	-2.082	-0.215	Strong decoupling
2015	9.070	-5.264	-0.580	Strong decoupling

Note: % $\Delta$ GDP is the growth rate of total output value; % $\Delta$ WC is the growth rate of WC;  $D(wc, g)$  is the decoupling elasticity coefficient.

in 2004 and the  $D(wc, g)$  value was 1.374, because the WC growth rate was faster than the economic growth rate in this year, which resulted in a reduction in water availability. Furthermore, expansive coupling occurred in 2007, 2011, and 2013, which indicates that the WC growth rate was basically consistent with the economic growth rate during these years.

### Decoupling analysis of WC and economic growth for primary industry

Table 2 shows the decoupling relationship between the WC and economic growth of primary industry in Jiangxi from 2000 to 2015. The WC of primary industry accounted for most of the total WC in Jiangxi from 1999 to 2015 (Figure 3(b)). As shown in Table 2, the GDP of primary industry continued to grow from 2000 to 2015, with a growth rate mostly around 4.5%; however, its WC was

**Table 2** | Decoupling trend between water consumption and economic growth of primary industry in Jiangxi Province (2000–2015)

Year	% $\Delta$ GDP	% $\Delta$ WC	$D(wc, g)$	Degree decoupling/coupling
2000	6.800	-0.046	-0.007	Strong decoupling
2001	4.200	-1.545	-0.368	Strong decoupling
2002	4.400	-11.281	-2.564	Strong decoupling
2003	2.700	-19.984	-7.401	Strong decoupling
2004	8.000	23.317	2.915	Expansive negative decoupling
2005	6.500	4.632	0.713	Weak decoupling
2006	6.500	-1.350	-0.208	Strong decoupling
2007	4.100	13.455	3.282	Expansive negative decoupling
2008	4.800	-1.602	-0.334	Strong decoupling
2009	4.500	16.138	3.586	Expansive negative decoupling
2010	4.000	-12.330	-3.082	Strong decoupling
2011	4.200	13.468	3.207	Expansive negative decoupling
2012	4.600	-11.214	-2.438	Strong decoupling
2013	4.500	12.861	2.858	Expansive negative decoupling
2014	4.700	-4.024	-0.856	Strong decoupling
2015	3.900	-8.588	-2.202	Strong decoupling

Note: % $\Delta$ GDP is the growth rate of total output value; % $\Delta$ WC is the growth rate of WC;  $D(wc, g)$  is the decoupling elasticity coefficient.

not stable (Figure 3(b)). The WC of primary industry showed sustained negative growth and this trend gradually accelerated from 2000 to 2003, mainly because agricultural irrigation water fell from 14.021 billion m<sup>3</sup> in 2001 to 12.351 billion m<sup>3</sup> in 2002, and then to 9.39 billion m<sup>3</sup> in 2003, which resulted in absolute D(wc, g) value in 2002 and 2003 much greater than 1.2 and an obvious strong decoupling state in 2000, 2001, 2002, and 2003. From 2003 to 2005, the WC of primary industry increased due to the restoration of agricultural irrigation water, especially from 2003 to 2004, when the WC rose as high as 23%. As a result, the decoupling state worsened, changing from strong decoupling in 2000–2003 to expansive negative decoupling in 2004 and weak decoupling in 2005. Agricultural irrigation water varied between 12.851 billion m<sup>3</sup> and 16.867 billion m<sup>3</sup> from 2006 to 2013, and was in an unstable state; thus, the decoupling state shifted to strong decoupling and expansive negative decoupling. From 2014 to 2015, the WC of primary industry decreased and the rate of decline accelerated, and the decoupling state was strong decoupling. From Figure 3(b), it can see that the proportion of WC in primary industry showed a downward trend with fluctuations, whereas the proportion of WC in secondary and tertiary industries showed the opposite trend. Therefore, in addition to the improvement of WC efficiency in primary industry, adjustments in consumption and trade structure are highly instrumental to the conservation of water resources (Guo et al. 2016).

### Decoupling analysis of WC and economic growth for secondary industry

As is shown in Table 3, in terms of secondary industry, the WC growth rate was lower than its economic growth rate in all years. Expansive coupling occurred in 2000 and 2007, strong decoupling occurred in five years (2001, 2005, 2006, 2009, and 2012), and weak decoupling occurred in the remaining years (2002, 2003, 2004, 2008, 2010, 2011, 2013, 2014, and 2015). However, the D(wc, g) values for the expansive coupling states in 2000 and 2007 indicate that the WC growth rate was basically consistent with the economic growth rate in these years. In addition, the WC of secondary industry experienced large fluctuations in 2001 and 2009, with D(wc, g) values reaching –10.632

**Table 3** | Decoupling trend between the water consumption and economic growth for secondary industry in Jiangxi Province (2000–2015)

Year	%ΔGDP	%ΔWC	D(wc, g)	Degree decoupling/coupling
2000	6.700	5.532	0.826	Expansive coupling
2001	12.900	–10.632	–0.824	Strong decoupling
2002	18.500	9.187	0.497	Weak decoupling
2003	24.300	0.863	0.036	Weak decoupling
2004	18.600	11.572	0.622	Weak decoupling
2005	17.100	–1.821	–0.107	Strong decoupling
2006	16.300	–1.250	–0.077	Strong decoupling
2007	17.300	15.879	0.918	Expansive coupling
2008	17.000	2.253	0.133	Weak decoupling
2009	17.100	–11.248	–0.658	Strong decoupling
2010	18.200	7.841	0.431	Weak decoupling
2011	15.200	5.737	0.377	Weak decoupling
2012	13.100	–3.166	–0.242	Strong decoupling
2013	12.000	2.401	0.200	Weak decoupling
2014	10.900	1.863	0.171	Weak decoupling
2015	9.400	0.604	0.064	Weak decoupling

Note: %ΔGDP is the growth rate of total output value; %ΔWC is the growth rate of WC; D(wc, g) is the decoupling elasticity coefficient.

and –11.248, respectively. Except for 2004 and 2007, the absolute D(wc, g) values were much larger than those of other years, due to the acceleration of transformation and upgrade of secondary industry (Figure 3(b)). Furthermore, during 2002, 2003, 2004, 2008, 2010, 2011, 2013, 2014, and 2015, there was a state of weak decoupling, with D(wc, g) values ranging from 0.036 to 0.622, which manifest as decoupling states that are generally considered satisfactory. As is shown in Figure 3(a), secondary industry has an essential role in pushing economic development, and the proportion of secondary industry increased while the proportion of the primary and tertiary industries decreased (Figure 3(b)). This indicates that the transformation and adjustment of industrial structure has a key role in improving water-use efficiency to achieve the goal of reducing water consumption (Wu et al. 2014).

### Decoupling analysis of WC and economic growth for tertiary industry

Table 4 shows the decoupling relationship between the WC and economic growth of tertiary industry in Jiangxi

**Table 4** | Decoupling trend between the water consumption and economic growth of tertiary industry in Jiangxi Province (2000–2015)

Year	% $\Delta$ GDP	% $\Delta$ WC	$D(wc, g)$	Degree decoupling/coupling
2000	10.400	-9.682	-0.931	Strong decoupling
2001	7.900	3.977	0.503	Weak decoupling
2002	6.900	4.989	0.723	Weak decoupling
2003	7.400	-5.649	-0.763	Strong decoupling
2004	9.800	3.693	0.377	Weak decoupling
2005	10.800	-4.155	-0.385	Strong decoupling
2006	9.900	0.450	0.046	Weak decoupling
2007	11.700	12.276	1.049	Expansive coupling
2008	11.500	2.446	0.213	Weak decoupling
2009	10.700	10.916	1.020	Expansive coupling
2010	11.200	5.448	0.486	Weak decoupling
2011	11.100	3.500	0.315	Weak decoupling
2012	9.500	5.113	0.538	Weak decoupling
2013	8.400	2.949	0.351	Weak decoupling
2014	9.100	1.786	0.196	Weak decoupling
2015	10.100	2.083	0.206	Weak decoupling

Note: % $\Delta$ GDP is the growth rate of total output value; % $\Delta$ WC is the growth rate of WC;  $D(wc, g)$  is the decoupling elasticity coefficient.

from 2000 to 2015. During this period, the WC showed negative growth in 2000, 2003, and 2005, whereas the other years showed positive growth, particularly in 2007 and 2009, when the WC growth rate was slightly more than the economic growth rate. The decoupling relationship exhibited the following states: strong decoupling for three years (2000, 2003, and 2005), expansive coupling in 2007 and 2009, and weak decoupling in the remaining years (2001, 2002, 2004, 2006, 2008, 2010, 2011, 2012, 2013, 2014, and 2015). The decoupling of tertiary industry can be roughly separated into two stages. The first phase was from 2000 to 2009, when the decoupling state of tertiary industry went from strong decoupling to weak decoupling to expansive coupling. It can be seen that the decoupling state of tertiary industry was not so stable during this period, that is, the economic growth of tertiary industry was inconsistent with the WC growth rate. The second phase was from 2010 to 2015, when the decoupling state of tertiary industry was always weak decoupling, that is, the WC growth rate of tertiary industry was slower compared with economic growth. From these results, it can be seen that the development

of tertiary industry can greatly increase water-use efficiency in Jiangxi.

### Decomposition analysis of WC

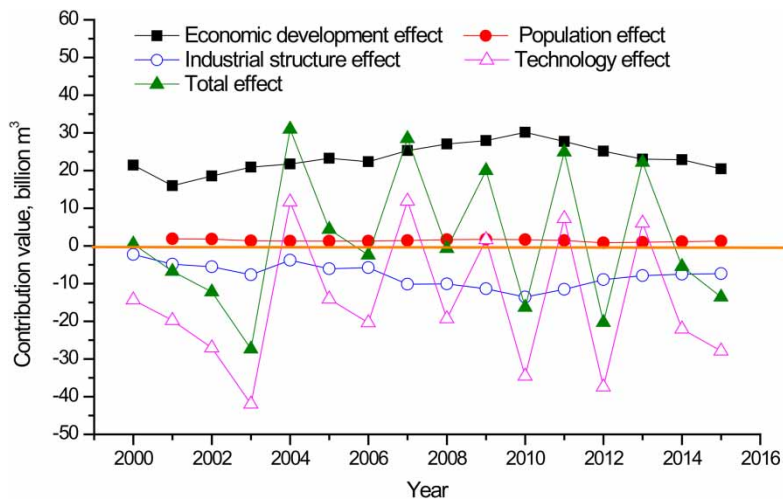
Table 5 shows the results of the decomposition analysis of WC in Jiangxi from 1999 to 2015. During 1999–2015, the cumulative WC of Jiangxi reached 26.60 billion m<sup>3</sup>. The cumulative economic development effect reached 374.034 billion m<sup>3</sup>, accounting for 1406.14% of the total effect, which was the principal driver of WC increase. Water resources utilization is a basic production factor in keeping the economy running and is highly correlated with the level of economic development. The population effect played a positive role in regional WC and was a stimulative factor of WC increase, but its degree of influence was much smaller than that of the regional economic development effect. The population effect showed a positive fluctuating trend (except for 2000) from 1999 to 2015, and its cumulative effect was 17.041 billion m<sup>3</sup>, accounting for 64.06% of the total effect (Table 5). Population growth is bound to be accompanied by an increase in residents' water consumption, economic scale and the water consumption, which results in an increase in water resources scarcity. During the study period, the industrial structure effect showed a downward fluctuating trend between 1999 and 2015, the cumulative effect reached -124.288 billion m<sup>3</sup>, and its absolute value accounted for 467.25% of the total effect (Table 5). It also was a negative driver of changes in regional WC, which indicates that industrial structure adjustment has an inhibiting effect on WC increase. As can be seen in Figure 2, the dominant industry started to shift from primary industry with high WC to second and tertiary industries with low WC, which had a positive effect on the decrease of WC. The cumulative technology effect reached -240.187 billion m<sup>3</sup>, its absolute value accounted for 902.96% of the total effect, and it was a negative driver of changes in regional WC, except in 2004, 2007, 2009, 2011, and 2013 (Table 5), which indicates that technical progress has an inhibiting effect on WC increase and is the most important factor in the WC decrease (Figure 4).

In summary, the economic development and population effects were positive drivers of WC changes, but the population effect was much smaller than the economic



**Table 5** | Decomposition analysis of WC in Jiangxi from 1999 to 2015 (billion m<sup>3</sup>)

Year	Economic development effect	Population effect	Industrial structure effect	Technology effect	Total effect
2000	21.421	-4.286	-2.274	-14.300	0.560
2001	15.979	1.914	-4.859	-19.754	-6.720
2002	18.584	1.784	-5.498	-27.040	-12.170
2003	20.922	1.385	-7.680	-41.967	-27.340
2004	21.766	1.281	-3.774	11.697	30.970
2005	23.247	1.317	-6.061	-14.123	4.380
2006	22.383	1.325	-5.725	-20.403	-2.420
2007	25.306	1.468	-10.166	11.902	28.510
2008	27.046	1.681	-10.044	-19.343	-0.660
2009	27.921	1.755	-11.357	1.671	19.990
2010	30.132	1.649	-13.586	-34.515	-16.320
2011	27.753	1.452	-11.513	7.248	24.940
2012	25.185	0.863	-8.957	-37.401	-20.310
2013	23.042	1.015	-7.902	6.045	22.200
2014	22.905	1.148	-7.507	-22.016	-5.470
2015	20.444	1.290	-7.386	-27.889	-13.540

**Figure 4** | The contribution value of factors influencing water consumption in Jiangxi Province from 2000 to 2015.

development effect, with average contribution rates of 1,406.14% and 64.06% from 1999 to 2015, respectively. However, the industrial structure and technology effects were negative drivers of WC changes, and the technology effect was more significant than the industrial structure effect, with average contribution rates of -467.25% and -902.96% from 1999 to 2015, respectively. Thus, it can be seen that the economic development level and

technology level are the determining factors of WC changes in Jiangxi.

## CONCLUSIONS

Based on water consumption (WC) and economic growth data for the three types of industry (primary, secondary, and tertiary

industries) in Jiangxi Province from 1999 to 2015, the decoupling relationship between WC and economic growth was analyzed by the Tapio decoupling model. Furthermore, the LMDI technique was applied to identify the main driving forces affecting changes in water consumption. The main conclusions drawn from the present study are as follows.

From 1999 to 2002, the three types of industry in Jiangxi exhibited a tertiary–secondary–primary structure, and generally followed a secondary–tertiary–primary structure from 2003 to 2015. In addition, changes in the industrial structure resulted in corresponding changes in the water consumption structure.

In 2000–2015, except for 2004 (expansive negative decoupling), Jiangxi's total WC showed good decoupling with economic growth, with nine years of strong decoupling (2001, 2002, 2003, 2006, 2008, 2010, 2012, 2014, and 2015), three years of expansive coupling (2007, 2011, and 2013), and three years of weak decoupling (2000, 2005, and 2009). The decoupling state of primary industry presented mainly strong decoupling during 2000 to 2003. Then, there was a shift to expansive negative decoupling and strong decoupling, except for 2005 (weak decoupling), which showed that the decoupling state of primary industry was very unstable and largely volatile. The WC of secondary industry in Jiangxi showed good decoupling with economic growth, with five years strong decoupling (2001, 2005, 2006, 2009, and 2012), two years of expansive coupling (2000 and 2007), and nine years of weak decoupling (2002, 2003, 2004, 2008, 2010, 2011, 2013, 2014, and 2015). The WC of tertiary industry also showed good decoupling with economic growth, with three years strong decoupling (2000, 2003, and 2005), two years of expansive coupling (2007 and 2009), and eleven years of weak decoupling (2001, 2002, 2004, 2006, 2008, 2010, 2011, 2012, 2013, 2014, and 2015).

The main factors affecting the decoupling of WC and economic growth in Jiangxi Province were the economic development level and technology level. The economic development effect was a large positive driver of WC changes and the technology effect was a large negative driver of WC changes.

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