



# Identifying the driving factors of water consumption from water-energy-food nexus in the Yangtze River Delta region, China

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## Abstract

The current water shortage in China is critical. Moreover, the water shortage has become the main bottleneck hindering sustainable economic growth. Against the background of China's dual control target of total water use and intensity, we choose the Yangtze River Delta (YRD) region as a research object, which encompasses Shanghai, Jiangsu, Zhejiang, and Anhui. Based on the perspective of water-energy-food nexus, we employ the generalized Divisia index method to decompose the change of water use into eight factors, regional economic scale effect, regional energy use scale effect, regional food production effect, regional water technology effect, regional energy technology effect, regional water-energy nexus effect, regional food-energy nexus effect, and regional water technology for food production effect, and analyze the contribution of each driver to identify the key drivers of total water use control. The results showed that the top four influencing factors are GDP, water intensity, energy consumption, and water-energy nexus in the YRD region. Regional economic scale is the first driving factor for increasing water use in the YRD region except for Zhejiang. Water intensity is the primary driving force of water-saving in Zhejiang. Energy consumption is the third driver of increasing water use in Jiangsu and Anhui. The effect of water-energy nexus is the third driving factor that affects the change of water use in Shanghai and Zhejiang. The authorities in the YRD region should vigorously develop water and energy utilization technologies to increase the water intensity and decrease energy consumption. The energy sector should decrease the water use to decrease the water-energy nexus which is also the main driving factor affecting the change of water use.

**Keywords** Yangtze River Delta (YRD) region · Water use · Index decomposition · Generalized Divisia index method · Water-energy-food nexus

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## Introduction

Water, energy, and food (WEF) resources are all essential requirements of human life (Liu et al. 2017; Liu et al. 2018a; Liu et al. 2019). These three resources are mutually related. According to the United Nations World Water Development Report 2014: Water and Energy, about 70% of water abstractions and 90% of water consumption are consumed for global food production, and 10% of total worldwide water abstractions are roughly occupied for generating energy and power. Food production and its supply chain account for about 30% of global energy usage, and water withdrawal and transportation and sewage treatment occupied about 8% of global energy usage. With economic growth in China, securing sufficient water, energy, and food to meet human demand is challenging. Water, energy, and food, which are the living resources for maintaining the stable development of society, have mutually reinforced and interdependent relationships. There is a severe water shortage in China, which has a severe impact on food security, economic development, and quality of life in China (Jiang 2009).

The Yangtze River Delta (YRD) is an economic powerhouse of modern China. The region encompasses Jiangsu Province, Zhejiang Province, Anhui Province, and Shanghai municipality (see Fig. 1). In 2018, the total GDP of the YRD region exceeded 21 trillion yuan, accounting for nearly one-fourth of China's total GDP. The total water use of the YRD region reached 115.5 billion m<sup>3</sup>, accounting for nearly one-fifth of China's total water use. In December 2019, the Chinese government unveiled a grand plan to further develop and integrate the region over the next 15 years. Further integrating the Yangtze River Delta is expected to help elevate the region's standing in the global economy and lead to more

cooperation and competition between China and the world. In this sense, planning and controlling water consumption is an essential social issue in the Yangtze River Delta (YRD). The three provinces and one municipality in the YRD region have a pivotal role in China. Shanghai plays a central role economically and financially in China. Jiangsu and Zhejiang provinces serve as China's frontiers of reforming for economic restructure and regional economic development engines. Anhui, the epicenter of China's rural reform but an agricultural province in tradition, is turning into the newly industrialized ground. The economic development aspects of the three provinces and one municipality in the YRD region are heterogeneous, and the water use patterns are also different.

Therefore, it is essential to uncover the factors that influence water consumption change in the YRD region from the point of water-energy-food nexus view. Consequently, exploring the factors of the change of water consumption in the YRD region would provide valuable theoretical insights for Chinese authorities to devise differentiated resource policies for the regions facing to achieve the Sustainable Development Goals (SDGs).

Extensive studies are decomposing the influencing factors of water use. The decomposition methods of factors affecting the change of water use can be divided into two types: structure decomposition analysis (SDA) (Cazcarro et al. 2013; Guan et al. 2014; Wang et al. 2014; Shang et al. 2017a; Liu et al. 2018b; Llop 2019; Sun et al. 2019) and index decomposition analysis (IDA) (Zhang and Zhang 2014; Shang et al. 2016; Shang et al. 2017b; Zhang et al. 2018; Long et al. 2019; Shi et al. 2019; Yao et al. 2019; Zhang et al. 2020a). The structural decomposition analysis method heavily relies on the input-output tables issued by relevant departments. The index decomposition analysis, especially the logarithmic

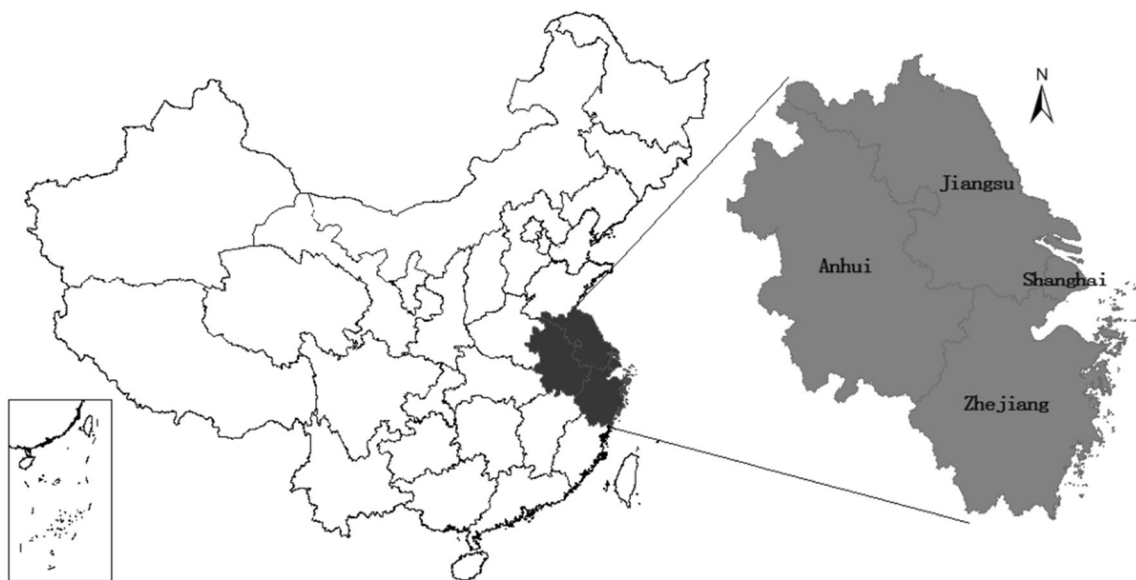


Fig. 1 The location of the YRD region in China

mean Divisia index (LMDI) decomposition method, has the advantage in terms of computation (Hoekstra and van den Bergh 2003). However, few studies illustrate how the water-energy nexus or water-energy-food nexus drive water consumption. Li et al. (2019) identified the driving factors of water-energy nexus in Beijing based on the LMDI method. However, they still factored using the changes of water use and energy use and ignored the linkage between water and energy. Duan and Chen (2020) applied structural decomposition analysis to extract six energy-related factors of the water-energy nexus in China from the water consumers' view.

The above studies found that the current factors affecting regional water use changes mainly include the regional economic development level (i.e., GDP) and the regional water intensity (i.e., water consumed per unit of GDP). Existing studies on factor analysis of water use have analyzed the impact on water use changes from direct factors such as economic development perspectives (Shang et al. 2016; Yang and Chen 2019; Zhang et al. 2020b; Li et al. 2021) while ignoring the effects of other indirect factors on water use changes. While the index decomposition analysis, especially the LMDI method, is adopted in various areas, some weaknesses of these methods are gradually uncovered. Vaninsky (2014) pointed out that the existing index decomposition analysis based on the Kaya identity decomposes the target variable all first into a form of multiplication of multiple factors. This approach makes each factor formally dependent on each other, and the decomposition result also depends on the selection of influencing factors. Because of the dependency, this decomposition method based on Kaya identity may lead to a conflicting decomposition conclusion. Meanwhile, the existing research found that the current index decomposition analysis can only test at most one scale factor (e.g., economic development scale) and cannot simultaneously analyze the contribution of other scale factors (e.g., population size) to changes in water use. It is difficult to fully consider the impact of changes in implicit relative variables (e.g., per capita water use) on changes in water use during the decomposition process. To solve the shortcomings mentioned earlier, Vaninsky (2014) proposed a generalized index decomposition analysis framework, namely the generalized Divisia index method (GDIM). The method enables a multidimensional analysis of the reasonable contribution of different driving factors that influence the target variable's change. Recently, GDIM has been applied to uncover the driving factors of the change of many targets, e.g., CO<sub>2</sub> emissions (Shao et al. 2016; Li et al. 2020; Zhang et al. 2020c), thermal electricity generation (Zhu et al. 2018; Yan et al. 2019a; Yan et al. 2019b), GHG emission in agriculture (Yan et al. 2017), sulfur dioxide emissions (Yang and Shan 2019), energy consumption (Zhang et al. 2020d) and electricity consumption (Fang et al. 2020).

To the best of our knowledge, no study employs the GDIM to uncover the driving factors of water consumption. In

summary, it can find that at present, the traditional analysis perspective is still used to uncover the factors of the change of water use, and the relationship among water, energy, and food is ignored. Thus, it is worthwhile to analyze the key factors that affect water use changes from the perspective of the water-energy-food nexus.

In this point of view, this study selects three provinces and one municipality in the YRD region as the research object. It applies the GDIM to uncover the factors that influence the change of water use in the three provinces and one municipality in the YRD region. We investigate the difference in the contribution of each driving factor in the process of water use and identify the key inducement to control the total amount of water use.

In this sense, the contributions of our research are the following: First, the driving factors of water consumption are first uncovered from the concept of water-energy-food (WEF) nexus, including scale effect, intensity effect, and nexus effect. Second, the generalized Divisia index method (GDIM) is first adopted to assess the contribution of WEF-related driving factors to the water consumption changes in the YRD region.

The structure of this paper is shown as follows. The research methods and data description are illustrated in the "Data and methodology" section. The "Results" section shows the result of the factor decomposition analysis. The "Discussion" section gives a detailed discussion about the result. Finally, the "Conclusion and policy implications" section concludes the research conclusions, and the policy implications are also proposed in this section.

## Data and methodology

### Data description

We adopt from 2000 to 2016 as our research span. This period is that China accelerates its urbanization after joining the World Trade Organization in 2001 and becomes the world's factory progressively (Wang et al. 2019). We gain our research data from the *China Statistical Yearbook (2001–2017)*, and *China Energy Statistical Yearbook (2001–2017)*. The relevant direct indicators are explained as follows:

- (1) The scale of regional water use is presented by the index of total regional water use (unit: 100 million cubic meters). The total amount of water use refers to the gross water use taken by various water users, including water loss. The data are obtained from the *China Statistical Yearbook*.
- (2) The regional economic development level is expressed by regional GDP (unit: 100 million yuan). The data are obtained from the *China Statistical Yearbook*. The gross

national product was deflated at the constant price in 2000 to ensure the data comparability.

- (3) The regional energy use scale is expressed by standard energy use (unit: 10,000 tons of standard coal). Standard energy use refers to the amount of energy use calculated by the energy standard measurement unit during the reporting period. The data are obtained from *China Energy Statistical Yearbook*.
- (4) The regional food production scale is expressed by food production (unit: 10,000 tons). Food production refers to the total amount of food produced by agricultural producers in a calendar year. It can be divided into summer grain, early-season rice, and autumn grain based on the harvest season, and it can be divided into cereals, potatoes, and beans based on the crop variety. The data are obtained from the *China Statistical Yearbook*.

### Decomposition of water use change via GDIM

The GDIM is a multidimensional factor decomposition model which is proposed by Vaninsky (2014). This method overcomes the shortcomings of the traditional index decomposition model, which has been popularized in the decomposition of the factors influencing the change of some targets in various regions and industries. This section will build a decomposition model to uncover the key factors influencing the change of water use based on the basic principles of the GDIM.

The current research shows that the factors affecting regional water use changes mainly include the regional economic development level and the regional water intensity. Prior studies on factor analysis of water use have analyzed the impact on water use changes from direct factors such as economic development perspectives while ignoring other indirect factors on water use changes. Our study will focus on the analysis of the impact of energy- and food-related factors on changes in water use based on the perspective of the water-energy-food nexus.

**Regional energy use** Due to the intricate relationship among water, energy, and food production, an increase in regional energy consumption will inevitably lead to an increase in energy production. In the process of energy extraction, production, transportation, and use, especially in traditional thermal power generation, a large amount of water is used for cooling. According to the World Water Development Report (WWDR) 2014, energy generation currently accounts for 15% of the world’s water consumption, and the increase in energy demand will cause the proportion to rise to 20% by 2035. Therefore, changes in regional energy use will inevitably lead to changes in regional water use.

**Regional food production** Water is one of the essential elements in the food production process. Agriculture is a domain of a tremendous amount of water use. The “China Water Bulletin 2018” stated that China’s total agricultural water use in 2018 reached 369.31 billion m<sup>3</sup>, occupying 61.4% of the total water use. Therefore, the increase in food production will inevitably lead to a rise in water use.

**Regional water-energy nexus** The water-energy nexus reflects the coupling relationship between regional water and energy uses. When the water-energy nexus is lower, the water use accompanying unit energy use is also lower. Given energy use, the lower the water-energy nexus is, the lower the water use is. Therefore, the regional water-energy nexus is also one of the key driving factors affecting regional water use.

**Regional food-energy nexus** The food-energy nexus reflects the coupling relationship between regional food production and energy use. When the food-energy nexus is higher, the food production accompanying unit energy use is higher. Given energy use, the higher the food-energy nexus is, the higher the water use is. Therefore, the regional food-energy nexus is also one of the key driving factors affecting regional water use.

**Regional energy intensity** The change in energy intensity reflects the change in production value per unit of energy use, indicating that the change in energy use is efficient. The smaller the energy intensity is, the higher the efficiency of energy consumption is. The practice would lead to a reduction in energy use. Therefore, changes in regional energy intensity will inevitably lead to changes in regional water use.

**Regional food production water intensity** Food production water intensity reflects water use per unit of food production, indicating changes in the efficiency of water used in food production. The lower the food production water intensity is, the higher the efficiency of food production water is, and the lower the amount of water used for food production is.

According to the relationship between the factors affecting the changes in water use proposed above, we can construct the following expression:

$$Water = \frac{Water}{Energy} * Energy = \frac{Water}{Food} * Food = \frac{Water}{GDP} * GDP \tag{1}$$

$$\frac{Energy}{GDP} = \frac{Water}{GDP} / \frac{Water}{Energy} \tag{2}$$

$$\frac{Food}{Energy} = \frac{Water}{Energy} / \frac{Water}{Food} \tag{3}$$

Water, Energy, and Food and GDP indicate regional water use, energy use, food production, and economic development level, respectively. Water/GDP, Water/Food, and Energy/GDP denote regional water intensity, regional food production water intensity, and regional energy intensity, respectively. Food/Energy indicates regional food-energy nexus, and Water/Energy denotes regional water-energy nexus. To simplify the above formulas, we denote  $X_1$  through  $X_8$ .

$$W = \text{Water}, X_1 = \text{Energy}, X_2 = \frac{\text{Water}}{\text{Energy}}, X_3 = \text{Food}, X_4 = \frac{\text{Water}}{\text{Food}}$$

$$X_5 = \text{GDP}, X_6 = \frac{\text{Water}}{\text{GDP}}, X_7 = \frac{\text{Energy}}{\text{GDP}} = \frac{\text{Water}}{\text{GDP}} \cdot \frac{\text{Water}}{\text{Energy}}$$

$$X_8 = \frac{\text{Food}}{\text{Energy}} = \frac{\text{Water}}{\text{Energy}} \cdot \frac{\text{Water}}{\text{Food}}$$

For the factor  $X$ , the contribution of the change in water use  $W=f(X_1, \dots, X_8)$  is expressed by a function  $W$ , so we can express Eqs. (1)–(3) into Eqs. (4)–(6), respectively:

$$W = X_1X_2 = X_3X_4 = X_5X_6 \tag{4}$$

$$X_7 = X_1/X_5 \tag{5}$$

$$X_8 = X_3/X_1 \tag{6}$$

According to the basic principles of the GDIM, Eqs. (4)–(6) are now transformed into Eqs. (7)–(11):

$$W = X_1X_2 \tag{7}$$

$$X_1X_2 - X_3X_4 = 0 \tag{8}$$

$$X_1X_2 - X_5X_6 = 0 \tag{9}$$

$$X_1 - X_5X_7 = 0 \tag{10}$$

$$X_3 - X_1X_8 = 0 \tag{11}$$

From Eq. (7), we can get the gradient of the factor contribution function of the water use change:

$$\nabla W(X) = (X_2, X_1, 0, 0, 0, 0, 0, 0)^T \tag{12}$$

A Jacobi matrix composed of various influencing factors from Eqs. (8)–(11) is shown in the Eq. (13).

$$(\Phi_X)_{ij} = \frac{d\phi_j}{dX_i}$$

$$\Phi_X = \begin{pmatrix} X_2 & X_1 & -X_4 & -X_3 & 0 & 0 & 0 & 0 \\ X_2 & X_1 & 0 & 0 & -X_6 & -X_5 & 0 & 0 \\ 1 & 0 & 0 & 0 & -X_7 & 0 & -X_5 & 0 \\ -X_8 & 0 & 1 & 0 & 0 & 0 & 0 & -X_1 \end{pmatrix}^T \tag{13}$$

According to the GDIM, changes in water use can be decomposed into the sum of the contributions of various influencing factors, as shown in Eq. (14):

$$\Delta W[X|\Phi] = \int_L \nabla W^T (I - \Phi_X \Phi_X^+) dX \tag{14}$$

Here  $I$  represents the identity matrix,  $L$  represents the time span, and  $\Phi_X^+$  represents the generalized inverse matrix of  $\Phi_X$ . If the column vectors in the Jacobi matrix  $\Phi_X$  are linearly independent, then  $\Phi_X^+ = (\Phi_X^T \Phi_X)^{-1} \Phi_X^T$ .

Applying Eq. (14), we decompose the change in water use into the sum of eight factors, including three scale factors and five intensity/ratio factors. The methodology steps are shown in Fig. 2.

The three scale factors are regional energy use scale change  $\Delta X_1$ , regional food production scale change  $\Delta X_3$ , and regional economic scale change  $\Delta X_5$ . They reflect the impact of the change in the scale of energy use, in the scale of food production, and in the economic scale on water use, which can be called regional energy scale effect, regional food scale effect, and regional economy scale effect, respectively. There are the other five relative quantity factors.  $\Delta X_2$  reflects the impact of the changes in water-energy nexus on water use changes, which can be called the regional water-energy nexus effect.  $\Delta X_4$  reflects the impact of the change in the intensity of water use in food production on changes in water use, which can be called regional water technology for food production effect.  $\Delta X_6$  reflects the impact of the change in water intensity on change in water use, indicating the impact of water technology progress on change in water use, and it can be called the regional water technology effect.  $\Delta X_7$  reflects the impact of the change in energy intensity on changes in water use, indicating the impact of energy technology progress on changes in water use, and it can be called the regional energy technology effect.  $\Delta X_8$  reflects the impact of the change in food-energy nexus on changes in water use, which can be called the regional food-energy nexus effect. In summary, we divide the effects of influencing water use into scale effect, technology effect, and nexus effect.

## Results

### Statistical analysis of factors influencing water use change

To accurately understand the historical tendency of the factors influencing the change of water use in the three provinces and one municipality in the YRD region, the water use changes from 2000 to 2016 and the change rate of driving factors are provided in Table 1.

Figure 3 shows that the three provinces and one municipality in the YRD region have different patterns of water-energy-food changes. Among the areas, the water use changes in Jiangsu and Anhui provinces are increasing. Anhui Province’s inflection point for changes in water use was in 2009. Before 2009, water use in Anhui grew rapidly, but after 2009, the growth rate of water use in Anhui slowed down,

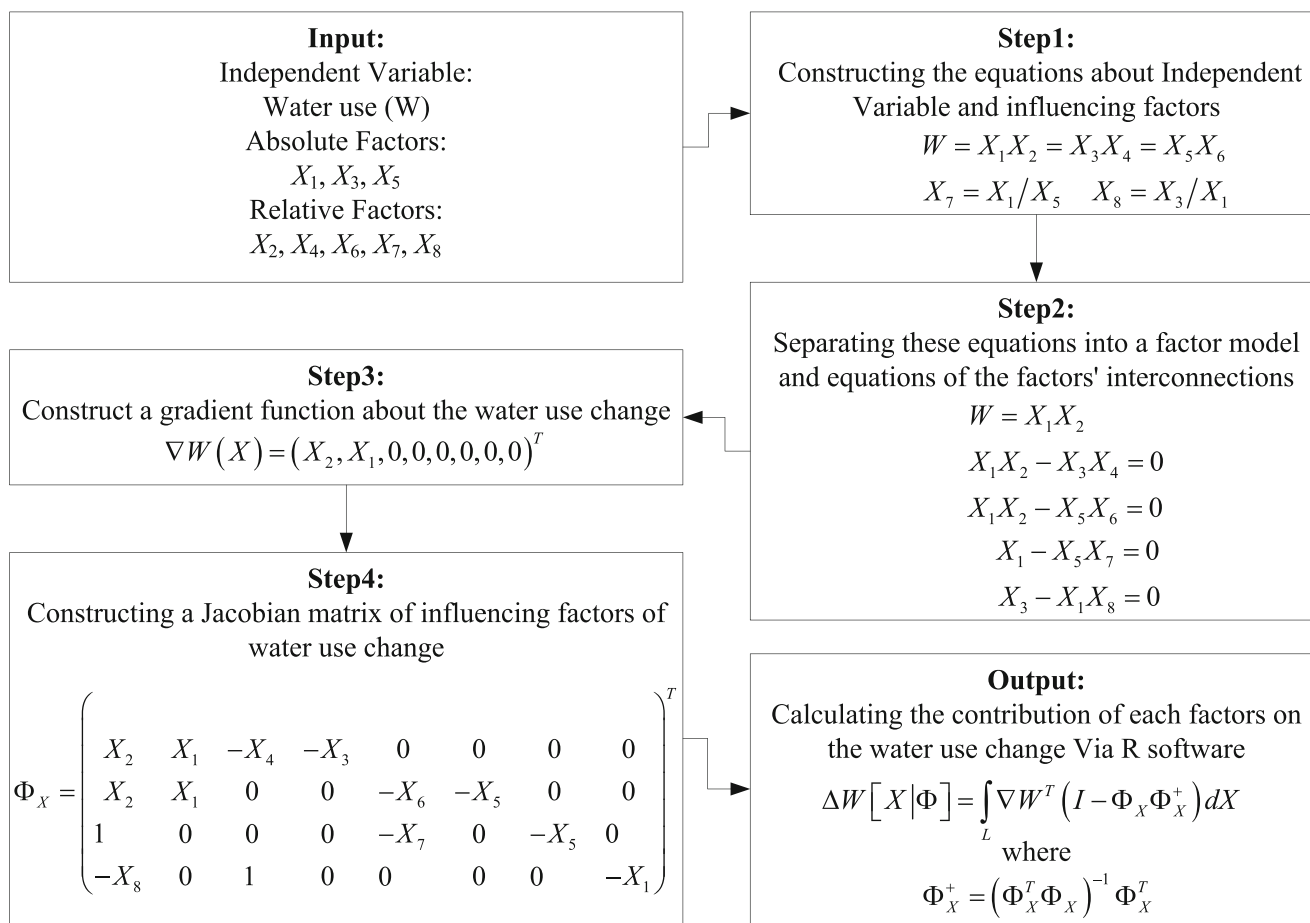


Fig. 2 The calculation steps of GDIM

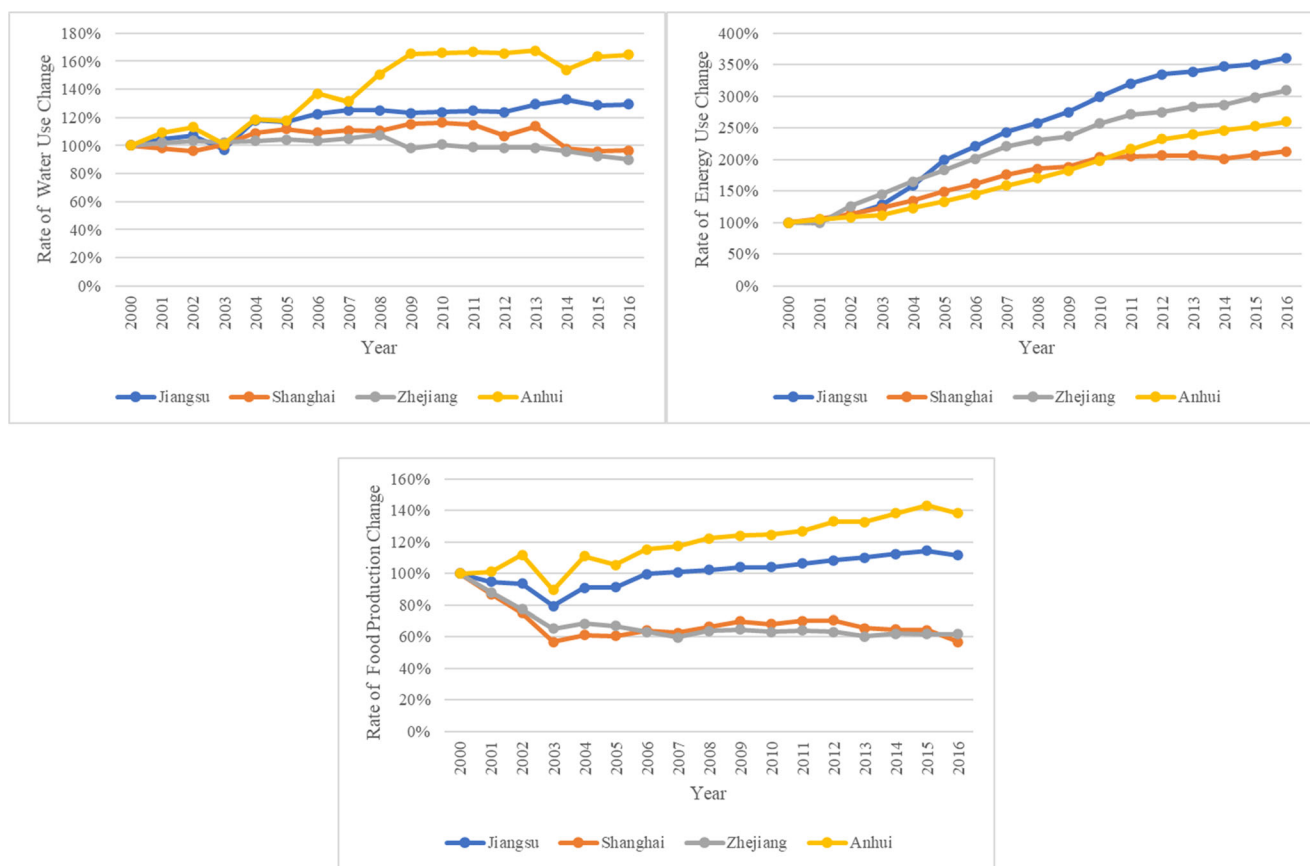
showing a slowly increasing trend. The annual average growth rate of water use in Anhui (3.16%) is the highest in the YRD region. It is significantly higher than the annual average growth rate of water use in Jiangsu Province (1.63%). Water use in Shanghai and Zhejiang shows a slowly decreasing trend. The decreasing trend of water use in Zhejiang Province is more prominent than that in Shanghai. The annual average reduction rate of water use in Shanghai is 0.21%, and the average annual reduction rate of water use in Zhejiang is 0.65%.

From the change of the five ratio factors that influence the change of water use in the YRD region (Fig. 4), we can observe that the regional food production water intensity usually

tends to increase from 2000 to 2016. The increase in the annual average of Shanghai’s regional food production water intensity is the fastest, with a growth rate of 3.36%, followed closely by Zhejiang, with an average annual growth rate of 2.38%. Due to the high level of early agricultural technology, including agricultural water-saving technology, the average annual growth rate of the regional food production water intensity in Jiangsu (0.94%) is relatively slow. Due to the different economic structures and the late development of agriculture, coupled with Shanghai’s advantageous geographical location and convenient transportation, the agricultural development of Shanghai is relatively lagged. Hence, Shanghai reports the fastest growth rate. Due to its low level of

Table 1 The change rate of water use and driving factors in the YRD region from 2000 to 2016

	Water	Energy	Water/energy	Food	Water/food	GDP	Water/GDP	Energy/GDP	Food/energy
Jiangsu	1.63%	8.35%	-6.20%	0.69%	0.94%	11.73%	-9.04%	-3.03%	-7.07%
Shanghai	-0.21%	4.84%	-4.81%	-3.45%	3.36%	9.91%	-9.21%	-4.61%	-7.91%
Zhejiang	-0.65%	7.31%	-7.42%	-2.97%	2.38%	10.77%	-10.31%	-3.13%	-9.57%
Anhui	3.16%	6.16%	-2.82%	2.04%	1.09%	11.40%	-7.40%	-4.70%	-3.88%



**Fig. 3** Trends of the change rate of water-energy-food (based on the quantity in 2000)

agricultural mechanization and insufficient cultivated land, Zhejiang's low level of agricultural development has become an essential reason for its increasing water intensity every year. Therefore, we can see that speeding up the development of water-saving technology and improving the level of agricultural technology are essential ways to reduce water use.

Observing the relative indexes of regional water-energy nexus, regional water intensity, and regional food-energy nexus that affect water use, we can find that all the three provinces and one municipality show a downward trend. Based on this aspect, we can observe that the water intensity in the YRD region shows a downward trend. The water use efficiency is continuously improving, and proper development and progress have been made in building a water-saving society. Among the areas, Zhejiang's annual average decline in water intensity, which reaches 10.31%, is the fastest, indicating that the annual decreasing rate of water use per unit of GDP ranks first among the three provinces and one municipality. The trend seems to be caused mainly due to the optimizing and upgrading of Zhejiang's economic structure and the steady development of industry and services in recent years. At the same time, Zhejiang's measures to promote balanced urban and rural development and accelerate new urbanization have resulted in a significant decline in regional water use in Zhejiang. Compared with the other three regions, the annual

average decreasing rate of water intensity in Anhui (7.40%) is slower. The result shows that compared with the others, Anhui has a considerable disadvantage in water-saving policies and technologies. Secondly, it indicates the deficiency of Anhui's industrial structure, so speeding up economic structural transformation is an urgent task for Anhui. In terms of regional food-energy nexus, Zhejiang also ranks first with an annual average decline rate of 9.57%, while Anhui ranked at the end with a decline rate of 3.88%. For the given energy use, Anhui's water use per unit of food production is significantly greater than the other three provinces and cities, which shows the difference in economic system and structure between Anhui and Zhejiang. Anhui's agriculture occupies a large proportion of the economic system, but Zhejiang does not. Therefore, accelerating Anhui's economic structural transformation and researching water-saving agriculture are important ways to reduce water use in Anhui and build a water-saving society.

Moreover, in terms of regional water-energy nexus, Zhejiang still ranks first with an annual average decline rate of 7.42%. According to the result, we can observe that Zhejiang is more efficient in the development and utilization of energy and is more outstanding in the development of water-saving technologies. In contrast, due to economic structural problems and underdeveloped local water-saving

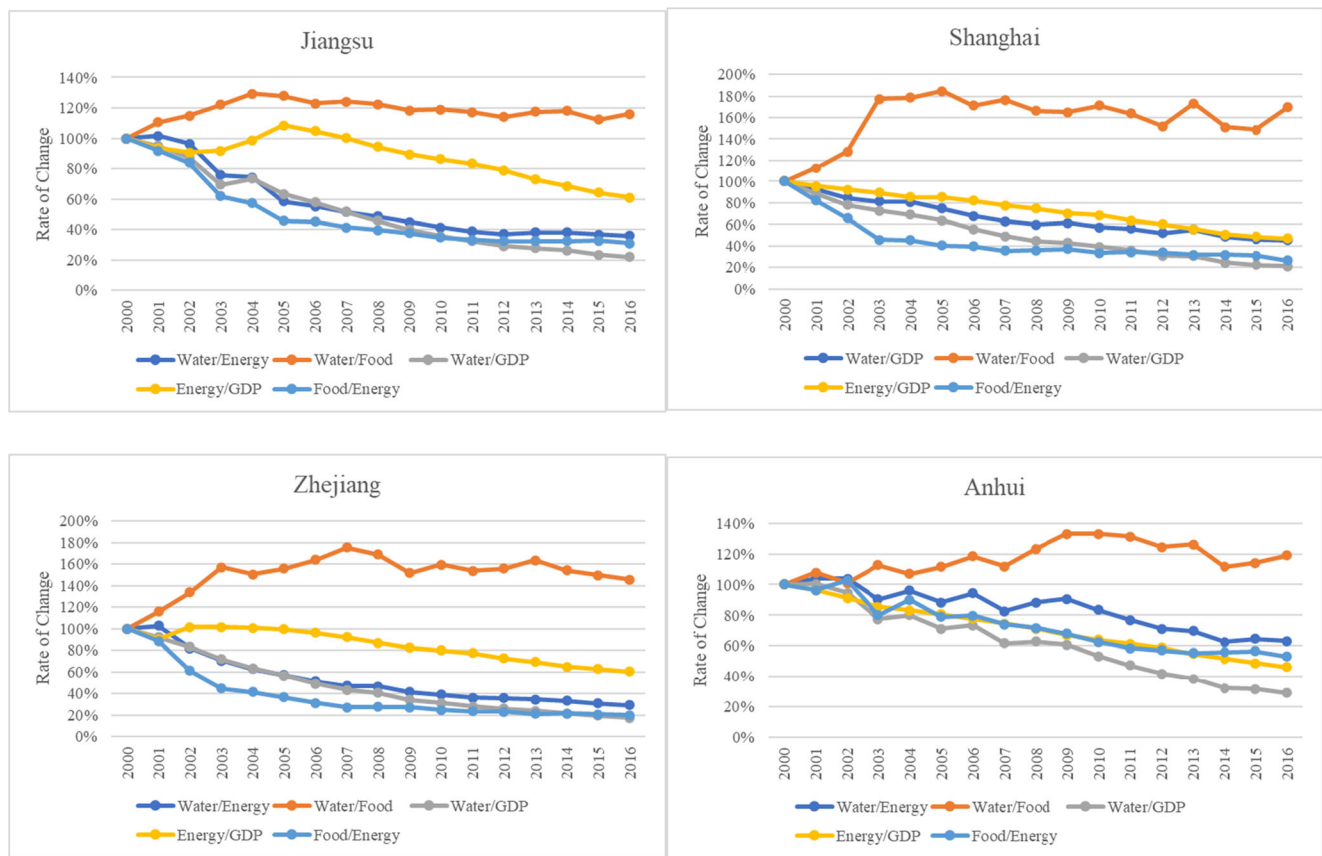


Fig. 4 Trends of ratio factors of water use changes in YRD region (based on water use in 2000)

technologies, Anhui’s annual decline rate is only 2.82%. The result shows that to reduce water use, not only should the local governments enact policies to promote it, but they must steadily improve the economic structure and technological level to match it.

In terms of regional energy intensity, we can witness that the annual average decreasing rate of energy intensity (4.70%) in Anhui ranks first in the YRD region, while Jiangsu’s annual average decline rate of energy intensity (3.03%) is the smallest. Anhui seems still to rely heavily on water consumption for economic development, while Jiangsu’s economic growth still depends on energy to a large extent.

**Contributions of factors influencing water use change**

To identify the key factors that affect water use in the YRD region, we adopt the software R to compute the results with Eq. (14). The contribution values of eight factors, including the economic development, regional food production, and regional energy use to the amount of water use in the YRD region, are shown in Tables 2, 3, 4, 5, 6, 7, 8, and 9. The results are shown in Tables 2–9. Based on the results, a stacking chart of the percentage contribution of various factors of the change in water use in the three provinces and one municipality in the YRD region is drawn in Fig. 5.

Figure 5 shows that the factors which affect the direction of the change of water use in the three provinces and one municipality in the YRD region are the same. Among the areas, the level of regional economic development, energy use, food production, and regional food production water intensity promotes regional water use. The regional water-energy nexus and the regional water intensity restrain regional water use from increasing. The following takes Jiangsu as an example to investigate the driving factors of the change in water use. The analysis steps of other provinces are similar and will not be introduced here.

For Jiangsu Province, Tables 2 and 3 show that the contribution rates and contribution values of the economic development level to changes of water use during 2000–2016 are always positive, indicating that the increase in Jiangsu Province’s economic development will lead to a rise in the amount of water use. For food production, it can be found that an increase in food production will promote a growth in water use. Water intensity reflects the degree of economic development dependence to water use. From 2000 to 2016, except for 2004, the contribution rate and contribution values of water intensity changes to water use changes were negative, which reflect that the decrease of water intensity in Jiangsu Province inhibit the amount of water use increasing. Various water-saving technologies have been developed and applied into



**Table 2** Contributions of factors of the change rate of water use in Jiangsu during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	0.0106	0.0050	-0.0181	0.0349	0.0270	-0.0108	-0.0005	-0.0014
2002	0.0268	-0.0177	-0.0040	0.0132	0.0445	-0.0343	-0.0006	-0.0016
2003	0.0469	-0.0721	-0.0486	0.0214	0.0407	-0.0704	0.0001	-0.0125
2004	0.0795	-0.0064	0.0490	0.0215	0.0500	0.0204	-0.0008	-0.0008
2005	0.0798	-0.0745	0.0006	-0.0046	0.0441	-0.0490	-0.0008	-0.0068
2006	0.0353	-0.0184	0.0300	-0.0132	0.0478	-0.0300	-0.0002	-0.0001
2007	0.0324	-0.0246	0.0038	0.0035	0.0474	-0.0387	-0.0005	-0.0013
2008	0.0198	-0.0199	0.0045	-0.0047	0.0404	-0.0390	-0.0007	-0.0005
2009	0.0213	-0.0267	0.0056	-0.0113	0.0391	-0.0432	-0.0006	-0.0005
2010	0.0281	-0.0259	0.0005	0.0013	0.0404	-0.0375	-0.0003	-0.0012
2011	0.0228	-0.0203	0.0073	-0.0051	0.0353	-0.0320	-0.0003	-0.0004
2012	0.0148	-0.0173	0.0064	-0.0089	0.0324	-0.0337	-0.0005	-0.0002
2013	0.0041	0.0108	0.0050	0.0097	0.0318	-0.0161	-0.0011	0.0000
2014	0.0074	0.0009	0.0066	0.0018	0.0286	-0.0194	-0.0006	0.0000
2015	0.0040	-0.0137	0.0066	-0.0161	0.0272	-0.0356	-0.0008	0.0000
2016	0.0089	-0.0072	-0.0089	0.0109	0.0255	-0.0230	-0.0005	-0.0006

production, which has effectively reduced the high water use in economic development. Therefore, the decrease in water intensity has a significant inhibitory effect on the change of water use in Jiangsu. The aspect shows that water-saving technology advancement seems to be the most important decisive factor to relieve water shortage. In terms of energy use, the change in energy use in Jiangsu accelerates the change in water use, indicating that with the increase in energy use in Jiangsu. The water use in the energy production process is

increasing due to the water-energy nexus. The increase in energy use would lead to an increase in water use in Jiangsu. The contribution of changes in water-energy nexus to the change in water use in Jiangsu generally shows an inhibitory effect. From Table 2, we can observe that only in the two periods of 2000–2001 and 2012–2014, the contribution rate of the water-energy nexus change to the water use change in Jiangsu is positive. The decrease in water-energy nexus indicates a continuous decrease in water use per unit energy use. If

**Table 3** Contributions of factors of the change of water use in Jiangsu during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	4.7027	2.2468	-8.0690	15.5495	12.0318	-4.8206	-0.2436	-0.6167
2002	12.5053	-8.2341	-1.8435	6.1776	20.7665	-15.9882	-0.2947	-0.7296
2003	22.4318	-34.5030	-23.2763	10.2604	19.4717	-33.7182	0.0535	-5.9999
2004	34.4524	-2.7538	21.2332	9.3362	21.6823	8.8508	-0.3449	-0.3342
2005	41.9572	-39.1639	0.3289	-2.4238	23.2006	-25.7549	-0.4048	-3.5997
2006	18.3403	-9.5521	15.6043	-6.8372	24.8657	-15.5923	-0.1250	-0.0337
2007	17.7074	-13.4911	2.0999	1.8938	25.8769	-21.1533	-0.2567	-0.7254
2008	11.0525	-11.1155	2.5207	-2.6065	22.5764	-21.7807	-0.4030	-0.2639
2009	11.8689	-14.9242	3.1090	-6.2927	21.8535	-24.1169	-0.3176	-0.2701
2010	15.4565	-14.2176	0.2792	0.7216	22.1833	-20.5892	-0.1885	-0.6840
2011	12.5983	-11.2274	4.0550	-2.8219	19.4704	-17.6921	-0.1638	-0.2381
2012	8.2199	-9.6182	3.5511	-4.9472	17.9984	-18.7603	-0.2816	-0.0924
2013	2.2684	5.9422	2.7867	5.3786	17.5660	-8.9079	-0.5860	0.0041
2014	4.2917	0.5366	3.7941	1.0645	16.4742	-11.1808	-0.3726	-0.0048
2015	2.3729	-8.1278	3.8922	-9.5269	16.0905	-21.0378	-0.4603	0.0072
2016	5.1395	-4.1625	-5.1269	6.2849	14.6288	-13.2251	-0.2920	-0.3467

**Table 4** Contributions of factors of the change rate of water use in Shanghai during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	0.0191	-0.0246	-0.0437	0.0411	0.0336	-0.0386	-0.0006	-0.0061
2002	0.0244	-0.0289	-0.0466	0.0453	0.0360	-0.0405	-0.0005	-0.0076
2003	0.0303	-0.0130	-0.0861	0.1157	0.0409	-0.0240	-0.0006	-0.0179
2004	0.0296	-0.0019	0.0254	0.0025	0.0466	-0.0178	-0.0004	-0.0001
2005	0.0362	-0.0260	-0.0029	0.0122	0.0357	-0.0264	0.0000	-0.0021
2006	0.0250	-0.0327	0.0180	-0.0258	0.0377	-0.0442	-0.0003	-0.0001
2007	0.0291	-0.0240	-0.0120	0.0176	0.0483	-0.0418	-0.0008	-0.0027
2008	0.0178	-0.0193	0.0191	-0.0204	0.0311	-0.0316	-0.0002	0.0000
2009	0.0052	0.0100	0.0174	-0.0021	0.0272	-0.0116	-0.0006	-0.0001
2010	0.0263	-0.0226	-0.0089	0.0124	0.0331	-0.0295	-0.0002	-0.0019
2011	0.0020	-0.0069	0.0098	-0.0145	0.0265	-0.0302	-0.0008	0.0000
2012	0.0026	-0.0257	0.0012	-0.0241	0.0236	-0.0452	-0.0007	0.0000
2013	-0.0005	0.0213	-0.0234	0.0456	0.0261	-0.0046	-0.0012	-0.0010
2014	-0.0071	-0.0404	-0.0044	-0.0426	0.0213	-0.0659	-0.0013	0.0000
2015	0.0089	-0.0156	-0.0013	-0.0054	0.0223	-0.0283	-0.0003	-0.0002
2016	0.0096	-0.0061	-0.0394	0.0458	0.0228	-0.0188	-0.0005	-0.0038

energy use is used to represent the cost of water use, then the decrease in water-energy nexus can indicate that the cost of water continues to increase. Therefore, the decline in the water-energy nexus can increase the cost of water use, thereby inhibiting the increase of water use in Jiangsu. As for the food-energy nexus, the food-energy nexus in Jiangsu continues to decrease, indicating that the food production per unit of energy use is continuously decreasing. It shows that energy use in the current food production process in Jiangsu Province is

increasing. In Table 2, the contribution rate of food-energy nexus to water use change is negative, which would inhibit the increase of water use in Jiangsu. As for the food production water intensity, an increasing trend from 2000 to 2016 in Jiangsu Province is reported, which would promote the increase of water use. Figure 5 shows that the increase in water use in Jiangsu Province from 2000 to 2001 was mainly caused by the increase in food production water intensity, which was the primary driving factor.

**Table 5** Contributions of factors of the change of water use in Shanghai during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	2.0693	-2.6669	-4.7343	4.4568	3.6435	-4.1845	-0.0690	-0.6649
2002	2.5896	-3.0713	-4.9554	4.8111	3.8278	-4.3051	-0.0534	-0.8034
2003	3.1582	-1.3596	-8.9827	12.0691	4.2598	-2.5053	-0.0577	-1.8619
2004	3.2310	-0.2018	2.7709	0.2682	5.0774	-1.9453	-0.0446	-0.0056
2005	4.2720	-3.0734	-0.3421	1.4404	4.2194	-3.1242	-0.0002	-0.2519
2006	3.0355	-3.9602	2.1799	-3.1274	4.5681	-5.3597	-0.0327	-0.0136
2007	3.4552	-2.8403	-1.4245	2.0814	5.7230	-4.9590	-0.0937	-0.3221
2008	2.1448	-2.3213	2.3004	-2.4479	3.7335	-3.7998	-0.0300	0.0004
2009	0.6233	1.1983	2.0794	-0.2564	3.2593	-1.3870	-0.0709	-0.0156
2010	3.2918	-2.8345	-1.1174	1.5533	4.1474	-3.6931	-0.0203	-0.2374
2011	0.2536	-0.8715	1.2377	-1.8297	3.3448	-3.8191	-0.1026	-0.0032
2012	0.3212	-3.2036	0.1438	-3.0051	2.9393	-5.6273	-0.0866	-0.0020
2013	-0.0568	2.4724	-2.7118	5.2861	3.0281	-0.5348	-0.1370	-0.1162
2014	-0.8719	-4.9781	-0.5407	-5.2523	2.6273	-8.1202	-0.1573	0.0025
2015	0.9383	-1.6495	-0.1419	-0.5702	2.3577	-2.9972	-0.0343	-0.0231
2016	0.9993	-0.6340	-4.0854	4.7533	2.3646	-1.9510	-0.0499	-0.3971

**Table 6** Contributions of factors of the change rate of water use in Zhejiang during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	-0.0016	0.0085	-0.0411	0.0513	0.0351	-0.0261	-0.0023	-0.0029
2002	0.0858	-0.0690	-0.0409	0.0513	0.0391	-0.0359	-0.0011	-0.0165
2003	0.0488	-0.0473	-0.0534	0.0575	0.0460	-0.0478	0.0000	-0.0136
2004	0.0434	-0.0394	0.0168	-0.0145	0.0455	-0.0420	0.0000	-0.0010
2005	0.0361	-0.0313	-0.0080	0.0121	0.0407	-0.0364	-0.0001	-0.0028
2006	0.0319	-0.0332	-0.0183	0.0170	0.0429	-0.0440	-0.0004	-0.0038
2007	0.0322	-0.0268	-0.0177	0.0236	0.0467	-0.0407	-0.0006	-0.0038
2008	0.0131	-0.0044	0.0211	-0.0121	0.0329	-0.0233	-0.0005	0.0000
2009	0.0095	-0.0389	0.0055	-0.0349	0.0275	-0.0552	-0.0005	-0.0001
2010	0.0274	-0.0179	-0.0078	0.0174	0.0384	-0.0286	-0.0003	-0.0019
2011	0.0183	-0.0256	0.0046	-0.0122	0.0287	-0.0353	-0.0002	-0.0003
2012	0.0046	-0.0054	-0.0050	0.0044	0.0260	-0.0258	-0.0007	-0.0002
2013	0.0103	-0.0098	-0.0156	0.0166	0.0267	-0.0255	-0.0005	-0.0012
2014	0.0032	-0.0127	0.0104	-0.0195	0.0244	-0.0327	-0.0006	0.0000
2015	0.0134	-0.0250	-0.0022	-0.0096	0.0255	-0.0364	-0.0003	-0.0005
2016	0.0110	-0.0200	0.0000	-0.0091	0.0243	-0.0326	-0.0003	-0.0002

## Discussion

### Average contributions of factors influencing water use change

According to the previous section, the contribution rate of factors influencing water use in the YRD in each year is different, making it difficult to carry out a comparative analysis of different regions. Therefore, in this section, we provide the

annual average of the decomposition of water use in the YRD region.

First, from Table 2, 3, 4, 5, 6, 7, 8 and 9, we calculate the cumulative contribution of each influencing factor in the four regions of the YRD region from 2000 to 2016. Using the cumulative contribution of each influencing factor and water use in the base period of 2000, we derive the cumulative contribution rate. Finally, we obtain the annual average contribution rate of each factor affecting water use (see Table 10).

**Table 7** Contributions of factors of the change of water use in Zhejiang during 2000–2016

Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
2001	-0.3162	1.7176	-8.2580	10.3116	7.0557	-5.2516	-0.4654	-0.5836
2002	17.6186	-14.1736	-8.3910	10.5338	8.0393	-7.3725	-0.2225	-3.3921
2003	10.1501	-9.8285	-11.1141	11.9498	9.5733	-9.9378	0.0059	-2.8187
2004	8.9417	-8.1214	3.4634	-2.9916	9.3691	-8.6540	-0.0067	-0.2106
2005	7.5085	-6.5041	-1.6571	2.5067	8.4512	-7.5552	-0.0237	-0.5865
2006	6.6948	-6.9619	-3.8441	3.5736	9.0005	-9.2297	-0.0809	-0.8023
2007	6.7045	-5.5712	-3.6844	4.9179	9.7263	-8.4689	-0.1167	-0.7875
2008	2.7625	-0.9388	4.4597	-2.5610	6.9371	-4.9059	-0.1052	-0.0084
2009	2.0553	-8.4322	1.1942	-7.5561	5.9556	-11.9491	-0.1157	-0.0123
2010	5.4217	-3.5455	-1.5436	3.4429	7.5991	-5.6522	-0.0624	-0.3801
2011	3.7207	-5.2024	0.9326	-2.4786	5.8173	-7.1757	-0.0437	-0.0704
2012	0.9115	-1.0641	-0.9952	0.8767	5.1717	-5.1274	-0.1489	-0.0443
2013	2.0420	-1.9498	-3.0826	3.2970	5.2895	-5.0429	-0.1086	-0.2346
2014	0.6375	-2.5105	2.0561	-3.8671	4.8394	-6.4885	-0.1222	-0.0048
2015	2.5831	-4.8236	-0.4282	-1.8537	4.9109	-7.0137	-0.0569	-0.0883
2016	2.0421	-3.7160	-0.0026	-1.6858	4.5310	-6.0621	-0.0609	-0.0462

**Table 8** Contribution of factors of the change rate of water use in Anhui during 2000–2016

Year	Energy	Water/energy	Food	Water/food	GDP	Water/GDP	Energy/GDP	Food/energy
2001	0.0167	0.0141	0.0039	0.0271	0.0301	0.0010	-0.0003	-0.0003
2002	0.0126	-0.0011	0.0346	-0.0220	0.0314	-0.0191	-0.0003	-0.0006
2003	0.0085	-0.0426	-0.0658	0.0365	0.0291	-0.0617	-0.0012	-0.0094
2004	0.0343	0.0235	0.0794	-0.0186	0.0452	0.0130	0.0000	-0.0026
2005	0.0264	-0.0281	-0.0166	0.0150	0.0369	-0.0383	-0.0003	-0.0029
2006	0.0296	0.0246	0.0328	0.0215	0.0440	0.0105	-0.0003	0.0000
2007	0.0297	-0.0428	0.0053	-0.0195	0.0438	-0.0557	-0.0004	-0.0010
2008	0.0260	0.0233	0.0146	0.0350	0.0433	0.0065	-0.0004	-0.0002
2009	0.0231	0.0088	0.0053	0.0270	0.0430	-0.0103	-0.0006	-0.0006
2010	0.0293	-0.0275	0.0011	0.0003	0.0461	-0.0431	-0.0006	-0.0013
2011	0.0286	-0.0266	0.0058	-0.0043	0.0428	-0.0399	-0.0004	-0.0009
2012	0.0238	-0.0262	0.0158	-0.0183	0.0383	-0.0396	-0.0003	-0.0001
2013	0.0098	-0.0060	-0.0010	0.0049	0.0337	-0.0286	-0.0009	-0.0003
2014	0.0084	-0.0360	0.0130	-0.0400	0.0285	-0.0541	-0.0006	0.0000
2015	0.0089	0.0114	0.0121	0.0083	0.0290	-0.0082	-0.0005	0.0000
2016	0.0097	-0.0074	-0.0114	0.0142	0.0284	-0.0251	-0.0006	-0.0008

Table 10 shows that the YRD regional economic development level and energy use promote regional water use, while water intensity and water-energy nexus hinder the increase in water use. Furthermore, other factors, such as the food production scale and energy intensity, have a smaller effect on water use change in the three provinces and one municipality in the YRD region. In addition, the annual contribution rate of each factor to water use change in the three provinces and one municipality is also different. Changes in food production

have a positive effect on water use in Jiangsu and Anhui and restraint in Shanghai and Zhejiang. The regional economic development level has the most significant driving effect on the increase of water use in Anhui, while it has the smallest effect on Shanghai. At present, Anhui may still be in an extensive economic growth mode driven mainly by factors or a slow economic transition, while Shanghai’s economic growth mode is gradually shifting to an innovation-driven economic growth mode. Regional food production water intensity has

**Table 9** Contribution of factors of the change of water use in Anhui during 2000–2016

Year	Energy	Water/energy	Food	Water/food	GDP	Water/GDP	Energy/GDP	Food/energy
2001	2.9474	2.4876	0.6906	4.7898	5.3100	0.1816	-0.0539	-0.0518
2002	2.4304	-0.2101	6.6728	-4.2449	6.0555	-3.6834	-0.0674	-0.1128
2003	1.7040	-8.5104	-13.1390	7.2997	5.8129	-12.3228	-0.2427	-1.8714
2004	6.1313	4.2041	14.1809	-3.3128	8.0712	2.3225	0.0021	-0.4586
2005	5.5373	-5.8936	-3.4774	3.1394	7.7360	-8.0397	-0.0697	-0.6022
2006	6.1623	5.1109	6.8164	4.4661	9.1591	2.1783	-0.0522	0.0003
2007	7.1933	-10.3608	1.2879	-4.7046	10.5949	-13.4771	-0.1030	-0.2506
2008	6.0398	5.3991	3.3776	8.1114	10.0444	1.4997	-0.1039	-0.0567
2009	6.1609	2.3415	1.3998	7.1986	11.4541	-2.7303	-0.1714	-0.1520
2010	8.5601	-8.0333	0.3305	0.0861	13.4594	-12.5839	-0.1673	-0.3907
2011	8.3918	-7.8087	1.7063	-1.2595	12.5419	-11.6828	-0.1193	-0.2598
2012	7.0145	-7.7286	4.6435	-5.3984	11.2889	-11.6647	-0.1029	-0.0425
2013	2.8600	-1.7642	-0.2810	1.4304	9.8498	-8.3708	-0.2646	-0.0798
2014	2.4819	-10.6601	3.8556	-11.8463	8.4309	-16.0188	-0.1735	0.0007
2015	2.4346	3.1124	3.2839	2.2537	7.8979	-2.2256	-0.1476	0.0020
2016	2.8081	-2.1326	-3.2904	4.1014	8.1872	-7.2474	-0.1865	-0.2399



Fig. 5 Changes in the contribution of the influencing factors of the change of water use in YRD region year by year

the greatest driving effect on the increase of Shanghai’s water use and the least driving effect on Jiangsu. The results seem to be mainly due to the developed agricultural development level in Jiangsu. The energy use has the most apparent driving effect on the growth of Jiangsu’s water use, and the least promotion to Shanghai’s water use. The result shows that Jiangsu’s economic growth still relies more on energy use and Shanghai depends on energy to a lesser extent. So, accelerating economic transformation is a long-term solution for reducing water use.

Water intensity has the highest inhibitory effect on the growth of water use in Jiangsu, indicating that the water use per unit of production value in Jiangsu decreases the fastest and that water efficiency or the use of water-saving technology is relatively leading in the YRD region. Among the three

provinces and one municipality in the YRD, the regional energy intensity has the highest inhibitory effect on Jiangsu and Anhui. In contrast, the regional energy intensity has the least inhibitory effect on Zhejiang. The difference seems to be mainly due to the different economic development patterns. The water-energy nexus has the most considerable inhibitory effect on the growth of water use in Zhejiang Province and the least inhibitory effect on Anhui, indicating that Zhejiang leads the other three provinces in terms of energy extraction and utilization and has very high energy efficiency. The regional food-energy nexus has the most substantial restraint on Zhejiang’s water use, and the least restraint on Anhui, which shows that Anhui’s agriculture accounts for a large proportion of the economy but also has insufficiently developed agricultural technology.

Table 10 Annual average contribution rate of the change of water use in YRD during 2000–2016

Year	Energy	Water/energy	Food	Water/food	GDP	Water/GDP	Energy/GDP	Food/energy
Jiangsu	3.16%	−2.42%	0.35%	0.30%	4.44%	−3.72%	−0.07%	−0.20%
Shanghai	1.70%	−1.73%	−1.06%	1.17%	3.41%	−3.36%	−0.06%	−0.27%
Zhejiang	2.47%	−2.54%	−0.96%	0.88%	3.49%	−3.60%	−0.05%	−0.31%
Anhui	2.79%	−1.43%	0.99%	0.43%	5.16%	−3.67%	−0.07%	−0.16%

### Contributions of factors influencing water use change at different periods

China adopts the five-year plan (FYP) for national economic and social development; in order to facilitate the comparison between different periods, our study carries the last year of the previous FYP as the base period of the next FYP. Therefore, 2000–2016 can be divided into three periods, namely 2000–2005, 2005–2010, and 2010–2016. In this section, we will analyze the changes in water use in the YRD region. The contribution rate of each factor to the change of water use in the YRD region is calculated during the four stages from 2000 to 2005, 2005 to 2010, 2010 to 2016, and 2000 to 2016, respectively (see Table 11).

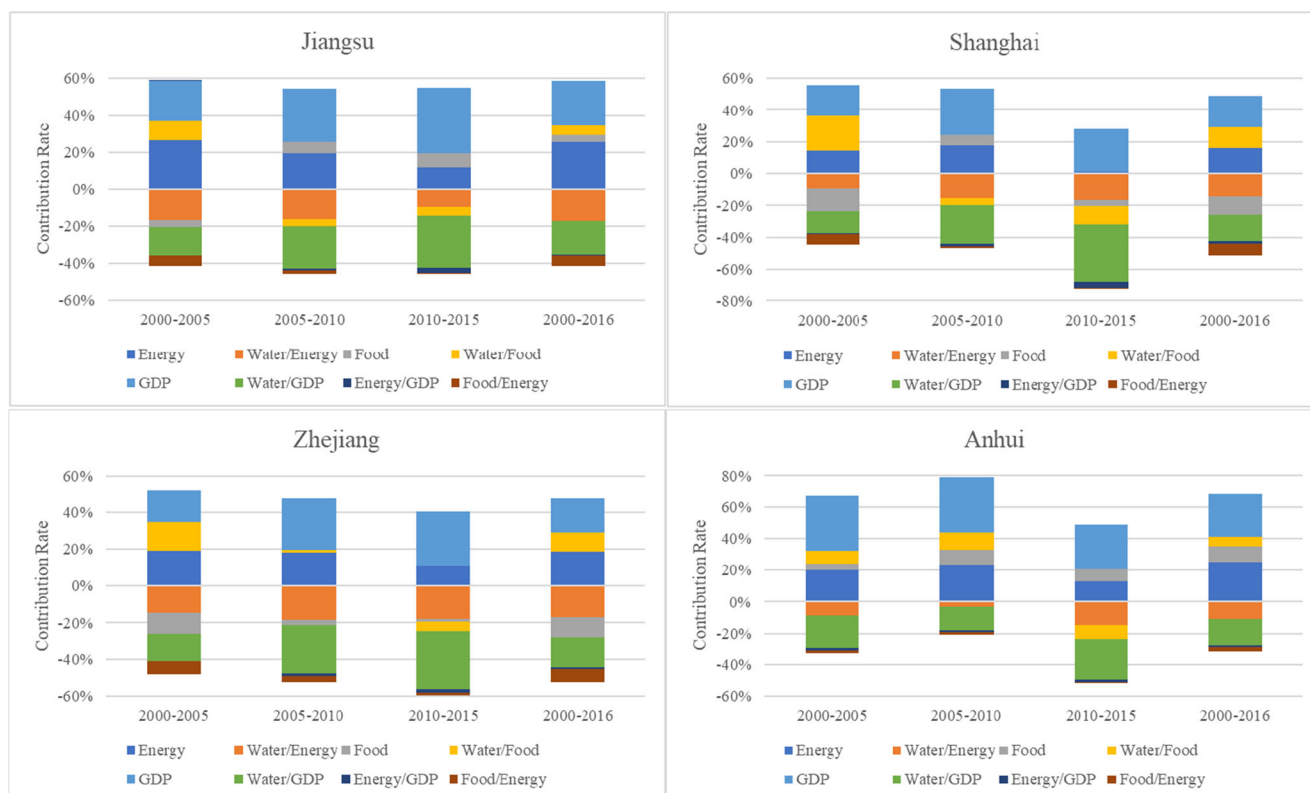
To compare the different influence factors on regional water use change to the importance of the contribution rate and analyze the changes in a different period, we provide an accumulation chart of percentage contribution rates of each factor to the change of water use Table 11 and Fig. 6. We can observe that during the 10th to the 13th FYP, the driving effect of economic scale change on water use in Jiangsu increased, while the driving effect of energy use scale change on water use in Jiangsu decreased. However, the inhibitory effect of water intensity change on water use change in Jiangsu is increasing. The water-energy nexus has continuously reduced the inhibitory effect on Jiangsu’s water use change. The driving effect of food production on Jiangsu’s water use change has continued to increase. The inhibitory effect of regional food-energy nexus on Jiangsu’s water use change has continued to decrease.

For Shanghai, the driving effect of the change of economic scale on the change of water use during the 11th to the 12th FYP has been increasing, while the driving effect of the change of economic scale on the change of water use in Shanghai decreased from the 12th to the 13th FYP. The change in energy use scale has a small driving effect on Shanghai’s water use change during the 13th FYP period. Generally speaking, the impact of energy use scale on water use change seems to disappear. The inhibitory effect of water intensity change on water use change in Shanghai increased first and then decreased, and the inhibitory effect of water-energy nexus on water use change in Shanghai also increased first and then decreased. During the 10th FYP period, the intensity of regional food production water use had a driving effect on Shanghai’s water use. From the 11th to the 12th FYP, the intensity of food production water use changed from promoting to restraining, and in the 14th FYP period, it turned into a drive for water use. From the 10th to the 12th FYP, regional food production first suppressed, then drove, and then suppressed water use in Shanghai.

For Zhejiang, the driving effect of changes in economic scale on the changes in water use in Zhejiang has been increasing, and the driving effects of changes in the scale of energy use on changes in water use in Zhejiang have been decreasing. However, the inhibitory effect of water intensity change on water use change in Zhejiang keeps increasing. The inhibitory effect of water-energy nexus on water use change in Zhejiang also keeps unchanged. The inhibitory effect of regional food production on water use keeps decreasing.

**Table 11** Contribution rates of factors of the change of water use in YRD at different stages from 2000 to 2016

Province	Year	Energy	Water/ energy	Food	Water/ food	GDP	Water/ GDP	Energy/ GDP	Food/ energy
Jiangsu	2000–2005	0.2593	-0.1645	-0.0335	0.1077	0.2068	-0.1525	0.0004	-0.0573
	2005–2010	0.1425	-0.1177	0.0460	-0.0282	0.2107	-0.1701	-0.0081	-0.0126
	2010–2015	0.0536	-0.0428	0.0327	-0.0204	0.1575	-0.1265	-0.0124	-0.0013
	2000–2016	0.4502	-0.3027	0.0607	0.0954	0.4195	-0.3152	-0.0140	-0.0981
Shanghai	2000–2005	0.1570	-0.1010	-0.1532	0.2369	0.2037	-0.1455	-0.0061	-0.0728
	2005–2010	0.1062	-0.0918	0.0396	-0.0286	0.1767	-0.1463	-0.0075	-0.0070
	2010–2015	0.0049	-0.0679	-0.0165	-0.0456	0.1116	-0.1479	-0.0151	-0.0016
	2000–2016	0.2865	-0.2581	-0.2075	0.2460	0.3559	-0.2955	-0.0334	-0.1269
Zhejiang	2000–2005	0.2220	-0.1714	-0.1308	0.1803	0.2022	-0.1779	-0.0001	-0.0809
	2005–2010	0.1145	-0.1183	-0.0180	0.0085	0.1790	-0.1674	-0.0083	-0.0227
	2010–2015	0.0484	-0.0771	-0.0076	-0.0219	0.1268	-0.1370	-0.0091	-0.0060
	2000–2016	0.3519	-0.3160	-0.2053	0.1927	0.3457	-0.3162	-0.0151	-0.1375
Anhui	2000–2005	0.1060	-0.0452	0.0186	0.0441	0.1822	-0.1101	-0.0080	-0.0102
	2005–2010	0.1620	-0.0229	0.0662	0.0771	0.2480	-0.1018	-0.0092	-0.0103
	2010–2015	0.0790	-0.0874	0.0461	-0.0549	0.1686	-0.1536	-0.0103	-0.0025
	2000–2016	0.4461	-0.1945	0.1788	0.1109	0.4792	-0.2885	-0.0330	-0.0537



**Fig. 6** Changes in the contribution rate of the factors of in YRD region at different stages

For Anhui, the driving effect of changes in the economic scale on changes in water use in Anhui has been increasing, but it has remained unchanged during the 13th FYP period. The driving effect of the energy use scale change on water use change in Anhui has been decreasing. The inhibitory effect of water intensity change on water use change in Anhui is an inverted U-shape that decreases first and then increases. The inhibitory effect of water-energy nexus on water use change in Zhejiang also showed an inverted U-shape that first decreased and then increased. The driving effect of regional food production on water use has been increasing but remained unchanged during the 13th FYP period. Overall, the change of water intensity in the YRD region has an increasing inhibitory effect on the increase of water use, indicating that the YRD region is regularly using water-saving technologies and other technological innovations to drive the decrease of the total water use and water intensity.

## Conclusion and policy implications

### Conclusion

Based on the perspective of the water-energy-food nexus, this paper adopts the GDIM to uncover the driving effect of the change of water use in the YRD into intensity effect, scale effect, and nexus effect. The period results from the 10th to

the 13th FYP show that regional economic scale and energy use scale are two major factors driving the total water use of the YRD region. The driving effect of the regional economic scale is the greatest, followed by the energy use scale. The development of water technology and water-energy nexus intensity are two major factors that restrain the total water use in the YRD region. Regional water intensity effect and regional food production effect on water use change are different.

During 2000–2016, regional economic development was the main driving factor for the growth of water use in Jiangsu. The increase of energy use, the increase of energy use scale, and the progress of energy technology are the other three important factors to promote the growth of water use in Jiangsu. The development of water technology, the decrease of water-energy nexus, and regional water intensity are the main factors to restrain the increase of water use in Jiangsu Province.

The total water use in Shanghai reduced from 2000 to 2016. The regional water use intensity was the primary factor driving the decrease of total water use in Shanghai. The decrease of water-energy intensity and regional food production became the second and third core factors, respectively, driving Shanghai's water use decrease. The regional economic development and the increase of energy use scale are the two major influencing factors to promote the increase of water use. However, as the inhibitory effect is greater than the promoting effect, the total water use in Shanghai is reduced.

From 2010 to 2016, the total water use in Zhejiang decreased, and the regional water use intensity became the primary factor to restrain the increase of water use in Zhejiang. The decrease of water-energy nexus and food-energy nexus were the second and third factors to restrain the water use in Zhejiang. The improvement of the economic level and the increase in energy use scale are the main driving factors for the increase in water use in Zhejiang province.

From 2000 to 2016, the total amount of water use in Anhui continued to increase. The increase in economic development has become the primary factor that promotes water use in Anhui. The energy use scale and the increase in regional food production have also become the second and third driving factors driving Anhui's water use increase. The decrease of regional water intensity has become the primary factor that restrains the increase of water use in Anhui. Advances in water-saving technologies and the decrease of water-energy nexus have also become important factors to promote the decrease of water use in Anhui. However, the inhibitory effect of the factors is less than the driving effect.

## Policy implication

At present, the water use efficiency in the YRD region still has much room for improvement. According to the above analysis, there are eight influencing factors of water use changes in the YRD region. However, there is a non-disposable factor in practice, i.e., GDP. The authorities cannot reduce water consumption by giving up economic growth. Therefore, the control of water use in the YRD region should be implemented around strategies such as saving food, improving water and energy efficiency, reducing energy use, water-energy nexus, and regional food production water intensity. In this sense, we make policy recommendations from two aspects of energy and food production and consumption. The following policy recommendations are given:

Food production is the largest human use of water. Clearly, agricultural practices need to be targeted to reduce wastage of water. This has been the center of attention for water-saving practices for some years (Blanke et al. 2007). Many actions have been taken to support farmers to save water through improved seeds, harvesting technologies, and storage and innovative ways to capture and beneficially use the rain water to lessen stresses on rivers and groundwater (Yu et al. 2017). However, losses of food between the farmers' field to our dinner table — in food storage, transport, food processing, retail, and our kitchens — are huge. This loss of food is equivalent to a loss in water (Lundqvist et al. 2008). Hence, there are additional ways to save water. Food consumers and businesses in the YRD region have a key role in saving water. The consumers should raise awareness among consumers about the water implications of their diets, overeating, and food wastage through incentives, practical guidance, and well-

designed campaigns (Jalava et al. 2016). The business community should take action to minimize water wastage through reducing food wastage in their processing and transport by benchmarking standards to indicate water use; taking action to minimize wastage in their processing and transport systems; and raising publicity about their water use.

Irrigated agriculture accounts for most freshwater use, far higher than drinking water and domestic consumption. But the energy sector is catching up fast. The water-energy nexus is also the driving factor that affects the change of water use. The electric power generation in the YRD region can reduce water usage by using waste water, seawater, or brackish groundwater for cooling and processing instead of freshwater; using cooling technologies that require less water or no water; switching to renewable energy technologies that do not need water for cooling — such as wind and solar electric; and introducing technologies to condense evaporation from cooling towers and capture and reuse the water. The authorities in the YRD region needs to accelerate the transformation and upgrade the traditional energy-dependent industrial structure, reduce the dependence of industrial development on energy, and improve energy utilization efficiency by strengthening the use of energy-saving technologies. The advance in energy use and energy technology can reduce water use in energy production and use. The YRD region should facilitate the use of non-fossil energy, such as solar energy and wind energy (Hightower and Pierce 2008), and promote the clean and efficient development and utilization of fossil energy to reduce energy consumption.

The YRD region residents should further strengthen their water-saving awareness (Seelen et al. 2019) and create positive water conservation habits (Martínez-Espiñeira and García-Valiñas 2013). Engaging citizens in protecting freshwater resources encourage environmentally responsible behavior (Martínez-Espiñeira et al. 2014). Sectors with extensive water use should install water-saving equipment (Thiam et al. 2021). It is also necessary to vigorously popularize water-saving instruments in urban and rural areas to create favorable conditions for saving water (Huang et al. 2017).

**Abbreviations** FYP, Five-year plan; GDIM, Generalized Divisia index method; IDA, Index decomposition analysis; LMDI, Logarithmic mean Divisia index; SDA, Structure decomposition analysis; WEF, Water-energy-food; WWDR, World Water Development Report; YRD, Yangtze River Delta

**Author contribution** Yu Yu: Writing — original draft, conceptualization, methodology, software, investigation. Chenjun Zhang: Data curation, writing — review and editing. Weiwei Zhu: Conceptualization, investigation. Soohoon Park: Writing — review and editing. Qinfen Shi: Supervision. All authors read and approved the final manuscript.

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