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Abstract:	The shortage of water resources restricts the sustainable development of economy, and the change of industrial water consumption plays a vital role in economy. In this paper, logarithmic average segmentation index (LMDI) index decomposition method and geographical weighted regression (GWR) model were used to measure the spatial heterogeneity of each driving effect on industrial water consumption, and to explore the spatio-temporal variation characteristics. The results show that :(1) From 2005 to 2016, China's industrial water consumption increased by nearly 2.3 billion m3 ; Economic level effect and population size effect promote the change of industrial water consumption. The effect of industrial structure and technological progress play an inhibitory role. (2) Population size effect and economic level effect have the greatest impact on the eastern coastal areas. Coastal areas can reduce industrial water consumption by population control, reasonable design of water prices, and collection of sewage charges and taxes.

Driving Factors and its Spatial Heterogeneity of Industrial Water Consumption in China

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Abstract: The shortage of water resources restricts the sustainable development of the economy, and the changing of industrial water consumption plays a critical role in economy, which directly affects the utilization of water resources, further the water shortage. In this paper, the Logarithmic Mean Divisia Index (LMDI) exponential decomposition method is used to decompose the driving factors of industrial water consumption into economic level effect, population scale effect, industrial structure effect and technological progress effect, and calculates the contribution value of each driving effect. The spatial heterogeneity of each driving effect on industrial water consumption is measured by Geographic Weighted Regression (GWR) model, and its temporal and spatial variation characteristics are explored. The results show that: (1) the industrial water consumption has increased by nearly 2.3 billion m^3 due to four effects from 2005 to 2016 in China. The economic level effect and population scale effect have promoted the change of industrial water consumption. The industrial structure effect and technological progress effects play a depressing role. (2) Population scale and economic level effects have the greatest impact on the eastern coastal areas, and coastal areas can reduce industrial water consumption by controlling population, designing rational water price and levying sewage charges and taxes. The technological progress effect has the greatest impact on the central and western regions, and the

industrial water consumption can be reduced by developing industrial water-saving and recycling technologies. The industrial structure has the greatest impact on the northern region. Therefore, the northern region should focus on the adjustment of the industrial scale and optimization of the industrial structure to reduce water consumption. Analysis of the driving effects of China's industrial water consumption and the adoption of corresponding measures to reduce industrial water consumption are the key to solving water shortages and economic development problems.

Keywords: Industrial water consumption; Driving effects; Regional heterogeneity; GWR model

1. Introduction

As one of the countries with severe drought and water shortage in the world, China's total freshwater resources account for only 6% of the world's total. The per capita water resources are only one-fourth of the world's average. China has become one of the 13 countries with the lowest per capita water resources in the world. Industry is an important supporting factor for economic development, its water consumption directly affects the utilization of water resources and then greatly affects the shortage of water resources. According to statistics (China Statistical yearbook, 2017), China's industrial added value has increased from 160.3 billion yuan in 1978 to 28517.6 billion yuan in 2016, with an average annual growth rate of 4.66 times. It is expected to continue to grow at a faster rate to drive the overall economic development in the future. At the same time, China's industrial water consumption is also growing rapidly, from 52.3 billion m^3 (11% of the total water consumption) in 1978 to 130.8 billion m^3 (21.6%) in

2016, and it becomes the fastest department in growth rate of water use. Therefore, it is of great significance to study the economic driving factors affecting industrial water consumption and to analyze their spatial and temporal distribution characteristics in order to better utilize water resources, better reduce industrial water consumption, improve water use efficiency and develop the economy.

There are three key scientific questions that need to be addressed:

(1) How does China's industrial water consumption change on a time scale?

(2) What are the main factors driving such changes?

(3) What are the spatial distribution characteristics and intensity of these driving factors?

Research on water consumption focuses on the following aspects:

First, the influencing factors of water consumption. Ward (1997) and Tate (1986) analyzed the growth of water use in developed counties and found that there were several factors affecting the growth of water demand, such as water resources conditions, per capita water use, population, water consumption per unit product, industrial structure, reuse rate of water resources and technical factors and so on. Shang et al. (2016) found that industrial expansion will increase water use, while technological advances and water efficiency improvements will reduce water use. Shang and Zhai (2016) studied the changes of industrial water use from 2003 in Tianjin City and obtained the main factors were industrial scale and water use efficiency. In addition, Shang and Lu (2016) classified the driving forces of industrial water use changes into three types: output, technological, and structural forces. In terms of the factors such as the economic development, population, industrial water use efficiency and water resources development and utilization effecting on the water consumption in Urumqi, the economic development and water intensity are the decisive factors (Yu-fang Zhang et al., 2015). There is a certain inverse U-shaped relationship between per capita industrial water consumption and GDP (Yue Zhang et al., 2017). Taking the metropolitan area of Barcelona as an example, the relationship between urbanization and water consumption of residents was studied. The results demonstrated that income and housing types played an important role in water consumption changes (Domene et al., 2006). The dominant factors affecting wastewater discharge were the economy and technological advance, however, the efficiency of resource utilization and population played a less important role in wastewater discharge (Chen et al., 2016).

Second, spatial analysis of water consumption mainly focuses on the water use efficiency and water pollution. The spatial dependence and local cluster from 2003 to 2012 were studied by Exploratory Spatial Data Analysis (ESDA) and Geographic Information System (GIS). The results showed that the percentage of industrial water in Hubei province shows a weak spatial dependence, and the center trajectory migrated to the northwest (Zhou et al., 2017). Cai et al. (2016) studied the impact of China's industrial transformation on water intensity and energy-related carbon intensity during 2003-2012. Ma et al. (2016) adopted the spatial panel data model to analyze the spatial correlation of China's water use efficiency, and found that there a large variation of water use efficiency varies among different provinces. Ding et al. (2018) measured respectively the spatial correlations of total, industrial and agricultural water intensity of 11 provinces in the Yangtze River Economic Belt. The spatial spillover effect of China's provincial water use efficiency was studied with the space Durbin econometric model. There is a significant spatial correlation based on China's provincial water use efficiency (Sun et al., 2014). By using the ESDA method to analyze the spatial and temporal distribution of total wastewater, it was found that the provinces with high wastewater discharge were mainly located in the coastal developed provinces such as Jiangsu province and Guangdong province(Chen et al., 2016).

The third, water research based on the GWR model. Taking Phoenix City and Mediterranean region of Spain as an example, it was concluded that the GWR model can better represent the spatial impact of the determinants of household water consumption by comparing the results of the OLS model with the GWR model(Villar-Navascués et al., 2018). Duan et al. (2015) indicated that the spatial distribution of water footprint in 36 major maize producing areas in northeast China was uneven with spatial autocorrelation analysis and GWR model. Kontokosta and Jain (2015) applied the weighted robust regression and GWR model to analyze the determinants and spatial patterns of water consumption in multi-family buildings in New York City. It was found that the occupancy rate, building areas and so on had a significant impact on the water intensity of multi-user.

Research studies dealing with the water consumption were analyzed from different angles, more and more factors have been considered, and the research dimension is gradually becoming wider and wider from time to space. However, little attention paid to the spatial impact analysis of the driving factors of industrial water consumption.

Most studies only focused on the influencing factors of industrial water consumption from a single dimension of time or space, and most of them ignored the correlation and heterogeneity of the various factors which affected industrial water consumption among different regions. So we establish the factor decomposition model based on the Kaya formula, find out the driving factors affecting industrial water consumption. Then build the LMDI exponential decomposition model to quantify the contribution value of each driving effect with the industrial water consumption data of 31 provinces from 2005 to 2016. Furtherly, we combine the driving factors with GWR model for spatial differentiation analysis and observe the distribution characteristics and influence degree of driving factors of industrial water consumption among different provinces. It will provide policy recommendations for rational utilization of industrial water consumption.

2. Methodology and data

2.1 Methodology

2.1.1 Decomposition of driving factors

Based on the Kaya identity concept, proposed by Japanese professor Yoichi Kaya (Kaya 1990) at a IPCC seminar, we expanded the Kaya identify and decomposed the industrial water consumption (W) into the four driving factors: industrial water efficiency (T), industrial structure (S), economic level (Q) and population scale (P) to measure the impact of water technology advancement, industrial structure changes, economic level improvement and population scale changes on Chinese industrial water use. The extended Kaya formala can be expressed as follows:

$$W_t = \sum_{i=1}^{I} W_i^t = \sum_{i=1}^{I} \left(T_i^t \times S_i^t \times Q_i^t \times P_i^t\right) \tag{1}$$

Where, $T_i^t = \dfrac{W_i^t}{GDP_i^t}$, $S_i^t = \dfrac{GDP_i^t}{GDP_t}, Q_i^t = \dfrac{GDP_t}{P_t}, P_i^t = P_t$.

Where, W_i^t and GDP_i^t mean the industrial water consumption and industrial added value of the *t*-year in the *i*-th province of China's 31 provinces. GDP_t is the total GDP of the *t*-th year. P_t is the total national population in the *t*-th year, and W_t is the total industrial water consumption in the *t*-th year of China. *I* represents 31 provinces and cities in China.

According to the Logarithmic Mean Divisia Index (LMDI) proposed by Ang (2004 and 2005), an analysis object (V) is composed of *i* subclasses, where each subclass has *n* driving factors $x_1, x_2, \cdots, x_n$. There V can be calculated as follows:

$$V = \sum_{i=1}^{n} V_i = \sum_{i=1}^{n} x_{1,i}\, x_{2,i} \cdots x_{n,i} \tag{2}$$

Suppose the base period $V_0 = \sum_{i=1}^{n} x_{1,i}^0 x_{2,i}^0 \cdots x_{n,i}^0$, the end of the period $V_t = \sum_{i=1}^{n} x_{1,i}^t x_{2,i}^t \cdots x_{n,i}^t$. In the additive decomposition mode, the contribution value of the *k*-th driving factor is denoted by ΔV_{x_n}, and the relationship between the variation value of *V* and the *n* driving factors is as follows:

$$\Delta V_{t0} = V_t - V_0 = \Delta V_{x_1} + \Delta V_{x_2} + \cdots + \Delta V_{x_n}, \tag{3}$$

$$\Delta V_{xk} = \sum_i \frac{(V_i^t - V_i^0)}{(\ln V_i^t - \ln V_i^0)} \ln\left(\frac{x_{k,i}^t}{x_{k,i}^0}\right) \tag{4}$$

Combine equations (1), (2) and (3), we can get ΔW using equation (5)

$$\begin{aligned}\Delta W &= W^{t+1} - W^t = \sum_{i=1}^{I}\left(T_i^{t+1} \times S_i^{t+1} \times Q_i^{t+1} \times P_i^{t+1}\right) - \sum_{i=1}^{I}\left(T_i^t \times S_i^t \times Q_i^t \times P_i^t\right) \\ &= \Delta T + \Delta S + \Delta Q + \Delta P\end{aligned} \tag{5}$$

Based on equation (4), we can obtain ΔT, ΔS, ΔQ, and ΔP:

$$\Delta T = \sum_{i=1}^{I} L\left(W_i^{t+1}, W_i^{t}\right) \times \ln\left(T_i^{t+1} / T_i^{t}\right) \tag{6}$$

$$\Delta S = \sum_{i=1}^{I} L\left(W_i^{t+1}, W_i^{t}\right) \times \ln\left(S_i^{t+1} / S_i^{t}\right) \tag{7}$$

$$\Delta Q = \sum_{i=1}^{I} L\left(W_i^{t+1}, W_i^{t}\right) \times \ln\left(Q_i^{t+1} / Q_i^{t}\right) \tag{8}$$

$$\Delta P = \sum_{i=1}^{I} L\left(W_i^{t+1}, W_i^{t}\right) \times \ln\left(P_i^{t+1} / P_i^{t}\right) \tag{9}$$

Where, $L\left(W_i^{t+1}, W_i^{t}\right) = \left(W_i^{t+1} - W_i^{t}\right) / \ln\left(W_i^{t+1} / W_i^{t}\right)$ (10)

2.1.2 Spatial autocorrelation

Spatial autocorrelation analysis is a method of quantitatively measuring whether a variable is spatially related or not. Before establishing the GWR model, the Moran’s *I* index value is used to test the spatial correlation of industrial water consumption and its driving effects. The Moran’s *I* formula is as follows:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W'_{ij} \left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n} \sum_{j=1}^{n} W'_{ij}} \tag{11}$$

Where, *I* is the Moran's *I* value, where *n* is the number of sample regions, equal to 31. x_i and x_j are the value of the driving effect in the adjacent space. W'_{ij} is the spatial neighboring weight matrix. If the two places are adjacent, then $W'_{ij} = 1$, otherwise $W'_{ij} = 0$. Moran's *I* index is in the range of values $(-1,1)$, which is an indicator for analyzing the global spatial correlation in spatial econometrics. Among them, if $I > 0$, there is a positive correlation in the space; if $I < 0$, the variable has a negative correlation in space; if $I = 0$, variables do not correlation in space.

2.1.3 GWR Model

The GWR model was proposed by Brunsdon et al. (2010) in order to study complex spatial parameter changes or spatial heterogeneity. The model shows that different geospatial spaces have different relationships. The results demonstrate that regional parameters with spatial dependence can be estimated, and the actual impacts or effects of different driving factors in different regions can be detected. It is widely used in the spatial analysis for economy, housing prices and ecology. The general form of the GWR model is as follows:

$$y_i = \beta_0(u_i, v_i) + \sum_{j=1}^{\mathrm{k}} \beta_{\mathrm{k}}(u_i, v_i) x_{ij} + \varepsilon_i \tag{12}$$

Where, (u_i, v_i) is the geographic coordinates of the the i-th provincial capital city. x_{ij} is the j-th driving factor in the *i-th* province, $\beta_{\mathrm{k}}(u_i, v_i)$ is the regression coefficient of driving factors in different regions; ε_i is the random error of regression model. The regression coefficients in the GWR model are affected by the spatial position, and the formula is as follows:

$$\hat{\beta}(u_i, v_i) = \left[X^T W'(u_i, v_i) X\right]^{-1} X^T W'(u_i, v_i) XY \tag{13}$$

$\hat{\beta}$ is the estimated value of β and W' is the spatial weight matrix assigned to the data points by the model at position (u_i, v_i).

2.2 Data sources and data processing

Figure 1 China's total water consumption and status of industrial water use

The object of this paper is how to estimate industrial water consumption. The economic level effect index of decomposition is selected by per capita GDP. The population size index is characterized by the year-end resident population. The technical progress effect indicator is characterized by water use efficiency, which is represented by industrial added value water consumption of 10,000 yuan and the structural effect is expressed by the proportion of industrial added value.

The data used in this paper mainly come from the China Statistical Yearbook and the China Water Resources Bulletin from 2005 to 2016, and the Statistical Yearbook of the 31 provinces in the National Bureau of Statistics from 2005 to 2016. The sample interval is defined as 2005-2016. Please note that the research lacks of relevant data in Taiwan, Hong Kong and Macao Special Administrative Regions.

3. Results and Discussion

3.1 Decomposition analysis of driving factors based on LMDI

Using formulas (4) and (5), the driving factors of industrial water consumption are calculated and listed in Table 1 and Figure 3.

In Table 1, the contribution of population scale and economic level to industrial water consumption is positive, indicating that both promotes the growth of industrial water consumption. The expansion of population scale has led to an increase in industrial water consumption about 7.742 billion m^3 (2.10%), and the improvement of economic level has made an increase to 184.12 billion m^3 (48.272%). The contribution of technological progress and industrial structure has positive or negative on industrial water consumption. The technological progress effect is about 164.735 billion m^3 (43.19%). Furthermore, the optimization and upgrading of industrial structure have also reduce the industrial water consumption around 24.824 billion m^3 (6.508%). Based on the above analysis, it is not difficult to find that the economic level has become the main driving force for the increase of industrial water consumption from the data. And the technological progress has become the main inhibitor of industrial water consumption. The industrial structure effect is the secondary inhibition factor, and the population scale effect has the least driving effect. The cumulative effect of population scale effect and economic level effect is better than the cumulative inhibition effect of industrial structure effect and technological progress effect. Therefore, China's total industrial water consumption increased by 2.305 billion m^3 from 2005 to 2016.

From the trend of time series changes in Figure 1, the improvement of economic level in 2005-2016 is the main driving factor increasing industrial water consumption in China. Industrial technology progress has become a major inhibitor of industrial water use, and industrial structural effects have also played a depressing role, which showed a periodic wave. From 2005 to 2008, China's economic level reflected a state of fluctuating growth, and industrial water consumption also increased. However, the 2008 economic crisis had a certain degree of impact on Chinese industry, directly leading to a slowdown of China's economic development, which made industrial water consumption reduce from 22.739 billion m^3 in 2008 to 11.642 billion m^3 in 2009. In addition, after the industrial structure became smaller and optimized, the water use efficiency had increased, but industrial water consumption reduced by 15.424 billion m^3. And the technological progress effect made industrial water consumption increase by 2.468 billion m^3. After the economic crisis, in 2010, the Chinese economy resumed growth. Industrial restructuring was restored, and technological progress continued to play its role, and water consumption also resumed growth. Since 2010, “Twelfth Five-Year Plan” has entered, in which “Eleventh Five-Year Plan” promoted the optimization and upgrading of industrial structure and the process of building a resource-saving and environment-friendly society, the economic level has maintained a medium-to-high-speed growth. However, the increasing in industrial water consumption has shown a slow decline. For population, its effect has promoted the increase of industrial water use, but the growth trend of population scale effect has been relatively flat.

3.2 Global spatial autocorrelation analysis

Before the spatial regression, the spatial autocorrelation of industrial water consumption should be examined. If the spatial effect is obvious, spatial modeling analysis can be performed. Otherwise, spatial analysis is not needed. In this paper, the GeoDa software (http://geodacenter.github.io) is used to calculate the global autocorrelation Moran’s I index of industrial water consumption in 31 provinces in China from 2005 to 2016. The Moran’s I index scatter plot is shown in Figure 4.

As shown in Figure 4, there is a positive correlation between China's industrial water consumption and more than 80% of the provinces in the first and third quadrants, indicating that the industrial water consumption in these provinces has a phenomenon of high concentration and low concentration.

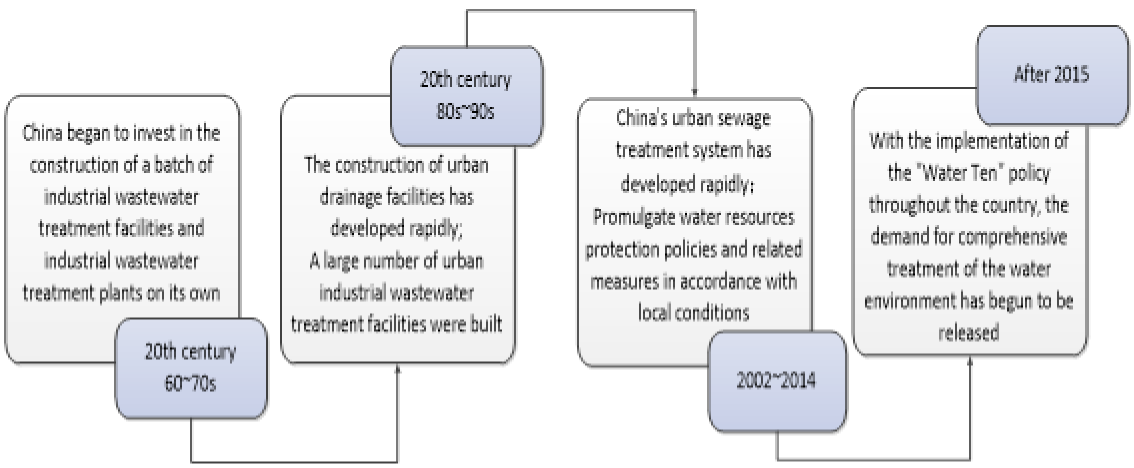


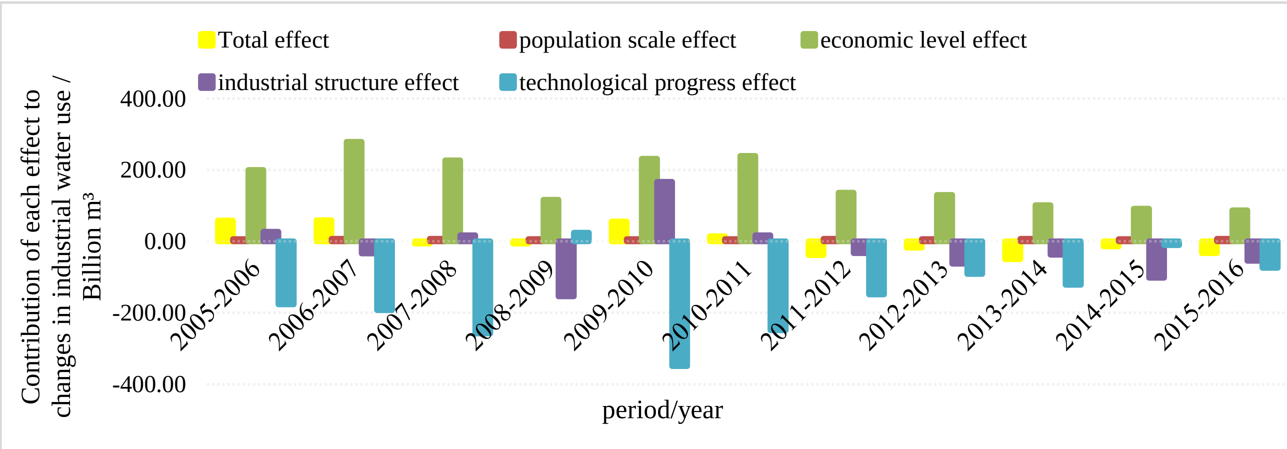
Figure 2 Development history of China's industrial water and waste water industry

By analyzing the Moran’s I index value, we can find its value fluctuates with a trend of “first increases and then decreases”. From 2005, the regions with similar industrial water consumption in the country are spatially concentrated and the maximum value of Moran's I index reaches up to 0.42 in 2012, mainly because of the rapid development of economy in this period. When the industrial level of each province has also increased, there is a strong correlation between the economic developments of the provinces. Consequently, the positive correlation of industrial water consumption in the space is gradually increased. Since 2013, the value of Moran's I index has decreased, however, the decline rate is less than the increase rate. The value of Moran's I index in 2013 is greater than the value in 2005 to 2008, indicating that the overall difference is gradually narrowing in the process of industrial water use. Mainly because most provinces developed the economic and related measures based on “adjust measures to local conditions” and then reduced the overall spatial positive correlation of industrial water consumption. More and more regions begin to combine and develop together and the new developed “economic independence” is booming. The overall difference of industrial water consumption in different provinces were reduced, and the spatial distribution of industrial water consumption is highly agglomerating locally.

Table 1 Decomposition results of various driving factors of industrial water consumption in China from 2005 to 2016

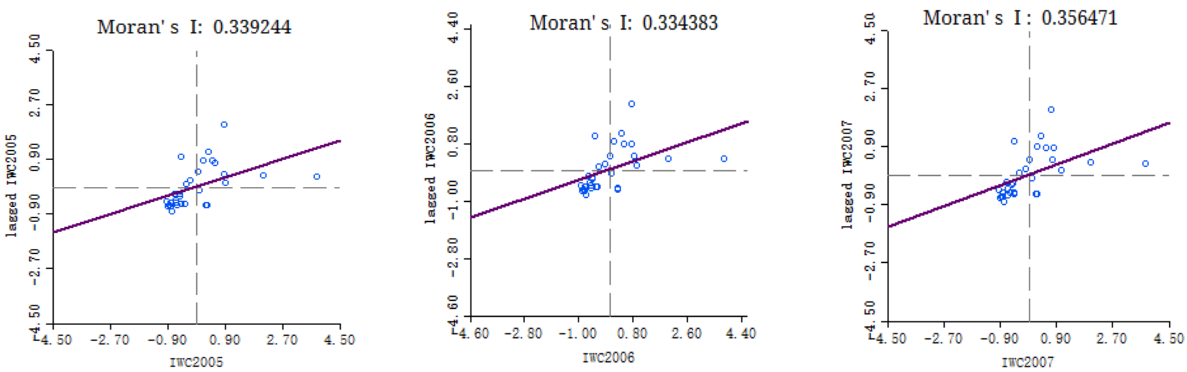
Period/year	Water consumption /Billion m^3	Contribution of various effects to changes in industrial water use / Billion m^3				Contribution rate of each effect to industrial water change /%			
		Population Scale	Economic Level	Industrial Structure	Technological Progress	Population Scale	Economic Level	Industrial Structure	Technological Progress
2005-2006	5.82	0.694	20.066	2.716	-17.656	1.687	48.784	6.603	42.925
2006-2007	5.912	0.71	27.874	-3.396	-19.276	1.385	54.382	6.626	37.607
2007-2008	-0.594	0.711	22.739	1.711	-25.755	1.396	44.66	3.36	50.583
2008-2009	-0.636	0.679	11.642	-15.424	2.468	2.247	38.533	51.051	8.169
2009-2010	5.634	0.68	23.182	16.741	-34.969	0.9	30.675	22.152	46.272
2010-2011	1.451	0.697	23.952	1.709	-24.907	1.36	46.722	3.334	48.585
2011-2012	-3.778	0.715	13.62	-3.262	-14.851	2.204	41.975	10.053	45.769
2012-2013	-1.755	0.696	12.986	-6.282	-9.155	2.39	44.596	21.574	31.44
2013-2014	-5.009	0.719	10.17	-3.735	-12.162	2.684	37.968	13.944	45.404
2014-2015	-1.426	0.667	9.14	-10.185	-1.048	3.17	43.441	48.408	4.981
2015-2016	-3.315	0.775	8.751	-5.416	-7.424	3.465	39.126	24.215	33.193
2005-2016	2.305	7.742	184.122	-24.824	164.735	2.03	48.272	6.508	43.19

Note: The positive values in the table represent the promotion effect, indicating that the increase of industrial water consumption is promoted; the negative values represent the inhibition effect, indicating that the inhibition of industrial water consumption increases.



Note: The total effect is the amount of industrial water consumption change.

Figure 3 Driving effects of industrial water consumption changes in 2005-2016



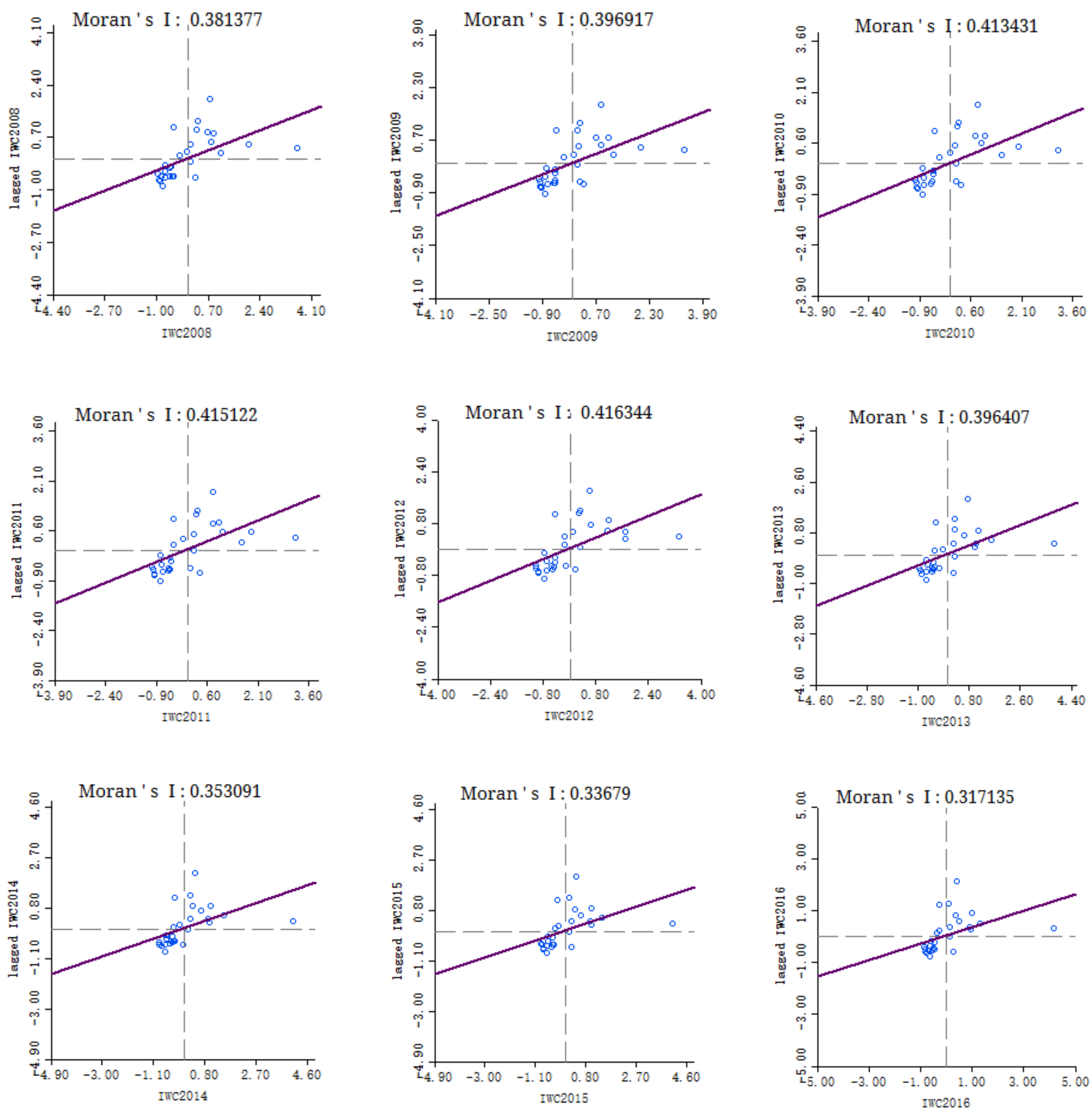
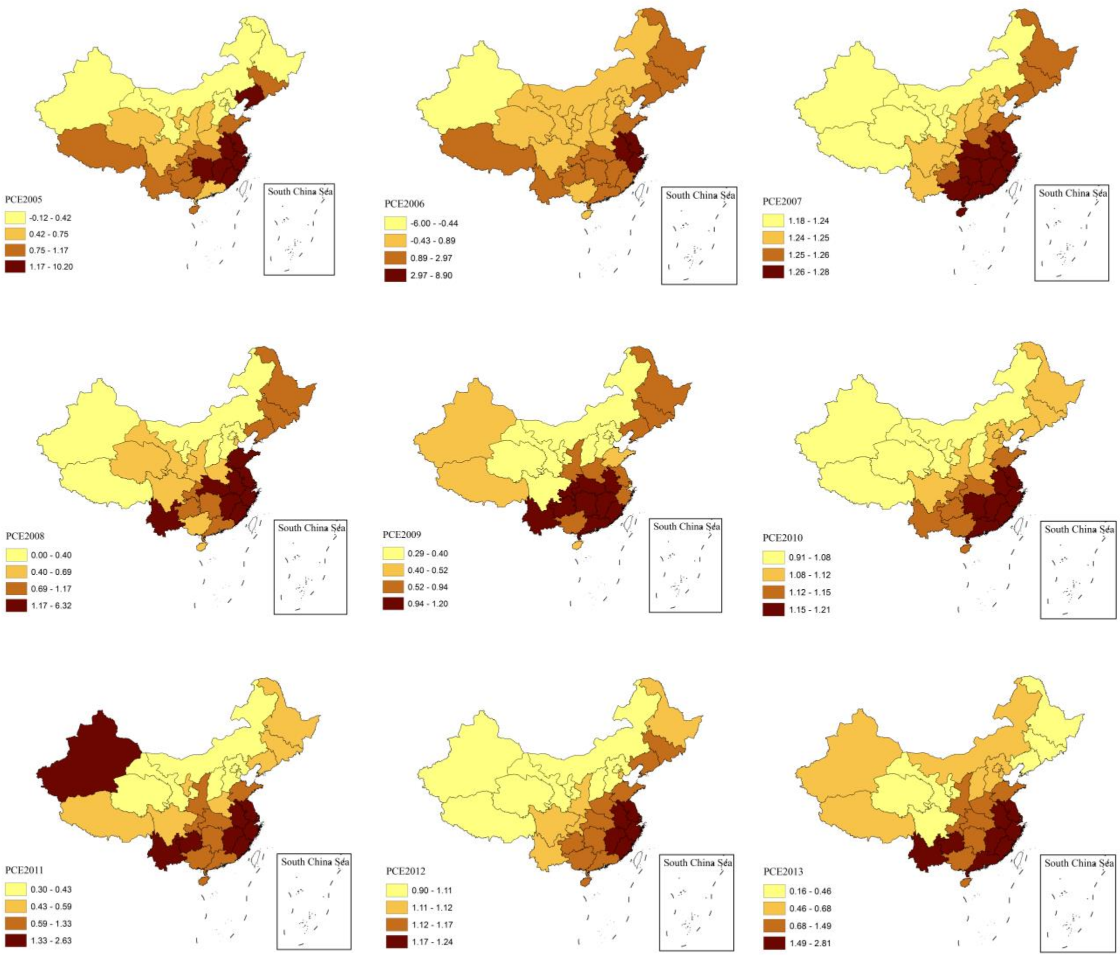


Figure 4 Moran 's I Index of Industrial Water Consumption in 31 Provinces of China, 2005-2016

Note: Objects without neighbors in spatial weights have been deleted; IWC indicates industrial water consumption

3.3 Spatial variation characteristics of driving factors

According to the global Moran's I index, the industrial water consumption is spatially autocorrelative, that is, the spatial evolution of industrial water consumption driving factors should be further explored. Therefore, it is necessary to establish a spatial regression model to measure the impact of four driving factors on industrial water consumption among 31 provinces (Duan et al., 2015). The industrial water consumption is the dependent variable, the four driving factors are the independent variables in the GWR model, and the Gaussian weight is adopted. The optimal bandwidth is determined by Akaike's Information Correlated Criterion (AICC). GWR v4.0 is used to get the regression coefficients of driving factors based on the latitude and longitude of 31 provinces. The effects of four driving factors on industrial water consumption in China can be shown in Figure 5-8.



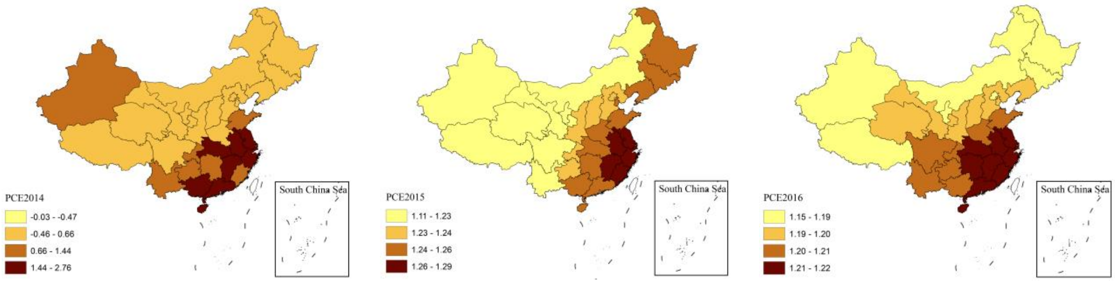


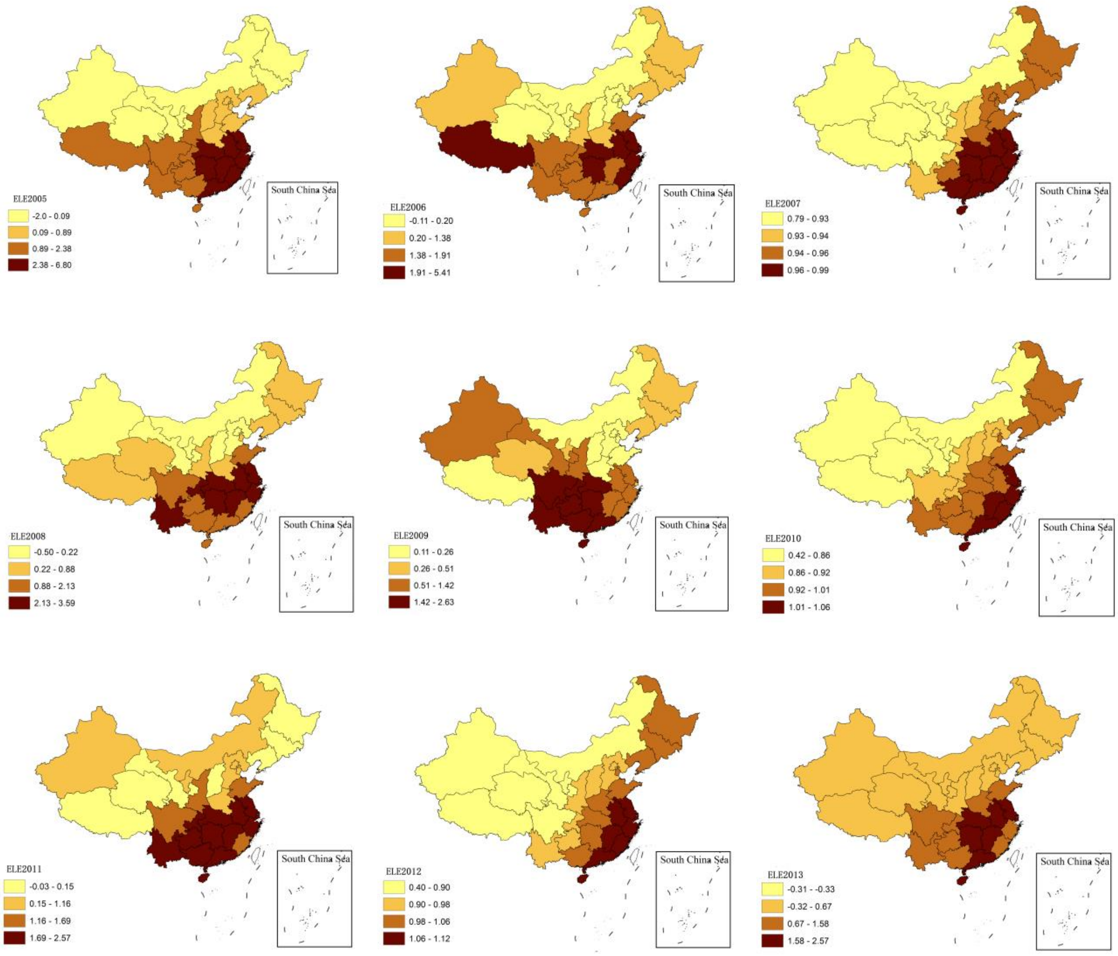
Figure 5 Spatial distribution of regression coefficients of population scale driving effect of GWR in 2005-2016

(1) Population scale

Figure 3 demonstrates that the spatial distribution of the regression coefficient population scale over years and it shows the population scale has positive relationship with industrial water consumption. In other words, the positive coefficient indicates that the expansion of the population has promoted the increase of industrial water consumption, and vice versa. As is shown in Figure 3, China's Xinjiang, Heilongjiang, and Jilin provinces have negative values in 2005, 2006, 2014. And the rest of the years are positive, indicating that the overall population scale expansion has a positive impact on the increase of industrial water consumption. Moreover, the coefficient value of population scale effect has gradually increased from 2005 to 2016, indicating that the degree of population expansion has gradually increased the impact on industrial water consumption.

In terms of spatial distribution, the areas with large population impact on industrial water consumption mainly move southward from the eastern coastal areas of China because the industry was developing and made the industrial water consumption increased, then it attracted more people to come here and increased the population in these areas during 2005 and 2008. However, the high-value area of population scale has extended to the west, including Yunnan, Guizhou, Hunan and Xinjiang regions during 2009-2011 with the Western development policy, but after 2012, its high-value areas gradually moved to the southeast coastal areas since the development of society made more and more people concentrate in the southeast coastal areas, which promotes the development of industry and the industrial water consumption. In general, the impact of population size on industrial water consumption increases from west to east and from north to south. Which is consistent with the disproportionate distribution of China's population. Therefore, the population in the provinces, which locates in the southeastern coastal areas with large industrial water consumption, should be appropriately controlled to reduce industrial water consumption. However, instead of spending a lot of effort controlling the number of migrants, it is better to carry out environmental and water-saving awareness education in these areas. The public have strong awareness of environmental protection, but their awareness of water conservation is quite weak. Hereby, local governments of those provinces should inform the citizens the actual conditions of local water use, the seriousness of water shortage and the quality of the population. The local governments should also implement activities to teach their citizen to be aware of saving water, and to make the public feel the pressure of water shortage and the urgency of water use. Furthermore, coordinating the relationship between economy, population and environment, the local governments should seek an efficient method to reduce industrial water consumption. At present, the Chinese government has issued the "Water Pollution Prevention and Control Law of the People's Republic of China", "Opinions on Comprehensively

Strengthening Ecological Environment Protection and Resolutely Fighting Pollution Prevention and Control", "Technical Guidelines for the Development of National Water Pollution Discharge Standards", and "Regarding the Issuance of Urban Sewage A series of policies related to the industrial wastewater treatment industry, including the Three-Year Action Plan to Improve Quality and Efficiency, have achieved remarkable results. Economic development cannot be "GDP alone", but must achieve a win-win situation between green and efficiency.



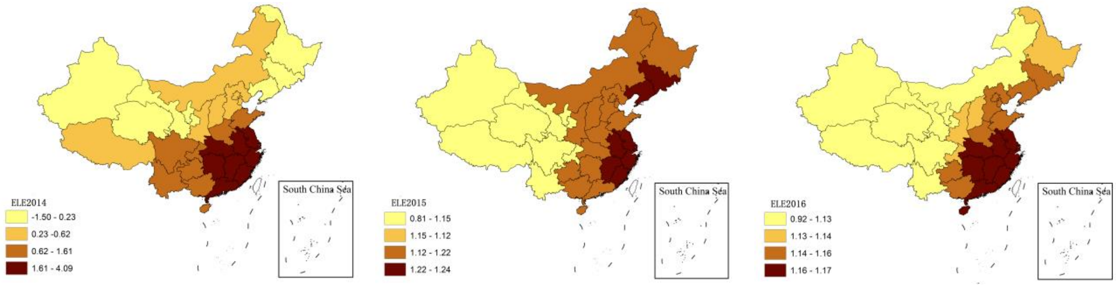


Figure 6 Spatial distribution of regression coefficients of economic level driving effect of GWR in 2005-2016

(2) Economic level

The regression coefficient of the economic level is positive which means that economic effect increases the industrial water consumption. It has played a positive role, and the economic improvement has promoted the increase of industrial water consumption. Moreover, the coefficient value of the economic level effect is also gradually increasing, indicating that the impact of the economic improvement on the industrial water consumption is also gradually growing. The level of economic development will directly affect the various infrastructure construction, technological investment and government funding of various provinces and municipalities. In the initial period of economic development, resource development and utilization are crucial to supporting the sustainable development of the economy. With the improvement of the economic level and the accelerated development of industrialization, the demand for industrial water consumption has increased year by year. However, the resulting industrial wastewater pollution and Water waste is becoming more and more serious. With the continuous improvement of the economy and industrialization level, people are more and more aware of the importance of water saving and will take measures to improve the efficiency of industrial water use.

As is shown in Figure 4, between 2005 and 2016, the coefficient of economic level effect decreased from south to north and then it changed to increase from the northwest to the southeast. The reason is that the economy rapidly developed in the southeastern coastal areas, and the industry is also increased, and then caused the increasing of the industrial water consumption. In theory, this increasing economic level is a sign of social development and progress. So the economic level should be improved actively. However, in such a stage, China's economic development needs to mainly rely on natural resources. Take the industry as an example, excessive pursuit of the economy will increase the use of industrial water. Therefore, for well-developed areas in the southeastern coastal areas, a step-by-step water price system is formed to play a role of raising factors like price and market in demand regulation and water resource allocation, and to enhance the awareness of industrial water conservation, which makes industrial enterprises price incentives and restraint mechanisms reduce industrial water consumption. It is also possible to impose industrial control measures such as sewage discharge fees and water resources taxes to control the waste water caused by industrial water use and to reduce industrial water consumption. In addition, all regions should pay attention to the survival status of water-saving enterprises, speed up the pace of perfecting its policy preferences and compensation system. Enterprises should arouse the enthusiasm of using new technologies and technologies with low water consumption. Only enterprises, continually strengthening the water-saving management system, constantly increasing the utilization rate of industrial water recycling and endlessly minimizing the waste rate of water use, can effectively reduce the rapid growth rate of industrial water.

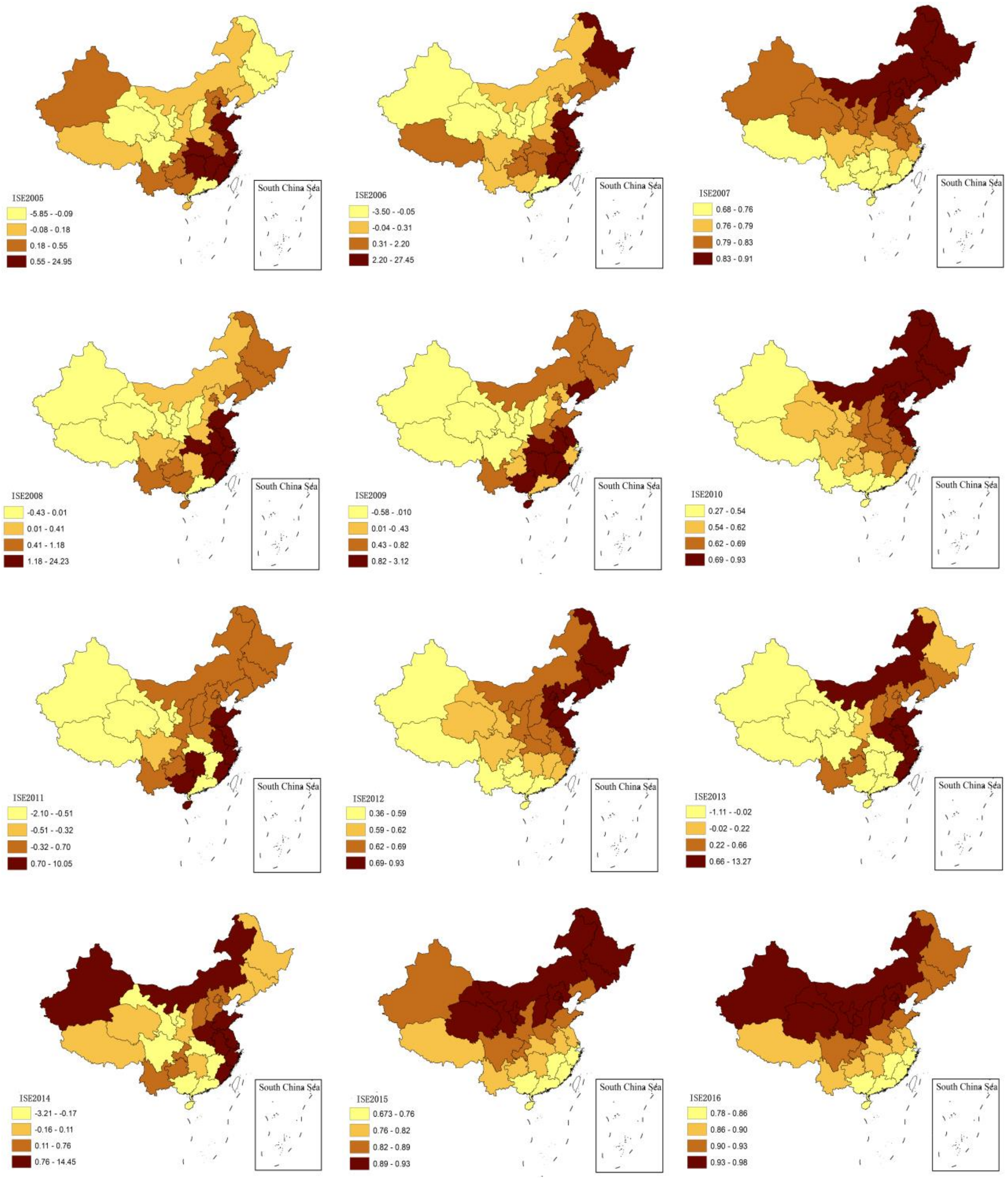


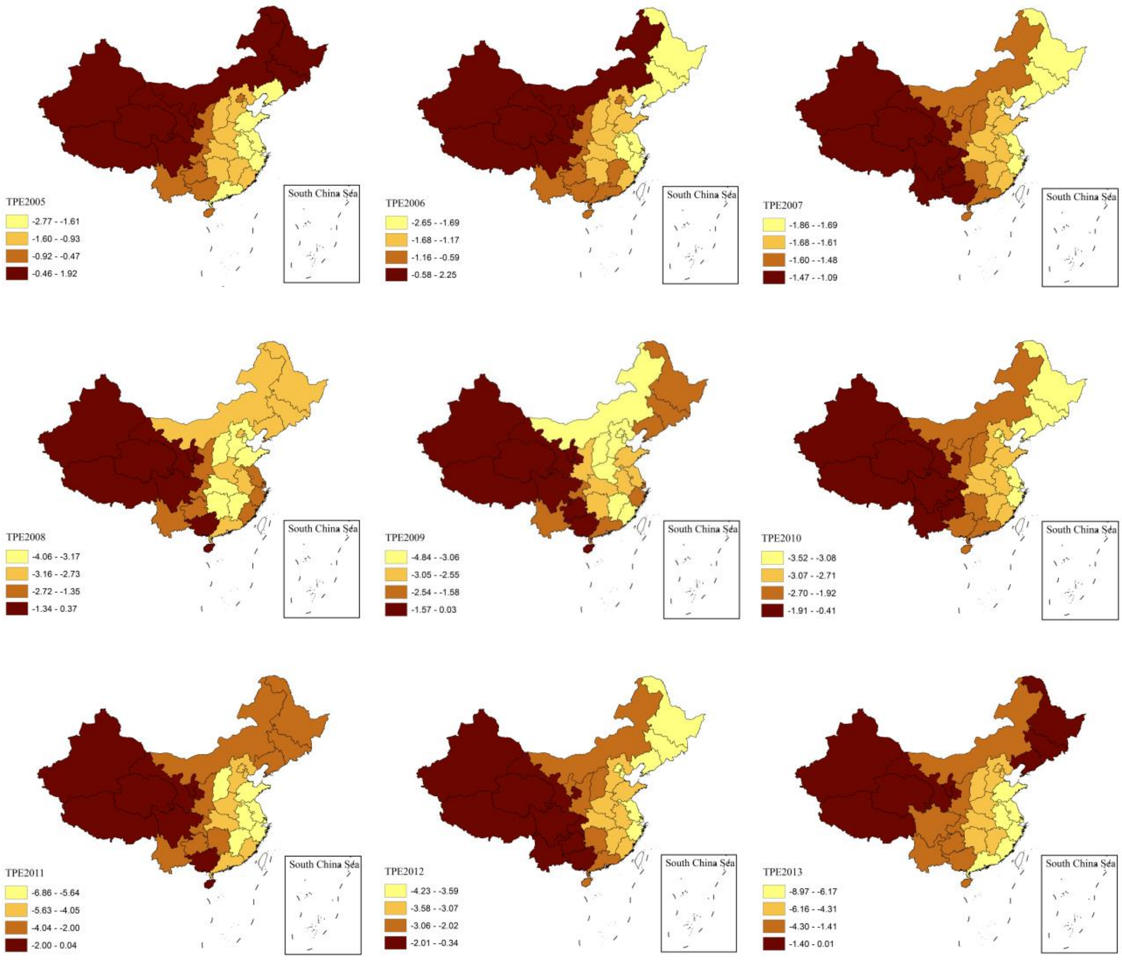
Figure 7 Spatial distribution of regression coefficients of industrial structure driving effect of GWR in 2005-2016

(3) Industrial structure

Figure 5 shows the spatial distribution of the regression coefficient of industrial structure (CIS). Compared with figures 3 and 4, we can easily found that the CIS is much smaller than the above two factors, indicating that the industrial structure has less influence on the industrial water consumption. Most regions have positive CIS values, which means the industrial structure effect has a positive impact on the increase of industrial water consumption over these regions, and the expansion of industrial structure also promotes industrial water consumption increasing.

In terms of spatial distribution of CIS in figure 5, the regions with a great influence on the increasing of industrial water consumption by industrial structure gradually transferred from the eastern coastal areas to the northeast and northern regions during 2005 and 2013. After 2014, most areas with high CIS value were switched between the eastern coastal areas and the northeastern regions. After 2015 and 2016, these areas moved to the northern China, and have an increasing trend. All of changes indicate that the influence of industrial structure effects on the increase of industrial water consumption had an increasing trend and should be paid attention to by the local governments. In general, the degree of influence of industrial structure on industrial water consumption showed a trend that gradually increased from northwest to southeast in 2005-2016. This was mainly because coastal cities were well-developed, and their industrial development was rapid and structurally stable, however, the central and northern regions were in the middle. During the period of industrial rise and expansion, industrial water consumption is greater than that of coastal areas, and industrial water consumption is relatively high. Therefore, it is necessary to properly adjust the industrial structure in the northern regions, optimize their structure, and rationally arrange the industrial structure to reduce industrial water consumption.

For example, these regions should collect and analyze the current data to master the actual situation, and then start from industrial structure of the industrial sector: 1) optimizing energy structure; 2) adjusting the industrial structure according to the analysis, 3) promoting the optimization and upgrade of the industrial structure, and 4) formulating scientific and rational policies instead of blindly adopting a “one size fits all” approach. After this series actions, these regions will accelerate the transformation from resource-intensive industries with high water consumption to knowledge-intensive industries with low water consumption (such as microelectronics, bioengineering, new materials and information industries) and also reduce water demand to form a healthy advanced virtuous cycle of effectively utilizing water use.



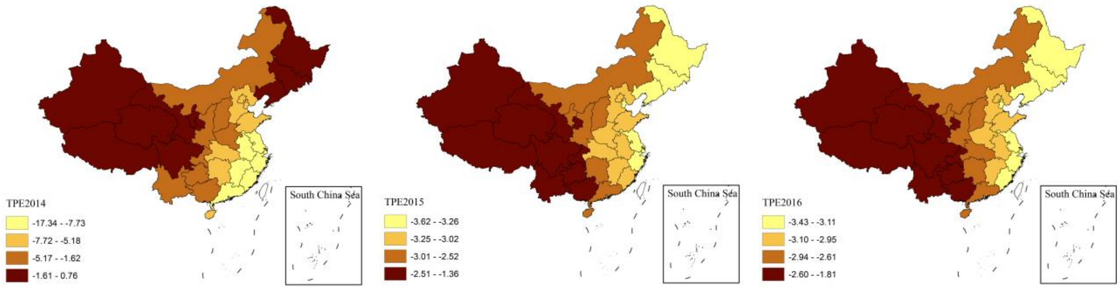


Figure 8 Spatial distribution of regression coefficients of technological progress driving effect of GWR in 2005-2016

(4) Technological progress

Figure 6 reveals that the regression coefficient of technological progress (CTP) was negative in all regions from 2005 to 2016, indicating that the technological progress effect had a negative impact on the increase of industrial water consumption. However, the absolute value of the CTP increased significantly with time, indicating that the technological progress inhibited the industrial water consumption. Compared with the other three driving factors, the absolute value of the CTP is the largest, which has the greatest impact on the change of industrial water consumption. It can be seen from the spatial distribution that absolute value of CTP has increased from the western and northern areas to the eastern coastal areas and then gradually transferred to increase from western to eastern areas, and its low-value areas gradually move to the southwest, indicating that the technological progress of the eastern coastal areas of China has a strong inhibitory effect on the increase of industrial water consumption, while the inhibitory of effects on southwestern and western regions are weaker. This is mainly because the pace of industrial development in the western region is relatively late, and the economy is under-developed. Furthermore, these regions have not enough industrial high-tech supported development and application and the equipment lack or miss technology for saving water and recycling wastewater, resulting in a larger industrial water consumption than the eastern coast. Therefore, the western region should realize the aim of reducing industrial water consumption, and increase investment in science and technology to improve industrial technology, such as vigorously developing industrial water-saving technologies and water recycling technologies, and using industrial water-saving equipment to improve industrial water efficiency and reduce units. The water consumption of output changes the extensive industrial water use mode to promote the level of industrial water recycling.

According to the experience of developed countries, the decline of industrial water can be divided into three categories. The first category is the optimization of industrial structure and the improvement of process technology, which has led to a rapid decline in industrial water use. Generally, it is more common in developed countries with more advanced industrial technology. A high-standard industrial water-saving system encourages the development of high-tech and low-energy-consumption aquatic industries, and ultimately reduces industrial water consumption and even causes zero growth in industrial water, such as America and Japan; The second category is that the industrial structure and technological level are not comparable to those of advanced countries such as the United States, but relying on certain technical conditions and using strict water intake and drainage policies and regulations to reduce industrial water consumption, such as Sweden and the Netherlands; The third category is to reduce the overall water consumption of the entire country under the pressure of very scarce water resources, such as Israel. Learning from the advanced experience of other countries can provide reference ideas for China's industrial wastewater treatment

4. Conclusions and implications

(1) Industrial water consumption has shown a slow growth trend on the whole, with a total increase of nearly 2.3 billion m^3 from 2005 to 2016. This paper mainly uses LMDI index decomposition method to decompose industrial water consumption into four driving effects: economic level, population scale, technological progress and industrial structure. Among them, the economic level effect totally increased by 184.12 billion m^3 of water, and the population scale effect increased the water consumption by 7.742 billion m^3. The technological progress effect reduced the industrial water consumption by 164.735 billion m^3, offsetting 89% of growth caused by the economic level effect. Industrial structural effect reduced the industrial water consumption by 24.824 billion m^3. It can be seen that the economic level effect is the main factor driving industrial water consumption growth, and the population scale plays a secondary role. Meanwhile technological progress plays a significantly inhibited effect on industrial water consumption, and industrial structural effect is a secondary inhibitory factor. .

(2) The GWR model is used to analyze the spatial heterogeneity of four driving effects on industrial water consumption. The results show that the technological progress effect has the greatest impact on inter-provincial industrial water consumption, followed by industrial structure effects, population scale effects and economic level effects. Among them, the economic level and population scale have promoted the change of industrial water consumption among provinces, and the influence gradually decreases from the southeast coastal area to the northwest area. Industrial structure also

plays a promoting role, and its influence gradually grows from south to north. Meanwhile technological progress has played a depressing role, the influence gradually increases from west to east.

According to the spatial distribution of the influencing factors, combined with the concept of innovation and green development of China in recent years, the following suggestions are proposed:

(1) Water price regulation and policy innovation plays the key role in reducing the industrial water consumption. A mature industrial water market is extremely important for optimizing the allocation of water resources. It is necessary to effectively improve the water price mechanism of industrial water use efficiency as the core, and truly give play to the role of industrial water price in improving the utilization of industrial water resources. The economic level has promoted the growth of industrial water consumption, especially in the eastern coastal areas, so it is more important to pay attention to the coordinated development of economy and water resources. Industrial water consumption can be reduced by designing rational water price and levying sewage charges and taxes. At the same time, local governments should innovate rewards and compensation policies, give preferential policies to water-saving enterprises, and promote enterprises to actively transform to the water -saving production.

(2) The population size is controlled in big cities and people's awareness of water conservation is raised. Actively propagate water-saving knowledge to industrial enterprises, help them establish water-saving awareness, and actively build a water-

saving management system centered on improving industrial water efficiency. Governments at all levels need to carry out various industrial water-saving publicity activities to enhance the initiative and consciousness of enterprises in industrial water-saving. At the same time, give play to the role of public opinion and supervision of the public to enhance the social responsibility of industrial water conservation.

(3) Water-saving technologies are developed and industrial water reuse methods are innovated. Increasing industrial technology and investment in science and technology can reduce industrial water consumption, especially for the central and western regions. Local governments should strengthen local science and technology investment, developing and promoting the technologies and equipment of conserving and recycling industrial water use. Furtherly reduce the water consumption per unit of output, and improve industrial water efficiency. Research and develop advanced industrial water-saving technologies and equipment, and fully apply modern science and technology to improve the efficiency of industrial water use. Especially in high water-consuming industries such as thermal power generation, textile printing and dyeing, petrochemicals, medicine, papermaking, metallurgy, and food processing, water-saving technologies must be upgraded and transformed. Increase investment in scientific research funds for enterprises, research and develop new water-saving equipment and processes.

(4) Adjusting the industrial structure and promoting industrial transformation. More attention is paid to strive for the goal of low-water, low-energy and high-output. Government should pay more attention to the impact of industrial structure on industrial water consumption and induce the adjustment of industrial structure. For different

regions, we should actively combine local conditions to plan the development model of low-water industries. For those industrial sectors with large water consumption, the proportion of their economic structure should be reduced, and enterprises with high water demand should be gradually transferred to low-water consumption. Judging from the empirical results of this article, the driving factors for industrial water use in eastern my country are more reasonable than those in the central and western regions. This also indicates that the industrial structure in the eastern region is relatively more reasonable. Therefore, we are adjusting the industrial structure and industrial layout. At this time, we must take care of the central and western regions. Pay attention to the spatial deployment of water-scarce areas and water-rich areas, and make sound adjustments to the industrial structure with enterprises as the main body, taking into account the natural endowment conditions of the region, and respond to the call of the national industrial policy to develop local characteristic industries.

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