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Analysis of Spatiotemporal Evolution and Driving Mechanism of Industrial Wastewater Discharge in China

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Abstract. This paper uses exploratory spatial data analysis (ESDA), logarithmic mean Dirichlet index (LMDI) and Tapio decoupling elasticity coefficient method to study the spatiotemporal evolution characteristics, main driving factors and decoupling status of industrial wastewater discharge in China from 2004 to 2019. The results show that: First, Second, economic development is the main driving factor for promoting industrial wastewater discharge; wastewater discharge intensity is the key factor in inhibiting industrial wastewater discharge; industrial structure plays an increasingly important role in wastewater reduction; the impact of population size is not significant.

Keywords: Industrial Wastewater; Exploratory Spatial Data Analysis; LMDI; Decoupling Analysis.

1. Introduction

Over the past 40 years of reform and opening up, China's economic system has undergone profound changes and has achieved remarkable development achievements. In 2014, GDP exceeded 10 trillion US dollars for the first time, ranking second in the world. However, in recent years, China's GDP growth rate has gradually declined, and it has entered a "new normal" marked by a medium-high growth rate of 7% from the past high-speed growth. In this new stage, China no longer only pursues the expansion of economic scale and the increase of per capita income, but pays more attention to sustainable economic growth, which is reflected in the characteristics of slowing economic growth, optimizing economic structure and changing driving force. To achieve this goal, China is stepping up the reform of economic structure, promoting supply-side structural reform, and promoting the transformation of economic development mode to high quality. As a key component of China's industrial structure, industry plays an important role in promoting high-quality economic development. However, in the current complex international environment, China's industrial development faces multiple challenges such as slowing growth and overcapacity. When judging industrial development, people no longer only focus on the proportion of industrial output value (added value), but more comprehensively consider factors such as the impact of industry on the development of other industries, the protection of the ecological environment, and the improvement of energy and resource utilization. Although China's industrial added value exceeded 30 trillion yuan in 2019 , accounting for 32% of GDP, the problems of high energy consumption, high emissions and high pollution in the industrial sector remain prominent and need further attention and solutions.

2. Research Methods

2.1. KAYA Identity for Industrial Wastewater Discharge

Based on the above analysis, this paper establishes a decomposition model for industrial wastewater discharge based on the KAYA identity. The specific expression is as follows:

$$W = \frac{W}{V} \cdot \frac{V}{G} \cdot \frac{G}{P} \cdot P = I \cdot S \cdot E \cdot P \tag{1}$$

Among them, W represents industrial wastewater discharge, V represents industry, G represents gross domestic product, and P represents population; $I = \frac{W}{V}$ represents wastewater discharge intensity, that is, the amount of industrial wastewater discharged for each unit increase in industrial output value; $S=\frac{V}{G}$ represents industrial structure, that is, the proportion of total industrial output value in GDP ; represents $E=\frac{G}{P}$ economic development, that is, GDP per capita ; P represents population size. Therefore, industrial wastewater discharge can be expressed as the product of four driving factors: wastewater discharge intensity, industrial structure, economic development and population size.

2.2. LMDI Decomposition Model for Industrial Wastewater Discharge

Under the guidance of international energy experts, we followed the principle of "joint generation and equal sharing" and properly handled the residual items generated during the structural decomposition process. Based on this principle, we successfully calculated the changes in industrial wastewater discharge in the current period relative to the base period.

$$\Delta W = W_t - W_0 = I_t \cdot S_t \cdot E_t \cdot P_t - I_0 \cdot S_0 \cdot E_0 \cdot P_0 = \Delta I + \Delta S + \Delta E + \Delta P \tag{2}$$

According to the decomposition of the LMDI model, the contribution of each driving factor to industrial wastewater discharge is expressed as formula (3) :

$$\begin{aligned} \Delta I &= \frac{W_t - W_0}{\ln W_t - \ln W_0} \cdot \ln(\frac{I_t}{I_0}) \\ \Delta S &= \frac{W_t - W_0}{\ln W_t - \ln W_0} \cdot \ln(\frac{S_t}{S_0}) \\ \Delta E &= \frac{W_t - W_0}{\ln W_t - \ln W_0} \cdot \ln(\frac{P_t}{P_0}) \\ \Delta P &= \frac{W_t - W_0}{\ln W_t - \ln W_0} \cdot \ln(\frac{E_t}{E_0}) \end{aligned} \tag{3}$$

Among them, ΔI the wastewater discharge intensity effect reflects the contribution of changes in industrial wastewater discharge per unit output value of the industrial sector to changes in industrial wastewater discharge; the ΔS industrial structure effect reflects the contribution of changes in the proportion of total output value of the industrial sector in ΔE GDP to changes in industrial wastewater discharge; the economic development effect reflects the contribution of economic growth to changes in industrial wastewater discharge; and the ΔP population size effect reflects the contribution of population size to changes in industrial wastewater discharge.

2.3. Data Sources

For data availability, this paper takes 30 provinces in China (excluding Tibet, Hong Kong, Macao and Taiwan) from 2004 to 2019 as the research object. The data on industrial wastewater discharge comes from the China Environmental Statistical Yearbook, the China Ecological Environment Statistical Yearbook and the provincial statistical yearbooks. Considering the various driving factors affecting industrial wastewater, this study uses the industrial added value, GDP and population data of each province and city, which come from the China Statistical Yearbook and the National Bureau of Statistics.

3. Temporal and Spatial Evolution Characteristics of Industrial Wastewater Discharge

Overall, China's industrial wastewater discharge shows a spatial distribution pattern of gradually increasing from west to east. Some provinces and cities in the eastern region are high-emission areas, the western region is a low-emission area, and most provinces in the central region are medium-low emission areas or low emission areas. From the trend of change, the number of high-emission provinces and cities has decreased. From Jiangsu and Guangdong in 2005, there are no high-emission provinces and cities in 2019; the number of medium-high emission provinces and cities has remained unchanged, from Zhejiang in 2005 to Fujian in 2019, which is due to the rapid rebound of Fujian's emissions in 2018 and 2019; the number of medium-emission provinces and cities has decreased by 4, from seven provinces in 2005, namely Hebei, Henan, Shandong, Liaoning, Hunan, Fujian and Guangxi, to three provinces, namely Shandong, Jiangsu and Zhejiang.

4. Analysis of Driving Factors of Industrial Wastewater Discharge

4.1. Decomposition and Contribution Analysis of the National Overall Driving Factor Index

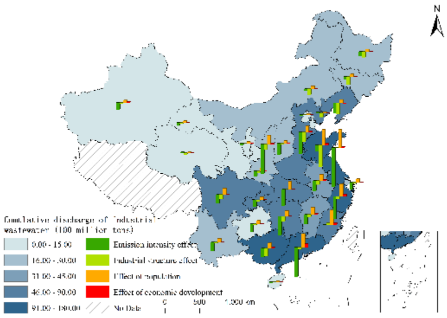
From formula (1) , we can see that the driving factors affecting industrial wastewater discharge are mainly wastewater discharge intensity, industrial structure, economic development and population size. According to formula (3) , the contribution value of each driving factor causing changes in China's industrial wastewater discharge from 2004 to 2019 is calculated respectively.

Table 1. 1results of driving factors of industrial wastewater discharge in China from 2004 to 2019 (100 million tons)

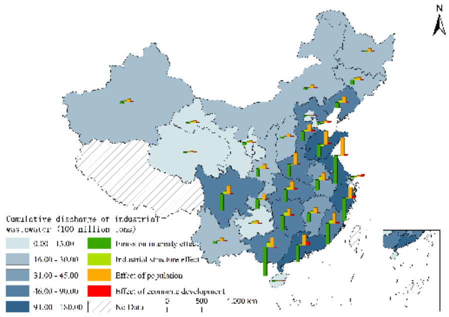
years	Changes in industrial wastewater discharge ΔW	Emission intensity effect ΔI	Industrial structure effect ΔS	Economic development effect ΔE	Population size effect ΔP
2004-2005	21.970	-19.220	14.114	27.953	-0.879
2005-2006	-2.897	-48.431	15.782	39.348	1.849
2006-2007	6.448	-41.063	15.965	18.648	1.857
2007-2008	-5.005	-52.357	21.005	24.530	1.817
2008-2009	-7.267	-23.870	-8.782	23.748	1.637
2009-2010	3.108	-47.231	22.596	23.815	3.928
2010-2011	-6.562	-49.859	17.794	24.346	1.157
2011-2012	-9.288	-26.621	-4.231	20.376	1.189
2012-2013	-11.751	-26.656	-4.611	18.425	1.092
2013-2014	-4.500	-12.002	-8.951	15.396	1.056
2014-2015	-5.913	-4.146	-16.952	14.007	1.178
2015-2016	-48.169	-53.664	-6.883	11.219	1.158
2016-2017	-20.716	-28.811	-1.862	9.034	0.923
2017-2018	1.168	1.221	-8.866	7.955	0.859
2018-2019	2.118	-4.968	-1.155	7.386	0.855

Combining Table 1 and, it can be seen that according to historical data, wastewater discharge intensity (wastewater discharge per unit of industrial added value) and economic development (GDP per capita) have the greatest impact on changes in industrial wastewater discharge. The interannual changes in the total amount of industrial wastewater discharge between 2004 and 2019 showed a steady downward trend. Between 2004 and 2012, the contribution of economic development to the growth of industrial wastewater discharge was 2-4 billion tons/year, with an average annual contribution of 25.346 tons; between 2012 and 2019, the contribution of economic development was 5-2 billion tons/year, with an average annual contribution of 11.917 tons. Although it has declined, it has always been positive, indicating that economic development has always been the dominant factor in promoting the growth of industrial wastewater discharge. Except for 2014-2015 and 2017-2018, wastewater discharge intensity is the most important factor in reducing industrial wastewater emissions, with an average annual contribution of -2.9996 billion tons, continuously reducing industrial wastewater discharge. The contribution value of industrial structure was basically positive between 2004 and 2011, and negative between 2011 and 2019.Impact of various driving factors on changes in industrial wastewater discharge in the province

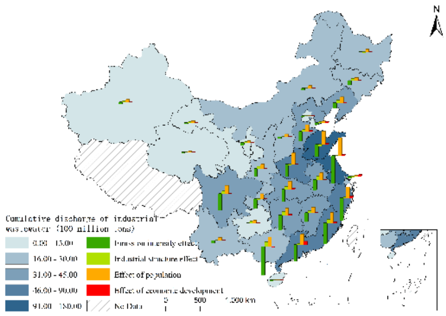
Due to historical and many realistic factors, there are provincial differences among China's regions in terms of resource endowment structure, economic development level, social structure, etc. In order to conduct an in-depth study of the driving factors and their changes in each province, the study period was divided into three time periods: 2004-2009 , 2009-2014 , and 2014-2019 . The index contribution value of each province was calculated using LMDI , and the contribution distribution map of each driving factor was drawn using ArcGIS, as shown in Figure 1.



(a) 2005-2010



(b) 2011-2015



(c) 2014-2019

Figure 1. Distribution of contribution values of various factors in industrial wastewater discharge among provinces in China

4.2. The Impact of Economic Development Effects

Economic development is the main driving factor for promoting industrial wastewater discharge. As shown in Figure 1 , from 2004 to 2009 , the increase in industrial wastewater discharge caused by economic development in Shandong, Henan, Zhejiang, Hubei, Hunan, Fujian, Guangdong, Guangxi, Chongqing, Sichuan and other provinces exceeded 500 million tons, and the increase in discharge in Jiangsu Province, which has a developed economy and abundant water resources, even exceeded 1 billion tons, reaching 1.59 billion tons. The rapid economic development will inevitably consume a large amount of water resources, leading to the continuous growth of industrial wastewater. At the same time, the economic development of Hainan, Guizhou, Gansu, Qinghai, Ningxia, Xinjiang and other provinces is relatively slow, and the increase in discharge in these provinces is even less than 100 million tons. From 2009 to 2014 , the contribution value of the national economic development effect decreased by 21.9 % compared with 2004-2009 , and the increase in discharge in Jiangsu Province decreased by 520 million tons compared with 2004-2009 . The number of provinces with an increase in discharge exceeding 500 million tons dropped from 11 to 7 . From 2014 to 2019 , the contribution of the national economic development effect decreased by 21.9 % compared with 2009-2014 , and the emission reduction rate was relatively stable. Only Jiangsu Province exceeded 500 million tons. The above results show that the impact of economic development factors on the growth of industrial wastewater emissions is getting smaller and smaller.

4.3. Impact of Emission Intensity Effect

As can be seen from the above, the emission intensity effect has the highest contribution to industrial wastewater reduction. According to Figure 1, from 2004 to 2009 , the emission intensity effect had a negative effect on industrial wastewater discharge in all provinces. The top five provinces that most significantly suppressed industrial wastewater discharge were Jiangsu, Hunan, Sichuan, Guangdong and Guangxi, with emission reductions of 2.04 billion tons, 1.35 billion tons, 1.22 billion tons, 1.2 billion tons and 1.04 billion tons. From 2009 to 2014 , there were five provinces with emission reductions exceeding 1 billion tons, namely Guangxi, Jiangxi, Zhejiang, Fujian and Sichuan. Among them, the provinces with greater emission reduction efforts than from 2004 to 2009 were Guangxi, Zhejiang and Fujian, indicating that the wastewater discharge per unit of industrial output value in these provinces has increased and the sewage discharge efficiency has been greatly improved.

4.4. The Impact of Industrial Structure Effects

The contribution of industrial structure effect to industrial wastewater reduction is becoming more and more important. As shown in Figure 1 , from 2004 to 2009 , only Shanghai and Heilongjiang had negative contribution values of industrial structure effect, indicating that the proportion of industrial added value to GDP in most provinces is unreasonable. From 2009 to 2014 , the contribution values of industrial structure effect in six provinces, namely Shandong, Heilongjiang, Chongqing, Henan, Shanghai and Jiangsu, were negative, with emission reductions of 1.0 , 0.47 , 0.41 , 0.40 , 0.36 and 0.09 million tons, indicating that the dependence of economic growth on the extensive development of the industrial sector is decreasing. From 2014 to 2019 , except Fujian, the contribution values of the other 29 provinces and cities turned negative, indicating that the vast majority of provinces have continuously adjusted and optimized their own structures and paid more attention to energy conservation, emission reduction and green and low-carbon development.

5. In Conclusion

This paper aims to explore the driving factors of industrial wastewater discharge and its decoupling from economic growth by using panel data from 30 provinces in China from 2004 to 2019. Taking into full consideration the current situation of unbalanced and uncoordinated development among regions in China, the spatial correlation characteristics of industrial wastewater discharge were analyzed in depth using exploratory spatial data analysis. In terms of research methods, we innovatively introduced the key variable of industrial output value on the basis of the original Kaya identity model, and improved and expanded the model, thus constructing a comprehensive theoretical model including multiple factors such as wastewater discharge intensity and industrial structure.

(1) From 2004 to 2019, China's industrial wastewater discharge has generally fluctuated and decreased, and has shown a spatial distribution pattern of gradually increasing from west to east. Some provinces in the eastern region are high-emission areas, the western region is a low-emission area, and most provinces in the central region are medium-low emission areas or low emission areas. From the trend of change, the number of medium-high emission provinces is decreasing, while the number of medium-low and low emission provinces is increasing.

(2) Economic development is the main driving factor for promoting industrial wastewater discharge; wastewater discharge intensity is the key driving factor for inhibiting industrial wastewater discharge; the contribution of industrial structure effect to the change in industrial wastewater discharge has changed from positive to negative , playing an increasingly important role in wastewater reduction; the impact of population size effect on industrial wastewater discharge in various provinces is not significant in terms of decomposition indicators.

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