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Original Research

Spatial-Temporal Evolution Analysis of Regional MWPIIs and the Development Path under the Integrated Strategy in the Yangtze River Delta, China

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Abstract

In the process of industry modernization, the manufacturing industry became an industry with intensive water pollution emissions. The major water pollutants discharged by the manufacturing sector in the Yangtze River Delta (YRD) accounted for more than 20% of the national total in China. The gross sales value of manufacturing industries in the YRD accounted for nearly 30% of the national gross sales value. Therefore, it is necessary to accurately identify the types of water pollution-intensive industries (WPIIs) in regions with developed manufacturing industries and water networks like the YRD in China, and analyze the spatial-temporal evolution of manufacturing water pollution-intensive industries (MWPIIs) of the YRD for both 2018 and 2020. The comparison method is used to analyze the spatial-temporal evolution in the YRD. Through empirical research, this paper reveals a certain dislocation in the development of manufacturing clustering in the three provinces and one municipality in the YRD. However, it is found that MWPIIs predominantly fall into Large-scale and Super-intensive types, indicating that more than half of water pollution emissions from MWPIIs exhibit both high-scale and intensity characteristics. Therefore, the suggestions for development paths and integrated strategies of MWPIIs are put forward to achieve enhanced regional water environmental governance performance through collaborative environmental governance in the YRD.

Keywords: spatial-temporal evolution, MWPIIs, the integrated strategy, the Yangtze River Delta (YRD)

Introduction

Recently, the extreme precipitation caused by climate variability will increase more than the average in China, and the increase in precipitation will be more regionally extreme [1]. In order to ensure water resources security, promoting water pollution-intensive industries to sustainable transition has become an important applicable measure to deal with climate change. Water resource is a kind of ecological and environmental resource with mobility. Society is still in the age of industrial civilization,

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although the fourth industrial revolution has been digitized, but it is also the age of industrial civilization, and the core of the age of industrial civilization is manufacturing. With the further acceleration of China's industrialization, the types and quantities of water pollutants produced by industry, especially for the manufacturing industry, are also increasing [2]. In an era characterized by a relatively stable and high-quality phase of global industrial development, the imperative for preserving the natural environments in which humanity resides has intensified. Recently, the emission reduction of industrial wastewater and water pollutants for the treatment of industrial water pollution has been mainly achieved by promoting the implementation of discharge standards. The environmental discharge standards in relatively economically developed regions are typically more stringent [3, 4], necessitating the transformation and upgrading of the industrial structure to maintain growth rate and efficiency. According to the standard of the Industrial classification for national economic activities (GB/T 4754–2017), there are 31 categories of manufacturing industry in the Yangtze River Delta (YRD). Water pollutant discharge industry standards in China are mainly concentrated in the manufacturing field, with a total of 48 items by the end of 2019, accounting for about 76% of the total number of water pollution discharge standards of the whole industry. This reflects that the manufacturing industry is an intensive industry with water pollution emissions. Therefore, based on identifying the different types of manufacturing water pollution-intensive industries (MWPIIs) in this region, then through the analysis of the spatial-temporal evolution of regional MWPIIs, the development trend of MWPIIs of the YRD can be found. Under the regional integration development plan of the YRD (2019), the integrated strategy of environmental governance for different types of MWPIIs in the region can be put forward targeted.

As for the definition of pollution-intensive industry (PII), Xia believes that PII is an industry that produces more pollutants in the production process, has adverse effects on biological health, and is harmful to the ecological environment [5]. According to Li and Yao's research, Pollution-Intensive Industries (PIIs) will directly or indirectly produce many pollutants if they are not controlled in the production process, which is harmful to human, animal, and plant life or health, promotes environmental deterioration, and affects ecological quality [6]. There are three methods to identify pollution-intensive industries: first is to compare the pollution reduction cost of each industry; second, according to the intensity of pollution emission; and third, to compare the pollution emission scale of each industry [7]. In recent years, there have been more and more studies on industrial agglomeration, mainly analyzing the impact of environmental regulation on the re-clustering of various pollution-intensive industries (PIIs) [4, 8] based on the pollution haven hypothesis (PHH) [9–12]. Therefore, some local governments often take "one-size-fits-all" measures to control pollution sources, so that PIIs lose the opportunity to upgrade and transform or develop environmental protection products [13, 14]. PIIs have been usually studied as a whole in previous studies, ignoring the differences among different pollution types [15]. At the same time, if divided according to environmental elements, air pollution and water pollution are the focus and difficulty of regional pollution control at present. Due to the complexity of water pollutants in pollution-intensive industries, there is not much research on water pollution-intensive industries (WPIIs) in the existing literature [16, 17]. Geng et al. (2014) analyzed regional differences in industrial wastewater discharge among the 31 provinces of China from 1995 to 2010, and used the Logarithmic Mean Divisia Index (LMDI) method to analyze the main driving factors of industrial wastewater emission changes in all provinces during the study period [18]. But there is still no more research on regional differences in industrial water pollutants such as chemical oxygen demand (COD) and Ammonia nitrogen (AN).

Relevant studies have shown that the COD emissions from industrial wastewater are highlighted due to the contributions of Manufacture of Paper and Paper Products, Manufacture of Foods, and Manufacture of Raw Chemical Materials and Chemical Products [19], which are mainly belong to manufactures and their industrial transfer is significantly influenced by policies. However, there is also rarely research on regional differences in manufacturing water pollutants. So, it is necessary to accurately identify the types of WPIIs in regions with developed manufacturing industries and water networks like the YRD in China, analyze spatial-temporal evolution of MWPIIs in the YRD, to demonstrate that manufacturing heterogeneity contributes to regional differences in spatial patterns of MWPIIs and regional imbalances in environmental governance performance. Therefore, the integrated strategy of environmental governance for MWPIIs in this region will be put forward. The conceptual framework of this article is shown in Fig. 1. Meanwhile, this paper uses manufacturing water pollutant COD and AN data instead of wastewater discharge data to calculate and identify the types of MWPIIs, which are index and method innovation. Therefore, it is a new research perspective that focuses on specific water pollutants to identify the spatial-temporal evolution of MWPIIs type, and a more targeted regional manufacturing development path will be put forward according to this perspective in this paper.

Materials and Methods

According to statistics disclosed by the Bureau of Ecology and Environment of three provinces and one municipality, Fig. 1 shows the wastewater discharge and major water pollutants from the manufacturing industry in the YRD account for the national proportion. AN emission proportion is 31.16%, COD emission proportion is 21.47%, and wastewater discharge proportion is 9.39%, as shown in Fig. 2.

As the YRD is in the lower reaches of the Yangtze River in Eastern China, the wastewater discharge and major

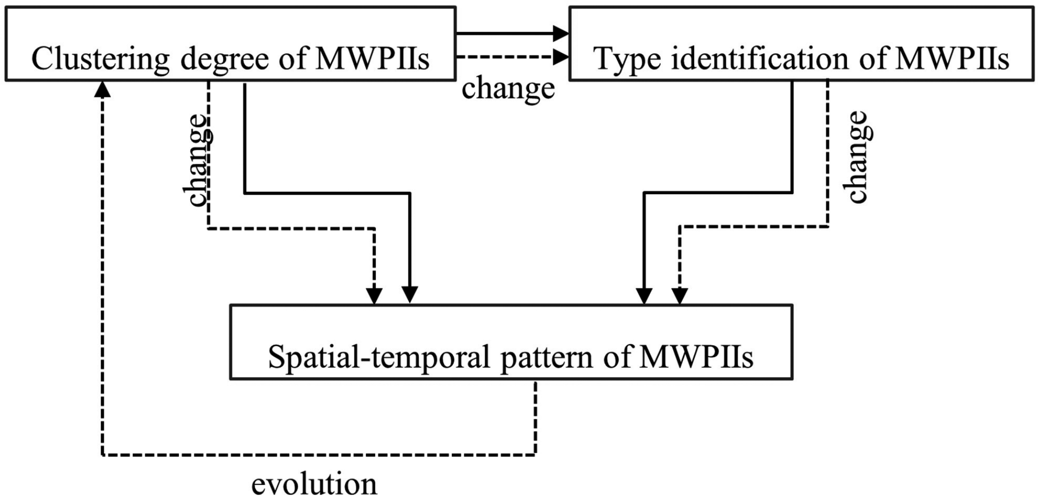

Fig. 1. Conceptual Framework.

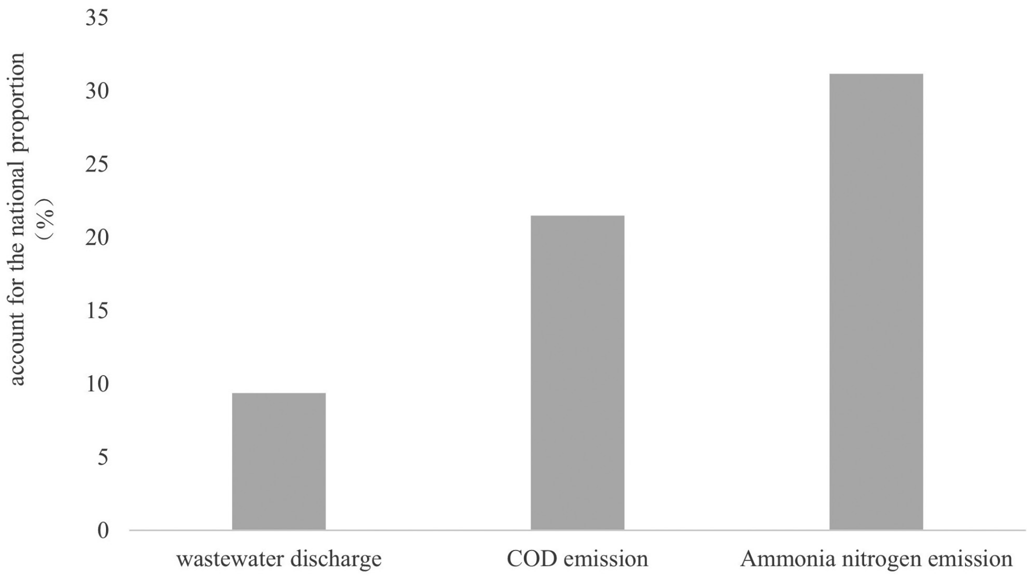

Fig. 2. Wastewater discharge and major water pollutants proportion of national from the manufacturing industry in the YRD in 2020.

water pollutants from the manufacturing industry may threaten the water environment in the YRD. According to GB/T 4754–2017 standard and Statistical Yearbook (2021) of three provinces and one municipality, there are 122.75 thousand manufacturing entrepreneurs in the YRD and Jiangsu Province has the largest number of enterprises (Fig. 3). So, the manufacturing wastewater discharge and manufacturing Gross Industrial Sales Value (GISV) in Jiangsu province is separately 1124287 thousand ton and RMB 11857.01 billion yuan, which are both biggest among three provinces and one municipality. However, the intensity of wastewater discharge from the manufacturing industry in Zhejiang province is 1.34 tons/ten thousand yuan, which is higher than the YRD average and is the highest intensity in the YRD (Fig. 4).

Methodology

Clustering Degree of MWPIIs

Location Entropy (LE) is a typical index for measuring the degree of regional industrial clustering. This index can identify the degree of industrial clustering of MWPIIs in the region. The larger the LE value is, the higher the degree

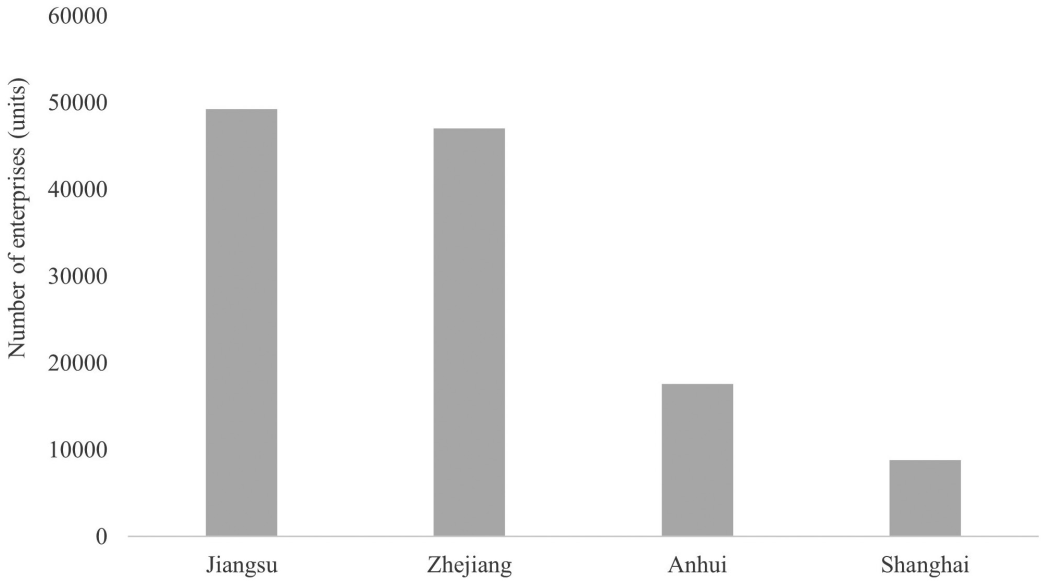

Fig. 3. Number of manufacturing enterprises of three provinces and one municipality in the YRD in 2020.

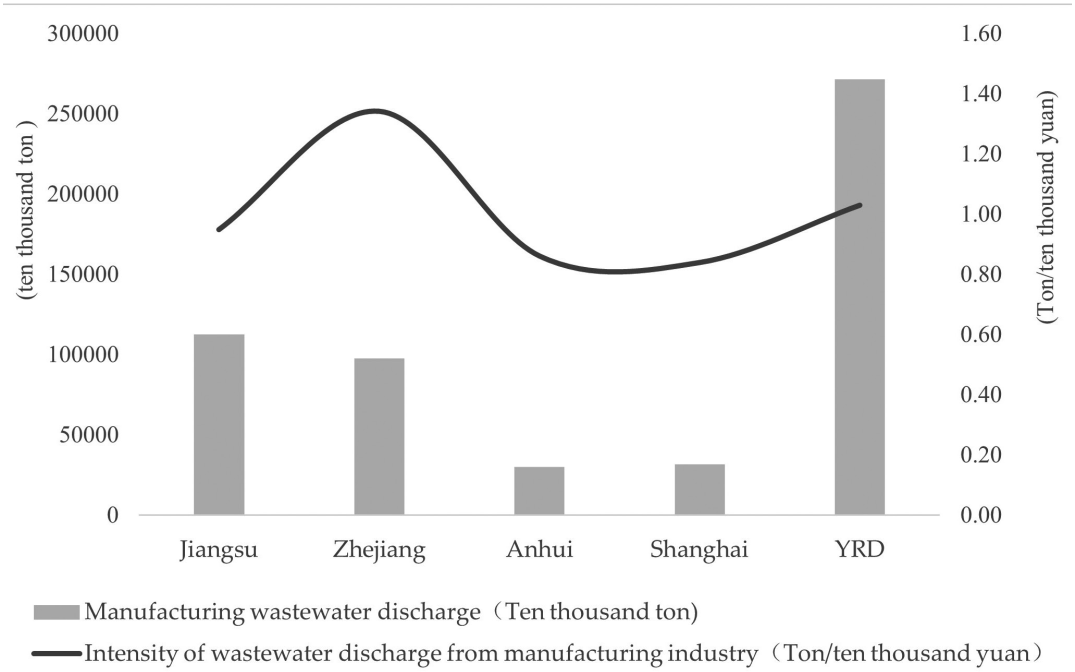

Fig. 4. Manufacturing wastewater discharge, GISV and Intensity of wastewater discharge from manufacturing industry in the YRD in 2020.

of industrial clustering is. When the LE value is greater than 1, it indicates that the industrial clustering degree of the industry in a certain region exceeds that of the whole region, and it belongs to the regional specialized sector. Otherwise, the industrial clustering degree of the industry is low. The ISV of manufacturing industries in the YRD is used as the calculation index to calculate the LE of regional industries, and the calculation results in 2020 are shown in Table 1.

Type Identification of MWPIIs

Scholars have used different standards to provide different definition methods for WPIIs: comparative industry pollution reduction cost [20], comparative industry pollution emission intensity method, that is, the pollution emission per unit of output value [21–24], comparative industry pollution emission [25–27]. Some scholars comprehensively compare pollution emission intensity

Table 1. The ISV and LE of 31 manufacturing industries in the YRD including three provinces and one municipality in 2020 (ISV unit: RMB billion Yuan)

Code Number	Jiangsu Province		Zhejiang Province		Anhui Province		Shanghai Municipality		The YRD	
	ISV	LE	ISV	LE	ISV	LE	ISV	LE	ISV	LE
1	287.48	0.48	97.26	0.26	212.77	1.20	43.38	0.23	640.89	0.48
2	85.91	0.36	60.11	0.41	54.53	0.78	83.90	1.11	284.45	0.54
3	64.17	0.35	44.59	0.40	53.73	1.00	13.36	0.23	175.84	0.43
4	86.13	0.61	93.61	1.09	42.84	1.04	106.12	2.37	328.70	1.05
5	429.63	1.48	411.78	2.32	67.79	0.80	23.77	0.26	932.97	1.45
6	175.18	1.02	189.37	1.81	61.20	1.22	28.55	0.52	454.30	1.19
7	22.44	0.18	80.09	1.05	30.17	0.82	12.70	0.32	145.39	0.52
8	72.81	0.68	46.55	0.71	41.57	1.32	4.36	0.13	165.29	0.69
9	35.08	0.40	104.37	1.95	23.78	0.93	30.70	1.10	193.92	1.00
10	134.46	0.83	146.14	1.47	35.38	0.74	29.48	0.57	345.46	0.96
11	70.33	0.86	52.30	1.04	37.38	1.55	21.18	0.81	181.19	0.99
12	125.29	0.83	133.01	1.43	34.04	0.76	65.23	1.35	357.57	1.06
13	155.44	0.30	197.12	0.62	58.80	0.39	109.78	0.67	521.14	0.45
14	865.97	1.10	559.86	1.16	218.39	0.94	332.61	1.33	1976.83	1.13
15	362.20	1.17	179.72	0.95	90.49	1.00	101.44	1.03	733.84	1.07
16	211.79	2.15	276.96	4.58	10.28	0.35	2.02	0.06	501.04	2.28
17	333.89	1.06	288.14	1.49	137.58	1.48	100.16	1.00	859.77	1.22
18	450.20	0.63	375.92	0.86	301.59	1.43	83.88	0.37	1211.59	0.76
19	983.38	1.09	200.08	0.36	212.83	0.80	167.36	0.58	1563.65	0.78
20	418.74	0.63	275.41	0.67	246.95	1.25	42.29	0.20	983.39	0.66
21	634.71	1.32	352.74	1.20	148.61	1.05	107.46	0.70	1243.52	1.16
22	846.32	1.67	563.13	1.81	166.33	1.11	340.25	2.10	1916.03	1.70
23	604.05	1.45	239.25	0.93	101.81	0.83	159.11	1.20	1104.23	1.19
24	701.60	0.70	533.19	0.86	279.40	0.94	772.78	2.41	2286.97	1.02
25	272.83	1.43	82.39	0.70	16.36	0.29	88.29	1.45	459.86	1.08
26	1346.71	1.58	865.63	1.65	379.83	1.51	262.06	0.96	2854.22	1.50
27	1845.01	1.21	617.27	0.66	348.80	0.78	563.33	1.16	3374.40	0.99
28	187.97	1.86	125.42	2.03	14.88	0.50	44.71	1.39	372.97	1.66
29	13.94	0.47	24.01	1.31	9.33	1.06	5.08	0.53	52.36	0.79
30	31.19	0.43	35.79	0.81	45.18	2.12	4.79	0.21	116.96	0.72
31	2.19	0.18	14.52	1.92	5.56	1.53	26.75	6.81	49.02	1.78

Note: Manufacturing Industry Code Number. 1~31 presents each manufacturing industry see APPENDIX 1.

and pollution emission scale [28–30], and some scholars directly refer to the key polluting industries promulgated in the First National Pollution Source Survey Plan [31–33]. In this paper, the pollution-intensive manufacturing industry is defined by measuring the emission scale of water pollutant emissions (COD and AN) of an industry. The total discharge of water pollutants COD and AN will be calculated and represent water pollution emissions of the manufacturing industry.

S_{ij} represents the industry water pollution emissions scale index of manufacturing industry i in region j. Its formula is as Formula (1):

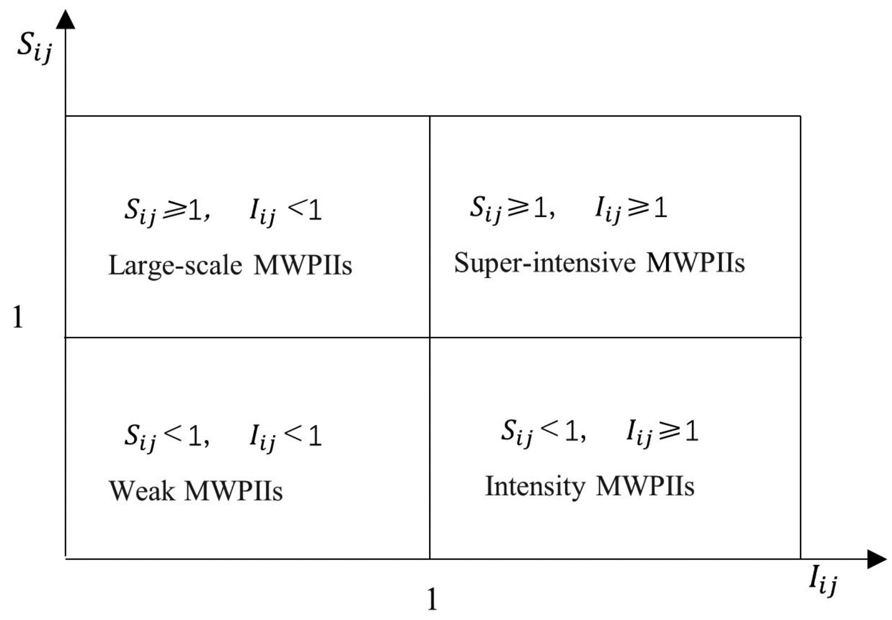

Fig. 5. Type identification basis of regional MWPIIs.

$$S_{ij} = \frac{A_{ij}/\sum_{i=1}^{n} A_{ij}}{\sum_{j=1}^{m} A_{ij}/\sum_{j=1}^{m}\sum_{i=1}^{n} A_{ij}} \quad (1)$$

In Formula (1), the A_{ij} represents water pollution emission of manufacturing industry i in region j, and $\sum_{i=1}^{n} A_{ij}$ represents total water pollution emissions of all manufacturing industries in region j. $\sum_{j=1}^{m} A_{ij}$ represents total water pollution emissions of the manufacturing industry i in China. $\sum_{j=1}^{m}\sum_{i=1}^{n} A_{ij}$ represents the total water pollution emissions of all manufacturing industries in China. So, $S_{ij} > 1$ means the scale of water pollution emissions in region j is bigger than the national average. $S_{ij} = 1$ means the scale of water pollution emissions in region j is equal to the national average. $S_{ij} < 1$ means the scale of water pollution emissions in region j is smaller than the national average.

I_{ij} represents the water pollution emissions intensity index of manufacturing industry i in region j. Its formula is as Formula (2):

$$I_{ij} = \frac{A_{ij}/B_{ij}}{\sum_{j=1}^{m} A_{ij}/\sum_{j=1}^{m} B_{ij}} \quad (2)$$

In Formula (2), the B_{ij} is ISV of manufacturing industry i in region j, and $\sum_{j=1}^{m} B_{ij}$ is total ISV of manufacturing industry j in China. So, $I_{ij} > 1$ means the intensity of water pollution emissions in region j is higher than the national average. $S_{ij} = 1$ means the intensity of water pollution emissions in region j is equal to the national average. $S_{ij} < 1$ means the intensity of water pollution emissions in region j is lower than the national average.

In this paper, the scale index and intensity index of water pollution emission are used as the vertical and horizontal coordinates respectively to form the four-classification type identification basis of MWPIIs as shown in Fig. 5.

(1) Super-intensive MWPIIs. When $S_{ij} \geq 1$, $I_{ij} \geq 1$, it indicates that the manufacturing industry in this region has the highest water pollution emission intensity, which is higher than the national average.

(2) Large-scale MWPIIs. When $S_{ij} \geq 1$, $I_{ij} < 1$, it indicates that the scale of water pollution emission of manufacturing industry i in region j is bigger than the national average, but its intensity of water pollution is lower than the national average.

(3) Intensity MWPIIs. When $S_{ij} < 1$, $I_{ij} \geq 1$, it indicates that the scale of water pollution emission of manufacturing industry i in region j is smaller than the national average, but its intensity of water pollution is higher than the national average.

(4) Weak MWPIIs. When $S_{ij} < 1$, $I_{ij} < 1$, it indicates that the manufacturing industry in this region has the lowest water pollution emission intensity, which is lower than the national average.

Comparison of Spatial-Temporal Change

In order to analyze the spatial-temporal evolution of MWPIIs in the YRD, the comparative method is used in this paper. By comparing the industry type of changes in MWPIIs in 2018 and 2020, the spatial-temporal evolution trend will be found. By comparing the ISV of manufacturing industries in the YRD with high LE, the spatial evolution trend will be found.

Data Acquisition

In this paper, the scale index and intensity index of water pollution [34] are used to identify the types of MWPIIs. In the selection of indicators, in Formula (1) requests total discharge of water pollutants COD and ammonia nitrogen as the indicator of water pollution emission, and in Formula (2) requests GISV and ISV as the indicator of each manufacturing industry output. According to the availability of environmental data, this study uses GISV and ISV in 2018 and 2020 from China Industrial Statistical Yearbook (2019, 2021) and from the Statistical Yearbook (2019, 2021) of three provinces and one municipality in the YRD. The amount of water pollutants (COD and AN) of 31 manufacturing industries in 2018 and 2020 was disclosed by the Ministry of Ecology and Environment of China on request. The Department of Ecology and Environment and Bureau of Ecology and Environment of three provinces and one municipality in the YRD disclosed the amounts of water pollutants of 31 manufacturing industries. The data of GISV and ISV of 31 manufacturing industries are derived from the Statistical Yearbook (2019, 2021) of three provinces and one municipality. Therefore, the calculation results are true and effective.

Results

Status Quo of the Clustering Degree of MWPIIs

The ISV of the manufacturing industry in the YRD reached RMB 26387.73 billion yuan in 2020, accounting for approximately 27% of China's total manufacturing industry. This proportion remained unchanged from 2018. However, there were notable spatial-temporal evolution observed in the industrial clustering patterns within this region. Industrial clustering refers to an economic phenomenon where various production factors are concentrated in specific spatial layouts within an industry. Based on statistics and calculations, it is evident that the top ten manufacturing industries with high LE exhibited significant overlap in 2018 Vs. 2020 across the three provinces and one city within the YRD region. Nevertheless, there was a certain degree of dislocation observed in terms of industrial clustering development among these regions (Table 2).

To summarize, the manufacturing industries in the YRD region with high LE include the Manufacture of Chemical Fibers, Repair Service of Metal Products, Machinery and Equipment, Manufacture of General Purpose Machinery, Manufacture of Measuring Instruments and Machinery, and Manufacture of Electrical Machinery and Apparatus. These industries are classified as ten key special remediation industries in the "Action Plan for Water Pollution Prevention and Control" issued in 2019, which identifies paper making, coking, nitrogen fertilizer production, non-ferrous metals processing, printing and dyeing, agricultural and by-product food processing, raw material manufacturing, leather production, pesticide manufacturing, and electroplating as major contributors to water pollution. Therefore, it can be observed that the manufacturing industries with high LE calculated in this study mainly belong to these aforementioned sectors.

Spatial-Temporal Evolution of Manufacturing MWPIIs

In the context of temporal evolution, the MWPIIs in the region have undergone transformations in 2018 Vs. in 2020 due to the issuance of the "Overall Plan for the Integrated Development of Ecological Green Demonstration Zone in the Yangtze River Delta" in 2019. The S_{ij} and I_{ij} values of MWPIIs present an overall downward trend from 2018 to 2020 (Fig. 6 and 7). Moreover, high S_{ij}

Table 2. Clustering degrees of manufacturing industries in three provinces and one municipality in the YRD in 2018 and 2020 (top ten).

Region/local	Year	Clustering Degree by LE from largest to smallest (Ranking the code of manufacturing industries)									
Jiangsu Province	2018	28	16	26	14	25	5	22	23	27	15
	2020	16	28	22	26	5	23	25	21	27	15
Zhejiang Province	2018	16	5	26	28	9	10	22	14	6	4
	2020	16	5	28	9	31	22	6	26	17	10
Anhui Province	2018	30	20	26	18	8	1	17	11	6	15
	2020	30	11	31	26	17	18	8	20	6	1
Shanghai Municipality	2018	24	4	31	22	27	28	14	25	2	23
	2020	31	24	4	22	25	28	12	14	23	27
The YRD	2018	16	28	26	22	14	5	23	15	24	4
	2020	16	31	22	28	26	5	17	6	23	21

Note: Number meaning is manufacturing industry code number (see APPENDIX 1)

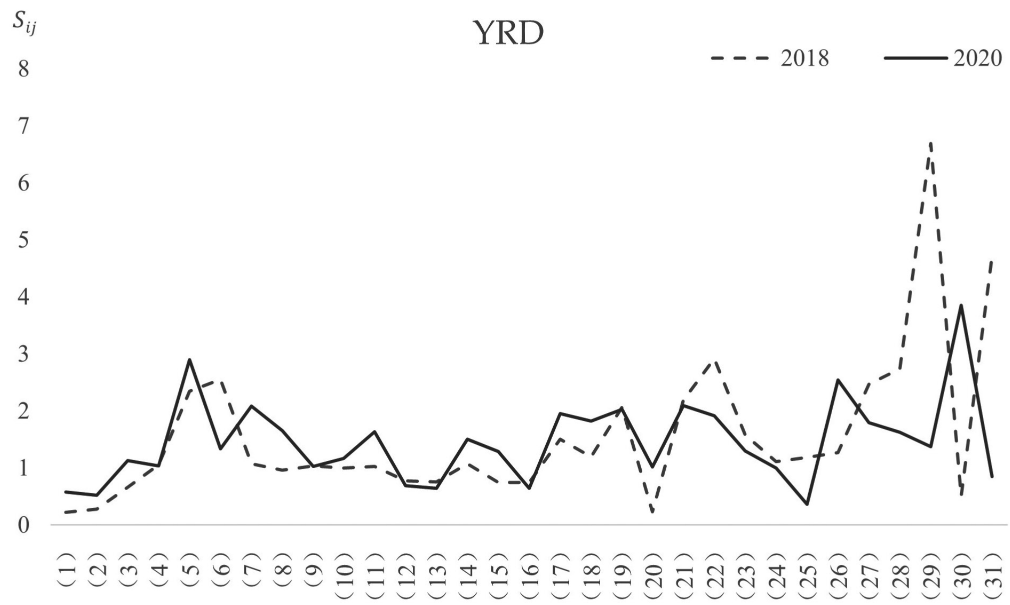

Fig. 6. The S_{ij} of MWPIIs in the YRD in 2018 Vs. 2020.
Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

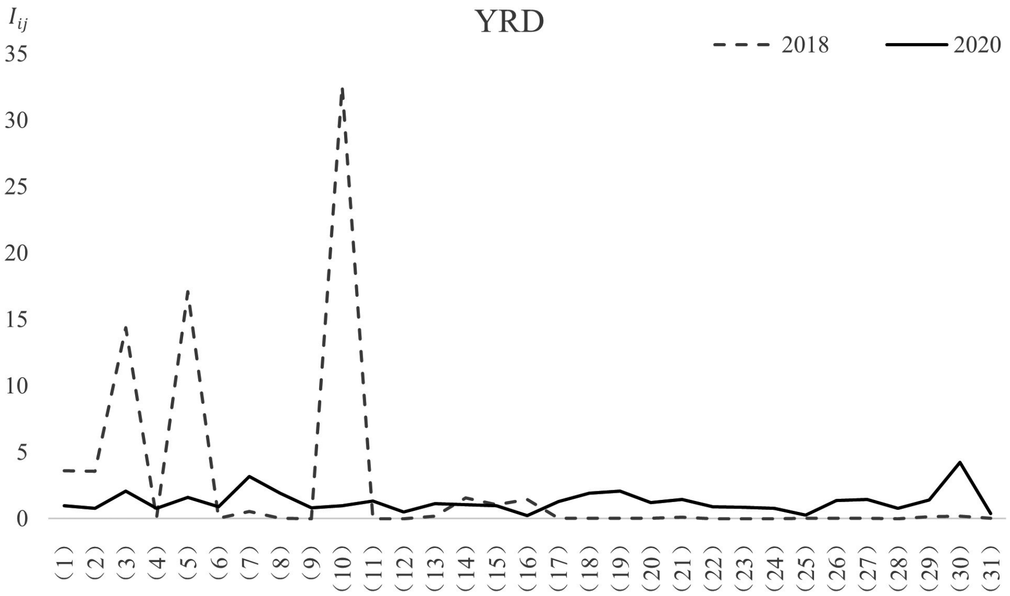

Fig. 7. The I_{ij} of MWPIIs in the YRD in 2018 Vs. 2020.
Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

values are observed in the MWPIIs related to the Utilization of Waste Resources, Manufacture of Textiles, Manufacture of Electrical Machinery and Apparatus, Manufacture of Metal Products, Manufacture of Leather, Fur, Feather, and Related Products and Footwear, Smelting and Pressing of Ferrous Metals. On the other hand, MWPIIs with high I_{ij} values primarily focus on industries such as the Utilization of Waste Resources, Manufacture of Leather, Fur, Feather, and Related Products and Footwear, Manufacture of Liquor, Beverages and Refined Tea, Smelting and Pressing of Ferrous Metals, Manufacture of Non-metallic Mineral Products, Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products.

Among these MWPIIs with high S_{ij} and I_{ij}, it can be observed that, apart from 30 Utilization of Waste Resources which is the manufacture to deal with wastewater in city, Manufacture of Liquor, Beverages and Refined Tea, Manufacture of Textile, Manufacture

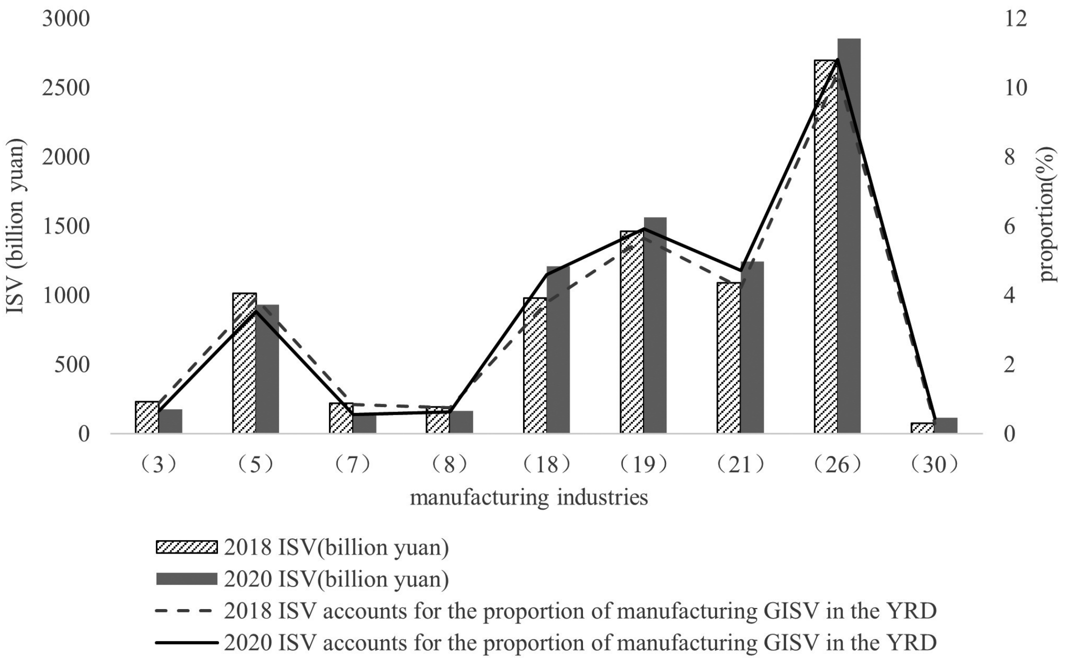

Fig. 8. The ISV and ISV proportion of MWPIIs with high S_{ij} and I_{ij} in the YRD in 2018 Vs. 2020.

Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

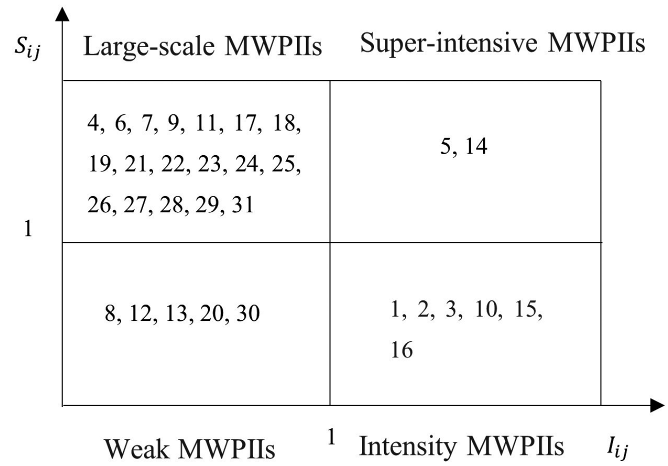

Fig. 9. Type identification of regional WPIIs in the YRD in 2018.

Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

of Leather, Fur, Feather, and Related Products and Footwear, Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products, Smelting and Pressing of Ferrous Metals, and Manufacture of Electrical Machinery and Apparatus also fall under the category of MWPIIs with high S_{ij} and I_{ij}. However, the Manufacture of Electrical Machinery and Apparatus stands out as the MWPIIs with the highest S_{ij} values. Additionally, the ISV for this manufacturing industry is also the highest among all manufacturing GISVs in the YRD region (Fig. 8.).

Therefore, from a temporal comparison perspective, the trend of water pollution caused by MWPIIs in the YRD region is characterized by both high intensity and large scale (Fig. 9 and 10). In 2020, there were more MWPIIs with high S_{ij} and I_{ij} compared to those in 2018. Moreover, pure high-intensity MWPIIs disappeared in 2020 and transformed into double-high MWPIIs.

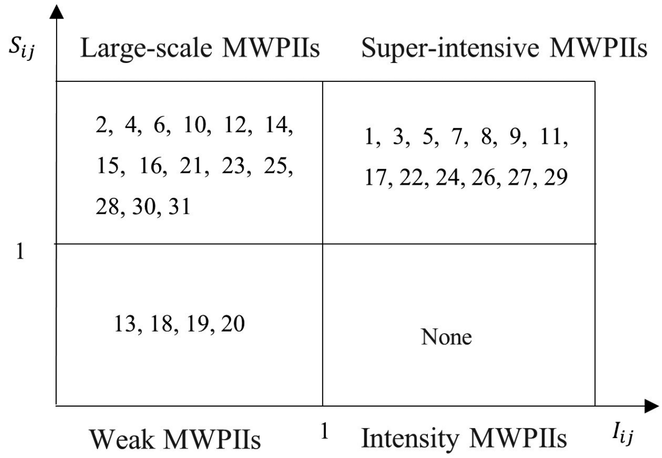

Fig. 10. Type identification of regional MWPIIs in the YRD in 2020.
Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

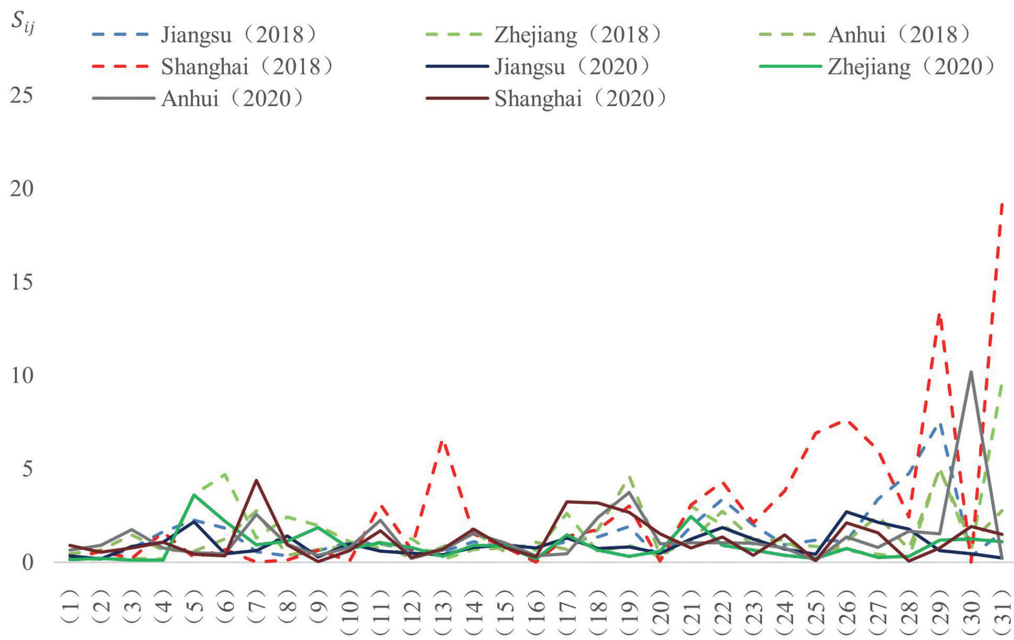

Fig. 11. The S_{ij} values evolution of the three provinces and municipality in the YRD in 2018 Vs. 2020.
Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

In terms of spatial and temporal evolution, considering the scale index, significant changes can be observed among the three provinces and one municipality. Specifically, the S_{ij} value for Shanghai municipality exhibited a considerable decrease from 2018 to 2020, with the value in 2020 being lower than that in 2018. On the other hand, the S_{ij} values for the remaining three provinces remained relatively stable (Fig. 11). However, it is worth noting that despite this decline, Shanghai municipality still maintained a higher S_{ij} value compared to others. Furthermore, in 2020, within the YRD, Anhui province demonstrated the highest S_{ij} value for 30 Utilization of Waste Resource, the ISV of which accounted for only a small proportion (1.3%) of manufacturing industries in Anhui province. Additionally, it should be highlighted that Zhejiang province's manufacturing sector specifically related to the Manufacture of Textile continued to exhibit higher S_{ij} values compared to its other manufacturing industries.

In contrast, considering the intensity index, it can be observed that the I_{ij} of Shanghai municipality exhibited a slight increase in 2020 compared to 2018. The elevated I_{ij} primarily focus on the Manufacture of Leather, Fur, Feather, and Related Products and Footwear, Manufacture of Rubber and Plastics Products, 18 Manufacture of Non-metallic

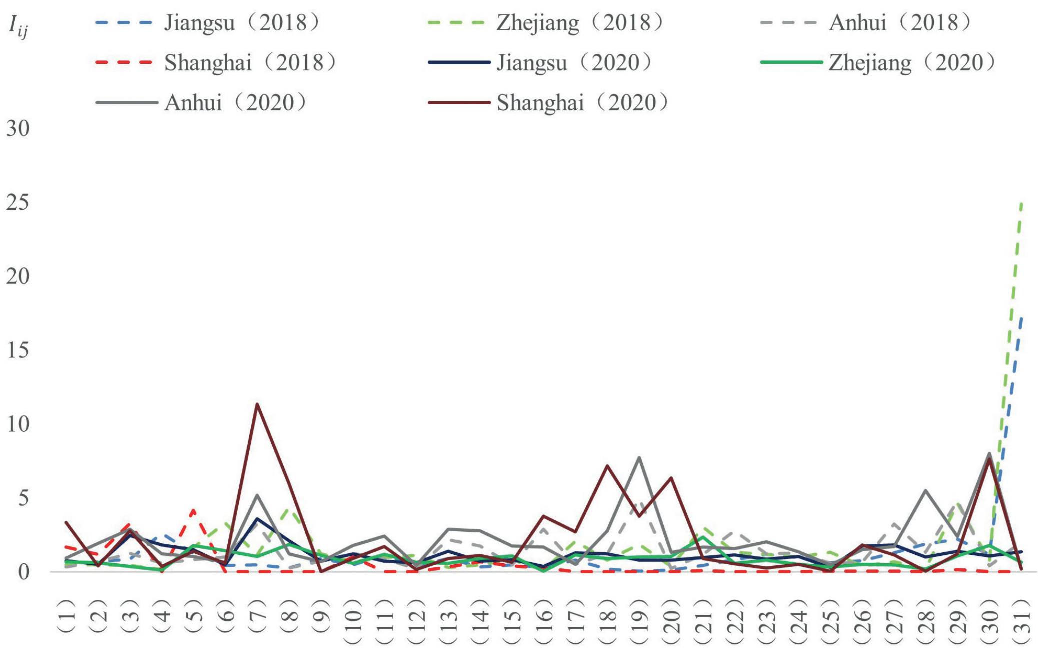

Fig. 12. The I_{ij} values evolution of the three provinces and municipality in the YRD in 2018 Vs. 2020.
Note: Number meaning is manufacturing industry code number (see APPENDIX 1).

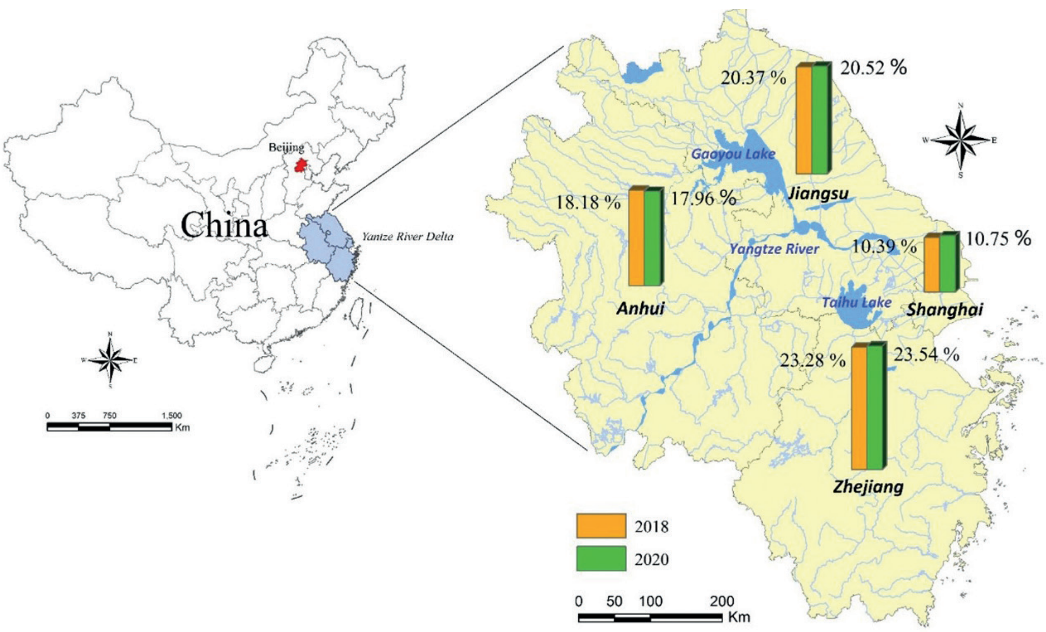

Fig. 13. The total proportion of ISV for the key MWPIIs in three provinces and one municipality of the YRD.

Mineral Products, Smelting and Pressing of Ferrous Metals, Utilization of Waste Resources, Repair Service of Metal Products, Machinery and Equipment. Similarly, Anhui province demonstrated a similar trend as Shanghai municipality (Fig. 12). It is noteworthy that three provinces and one municipality experienced changes in their I_{ij} value within the region; regardless of the specific province or municipality considered, high S_{ij} or high I_{ij} values were consistently associated with the industry related to 30 Utilization of Waste Resource.

Meanwhile, based on the clustering degree of MWPIIs and the type identification of regional MWPIIs, the key MWPIIs identified in the region include five manufactures with industrial code numbers 5, 7, 21, 26, and 30. Furthermore, it is evident from the spatial distribution map that the total proportion of ISV for these key MWPIIs in three provinces and one municipality has increased from 2018 to 2020, except for Anhui province (Fig. 13). Jiangsu province and Anhui province act as upstream provinces in the YRD, where water pollutants from their key MWPIIs continue to pose a threat to Zhejiang province and Shanghai municipality downstream.

Discussion

Suggestions for the Development Path of MWPIIs in the YRD

As the impact of environmental regulation on *PIIs* has both "crowding-out effect" and "innovation compensation effect", there may be a nonlinear relationship between environmental regulation and pollution-intensive industry transfer [35]. Therefore, based on the analysis of spatial-temporal evolution of MWPIIs in the YRD, there are some suggestions for the development path of MWPIIs in the region.

Promoting the Transfer of Low-End MWPIIs

Through identifying the key MWPIIs in the YRD, it is found there are some low-end manufactures in the key MWPIIs, such as the Manufacture of Leather, Fur, Feather, and Related Products and Footwear, which belongs to Large-scale MWPIIs or Super-intensive MWPIIs should be closed or transferred. Promoting the transfer of low-end MWPIIs to central and western regions is not only beneficial to vigorously develop high-level manufacturing industries in the YRD, but also beneficial to driving the economy of less developed areas. With "Detailed Plan for the Land Space of the Ecological and Green Integrated Development Demonstration Zone in the Yangtze River Delta Water Town Living Room (2021–2035)" approved by State Council in 2023, the rapid economic development of the YRD is limited by the capacity of water environment, and the water environment regulation of the YRD industry is constantly strengthened, promoting the transfer of MWPIIs to areas with lower environmental standards and relatively looser regulations. It is suggested that from the perspective of promoting the economic integrated development strategy of the YRD, after the change of water resource environmental capacity, manufacturing enterprises should gradually transfer the production, sales, research, and development (R&D) and even corporate headquarters of MWPIIs to other regions in batches by means of cross-regional direct investment, international trade, technology transfer, and the establishment of marketing outlets or processing points. In particular, the low-end links in the Super-intensive MWPIIs should be transferred as soon as possible. It is necessary to cultivate and develop high-end manufacturing with less pollution and good economic benefits and reduce the pressure of water pollution emissions on the regional water environment.

Strengthening Environmental Regulation of MWPIIs

For manufactures with regional features, such as the Manufacture of Textile and Utilization of Waste Resources, which also belong to Super-intensive MWPIIs, strengthening the environmental regulation of MWPIIs can reduce the water pollution emissions of regional MWPIIs through incentive measures. The previous research results show that if a regional government implements stricter environmental supervision, regulation, and investment policies, it will greatly improve the production technology and product production process of the manufacturing industry, thus enhancing competitiveness. Especially for MWPIIs, strict regulatory policies can promote their improvement and upgrading of product standard system [36]. Therefore, the government should formulate positive and reasonable environmental regulation policies, classify MWPIIs into four types from intensity and scale, formulate environmental regulation policies according to different emission scales, and intensity of the manufacturing industry, and determine environmental standards and norms, even put the different type MWPIIs into industrial parks. At the same time, it is necessary to formulate corresponding fiscal policies, financial policies, talent policies, and other policies [37] to promote the investment in innovation resources for MWPIIs green updating and support technological innovation to reduce the average water pollutant emissions of the manufacturing industry. For Super-intensive and Intensity MWPIIs, the way of compulsory orders should be changed, but innovation support for MWPIIs should be increased through tax policies, and various means such as pollutant discharge charges, pollutant discharge rights trading, and emission reduction subsidies [38] should be used to stimulate the innovation enthusiasm of reducing water pollution emissions.

Increasing the Added Value of Traditional Manufacturing Products

But for many traditional MWPIIs like the Manufacture of Metal Products, Manufacture of Electrical Machinery and Apparatus, increasing the added value through product innovation will enhance the output benefit of MWPIIs. The famous smile curve theory shows that with the investment and innovation of technology R&D, the added value of products upstream of the value chain shows an upward trend. Manufacturing production and processing become the bottom end of the entire value chain. Although the manufacturing industry in the YRD is relatively large, some regions, such as Jiangsu province, may not have strong independent research and development capabilities, lack core technologies, and have a high degree of dependence on foreign technologies. Manufacturing enterprises are in the process of processing and assembly, with fewer packaged and high-end products and technologies, and more parts and material products in the intermediate link. It is suggested to comprehensively enhance the technological innovation R&D capability of enterprises, attach importance to the expansion of technological innovation in the application field, and select a number of representative and distinctive enterprises to carry out the construction of R&D centers centering on the application level. At the same time, it is necessary to promote building brand of the manufacturing industry in the YRD, guide enterprises to formulate brand planning, and improve brand quality along the whole value chain, such as R&D innovation, production and manufacturing improvement, quality management improvement, and marketing service system improvement, and consolidate the foundation of brand development, so as to continuously improve the added value of manufacturing products and increase MWPIIs' profits of the YRD.

Discussion for an Integrated Strategy of Environmental Governance in the YRD

The implementation of independent control measures alone, without identifying the water pollution manufacturing industry in the region, falls significantly short. It is imperative to enhance the overall effectiveness of water environmental governance in the YRD through inter-governmental collaborative efforts under the Action Plan for Water Pollution Prevention and Control and the Overall Plan for the Demonstration Zone of Ecological and Green Integrated Development in the YRD in 2019.

Firstly, with regards to urban sewage treatment plants, where the total discharge of water pollutants accounts for nearly 40%, China has initiated a proposal to revise the national 'Urban Sewage Treatment Plant Emissions' standard (GB18918–2002) in 2022, focusing on enhancing the discharge concentration standards. However, Anhui Province, situated in the upper reaches of Taihu Lake Basin in the YRD, only issued the discharge limits standard (DB34/2710–2016) of major water pollutants in Chaohu Lake Basin for urban sewage treatment plants and industrial industries. Furthermore, there have been no established discharge limits for major water pollutants applicable to urban sewage treatment plants and industrial industries within Anhui province. The proposed discharge standards for major water pollutants concerning urban sewage treatment plants and industrial industries in Anhui Province's Huaihe River Basin (draft for comments) were introduced in 2019; however, they have not yet been implemented despite covering a broader administrative scope. Meanwhile, Zhejiang Province and Shanghai municipality revised and released new discharge standards for main water pollutants applicable to polluted water treatment plants which are standard DB33/2169–2018 and standard DB31/199–2018, respectively. Both Zhejiang Province and Shanghai Municipality also adopted transitional standard limits before and after implementing these new standards. It is evident that significant disparities exist among the water pollutant discharge standards of urban sewage treatment plants across these three provinces and one city, which hinder integrated improvements in water pollutant treatment performance within the YRD.

Secondly, given the increasingly stringent environmental regulations in China, it is imperative to enhance regional water ecological and environmental performance through collaborative governance for MWPIIs management in the transboundary area of the Yangtze River Delta Eco-Green Integrated Development Demonstration Zone. It is necessary not only to request the low-end and high-intensity MWPIIs within the demonstration zone benchmarking water pollution emission standards in the region, but also to elevate the level of water pollution control through green upgrading and transformation. Furthermore, leveraging exceptional third-party water pollution control enterprises in the YRD can facilitate promoting water pollution control among public sector and MWPII enterprises while enhancing efficiency in regional water pollution control. So, this collaborative governance is not only among regions but also among different departments of governments, enterprises, and society, which need to break regional segmentation through the innovation of institutional mechanisms.

Thirdly, digital technology empowers collaborative governance of MWPIIs' pollutants emission. To ensure the long-term effectiveness of governance performance in MWPII enterprises within the YRD, a monitoring platform and database for water pollutant discharge from these enterprises have been established. Using digital technology and data sharing enables real-time monitoring of discharge concentrations of various types of water pollutants from MWPII enterprises in the region, facilitating timely identification of issues such as excessive discharge, leakage, and unauthorized discharges. This is helpful to accurately, timely and comprehensively reflect the current situation and development trend of environmental quality in the YRD and provide a scientific basis for the collaborative governance of water pollutants emission. Meanwhile, the Yangtze River Delta Regional Emissions Trading Platform was established in June 2024. This new platform is now only available in the pilot region, including Qingpu district of Shanghai municipality, Wujiang city of Jiangsu Province, Jiashan city of Zhejiang Province, Guangde city of Anhui Province. In the future, it should explore the establishment of a unified regional system for accounting for the total amount of pollutants and allocating the right to ascertain the right to pollutant emission. So, this trading platform could accommodate a wider range of MWPIIs in the YRD with digital technology upgrading.

Finally, a compensation mechanism based on the Regional Emissions Trading Platform should be established to achieve integrated governance of total regional pollutants emissions and improve governance performance. The unified compensation standard and rates should be open and transparent to the public through a digital platform, which will enhance public understanding of and trust in environmental governance and promote public participation and oversight.

Conclusions

Taking three provinces and one municipality in the YRD as an example, this paper analyzes the clustering degree of 31 manufacturing industries and the types identification of MWPIIs in the YRD and three provinces and one municipality for both in 2018 and 2020, and puts forward the strategies to deal with the water pollution emission of manufacturing industries at the regional levels, including the industrial adjustment countermeasures to distinguish urban sewage treatment plants from traditional manufacturing industries. The proposed countermeasures and suggestions will play a positive guiding role in the high-quality development of water pollution prevention and control of regional manufacturing industries and water environment governance in the future 5 years.

Through empirical research, this paper reveals a certain dislocation in the development of manufacturing clustering in the three provinces and one municipality in the YRD. However, by analyzing spatial-temporal evolution of MWPIIs in the YRD, it is found that MWPIIs with high and values are focused on MWPIIs with industrial code numbers 3, 5, 7, 8, 18, 21, 26, 30. Among these key MWPIIs, Manufacture of Electrical Machinery and Apparatus stands out with the highest S_{ij} value, as well as its ISV and ISV accounts for the proportion of manufacturing GISV being highest in the region. Additionally, the Utilization of Waste Resources emerges as an important MWPII with high S_{ij} and I_{ij} values across three provinces and one municipality within the YRD. Notably, there were no pure-intensity MWPIIs throughout the entire YRD in 2020. MWPIIs in this region predominantly fall into Large-scale and Super-intensive types, indicating that more than half of water pollution emissions from MWPIIs exhibit both high-scale and intensity characteristics. In terms of spatial evolution based on scale index perspective, the MWPIIs in Shanghai municipality experienced a significant change in water pollution scale and intensity characteristics between 2018 and 2020, with a decrease observed, whereas the other three provinces show relatively stable trends. Furthermore, the clustering degree analysis reveals five key MWPIIs industries identified within this region: their industrial code numbers are 5, 7, 21, 26, and 30. The spatial distribution map further confirms an increase in total ISV proportion for these key MWPIIs across three provinces and one municipality from the year 2018 to 2020, except for Anhui province. The upstream provinces like Jiangsu province and Anhui province in the YRD still pose a threat to downstream regions like Zhejiang province and Shanghai municipality due to the presence of key water pollutants.

Based on the empirical results, this paper proposes suggestions for development paths of MWPIIs in the YRD, including (1) promoting the transfer of low-end MWPIIs; (2) strengthening environmental regulation of MWPIIs; (3) increasing the added value of traditional manufacturing products in the YRD. Additionally, the integrated strategies and recommendations of MWPIIs in the YRD have been proposed, including unifying and benchmarking the best water pollutant emission standard; digital technology empowers collaborative governance; promoting Regional Emissions Trading Platform; and establishing regional compensation mechanisms.

Although this paper uses new data and index methods to analyze the spatial-temporal evolution of MWPIIs in the YRD for both 2018 and 2020, it still has some deficiencies such as a lack of continuity in data, lack of trade-off game analysis of MWPIIs transferring in and out of the YRD. These research deficiencies will be improved in future studies. Therefore, the development paths and integrated strategies for MWPIIs in the YRD will be put forward more systematically and targeted.

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Conflict of Interest

The authors declare no conflict of interest.

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APPENDIX 1

Manufacturing Industry	
Code Number	Name
1	Processing of Food from Agricultural Products
2	Manufacture of Foods
3	Manufacture of Liquor, Beverages and Refined Tea
4	Manufacture of Tobacco
5	Manufacture of Textile
6	Manufacture of Textiles, Wearing Apparel and Accessories
7	Manufacture of Leather, Fur, Feather and Related Products and Footwear
8	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products
9	Manufacture of Furniture
10	Manufacture of Paper and Paper Products
11	Printing and Reproduction of Recording Media
12	Manufacture of Articles for Culture, Education, Arts and Crafts, Sports and Entertainment Activities
13	Processing of Petroleum, Coal, and Other Fuels
14	Manufacture of Raw Chemical Materials and Chemical Products
15	Manufacture of Medicines
16	Manufacture of Chemical Fibres
17	Manufacture of Rubber and Plastics Products
18	Manufacture of Non-metallic Mineral Products
19	Smelting and Pressing of Ferrous Metals
20	Smelting and Pressing of Non-ferrous Metals
21	Manufacture of Metal Products
22	Manufacture of General Purpose Machinery
23	Manufacture of Special Purpose Machinery
24	Manufacture of Automobiles
25	Manufacture of Railway, Ship, Aerospace and Other Transport Equipment
26	Manufacture of Electrical Machinery and Apparatus
27	Manufacture of Computers, Communication, and Other Electronic Equipment
28	Manufacture of Measuring Instruments and Machinery
29	Other Manufacture
30	Utilization of Waste Resource
31	Repair Service of Metal Products, Machinery and Equipment

Source: Industrial classification for national economic activities (GB/T 4754–2017).
https://www.stats.gov.cn/sj/tjbz/gmjjhyfl/202302/P020230213400314380798.pdf.