Factor Decomposition Analysis of Industrial Wastewater Discharge: A Case of China's Jiangxi Province

Mianhao Hu[1*] Yunling Hu[1] Juhong Yuan[2] Fucai Lu[1]
1. Institute of Ecological Economics, Jiangxi University of Finance & Economics, Nanchang 330032, China
2. Institute of Environment and Plant Science, Jiangxi University of Finance and Economics, Nanchang, 330032, China

Abstract
Industrial wastewater discharge is a serious problem for the environmental management of water in Jiangxi, China. In order to analyze the drivers of industrial wastewater discharge in 2004-2015, we used a Logarithmic Mean Divisia Index (LMDI) method to examine four effects including scale , structure , discharge intensity, and technology on the discharges. In 2004-2015, the wastewater discharge from Jiangxi's industrial sectors increased by 2348.918 $\times 10^4$ tons. The expansions of production scale and discharge intensity were the main factors leading to increases in industrial wastewater discharges, by1.392-fold and 1.028-fold, respectively. Improvements in abatement technology and adjustment of industrial structure was most important role in decreasing industrial wastewater discharge by 0.659-fold and 0.996-fold, respectively. The main industries that led to increased wastewater discharge during 2004-2015 were WC, MPNFMO, PFAP, Mte, MPPP, MRCMCP, MM, and MCCOEE. We showed that if control of wastewater discharge in Jiangxi's industrial sectors is to be achieved in future, the industrial sectors should continue to rely on advanced technology to improve efficiency of water use in the short term, and should simultaneously limit expansion of energy-intensive and highly polluting industries. This may help accelerate restructuring and upgrading of the industrial sector in China in the long run.
Keywords: decomposition factors, wastewater discharge, Jiangxi, industrial sectors, LMDI

1. Introduction

Industry is a vital component of the economy in China but it is also one of the main sources of wastewater discharge into the environment. For years, industrial wastewater discharge has accounted for more than 40% of the total wastewater discharge in China (Li et al., 2013). Since emission reduction targets were proposed as part of the 11th Five-Year Plan, a large number of studies have been conducted on the mechanisms associated with wastewater reduction. The methods involved include Environment Kuznets Curve (EKC) (Gu et al., 2009; Xiong et al., 2017), Input-output model (Okadera et al., 2006; Tang and Xia 2015), Vector Error Correction Model (VECM) (Xiao et al., 2011), life cycle assessment (LCA)-based water footprints (Gu et al., 2014), Information Entropy-Grey System theory (Wu et al., 2016), the Vector Auto-regression (VAR) model (Chen et al., 2013), and the Logarithmic Mean Divisia Index (LMDI) method (Lei et al., 2012; Geng et al., 2014; Chen et al., 2016). However, because the LMDI method can eliminate both residuals and legislate for zero values, using a simple calculation process and intuitive decomposition results (Ang 2005; Ang 2007), it has been widely adopted and continuously refined in various fields. These range from policy-making in relation to the environment (Sun 1998), causes of environmental pollution (Ang 2004), energy efficiency (Ang and Xu 2013; Carmona and Collado 2016; Li and Zhang 2017), and reduction of carbon emissions (Wang et al., 2013; Shao et al., 2014; Xu et al., 2014; Zhou et al., 2014; Su et al., 2014; Chen and Yang 2015; Ouyang and Lin 2015; Zhang et al., 2015; Wu et al., 2016; Ang et al., 2016; Li et al., 2016). Recently, studies have investigated the characteristics of industrial wastewater discharge at both national or provincial scales (Popa et al., 2012; Shirin and Yadav 2014; Li et al., 2014). In addition, they have also examined industrial wastewater discharge and the drives (Li et al., 2013; Chen et al., 2016), and the measurement of regional wastewater discharge (Lei et al., 2012; Guo et al., 2014). However, due to the large gap in regional socio-economic development, as well as the effects of regional heterogeneity on industrial wastewater discharge being ignored, there are still some gaps in the effects of regional wastewater discharge. Therefore, in the context of sustainable development, further research on industrial wastewater discharge and its drivers is necessary at both national and regional scales.

The State Council of the People's Republic of China published ''Opinions on applying the strictest water resources management system'' in January 2012. A ''red line'' relating to water resources was proposed in the Opinions paper, which also included a ''red line'' relating to water utilization (700 billion m^3 by 2030). The 'red line' denotes the threshold that should not be reached. The ''red line'' relating to water efficiency (approaches or attains levels in the developed world by 2030 and water consumption per ten thousand yuan should be reduced to below 40 m^3); the ''red line'' also relates to the pollutant discharge limits in water function zones (the water quality qualification rate in water function zones must exceed 95% by 2030). The promulgation and implementation of the policy provides powerful support for restricting regional industrial wastewater discharge and gradually improving the industrial water utilization efficiency in the medium and long term. For that reason, this paper analyzes the wastewater discharge situation and its influencing factors in Jiangxi's industrial sectors using the the LMDI method from 2004 to 2015. We then analyzed the specific effect of each influencing factor on wastewater discharge at different intervals, and focused on the influence of sector structure factors on wastewater discharge. The aim of this paper is to: (1) identify the dominant factors that drive the change in wastewater discharge by Jiangxi's industrial sectors; (2) provide a basis for establishing mitigation strategies for wastewater discharge in Jiangxi's industrial sectors and achieving harmonized development between economic growth and environmental sustainability in the Jiangxi Province.

2. Materials and Methods

2.1 Research location

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

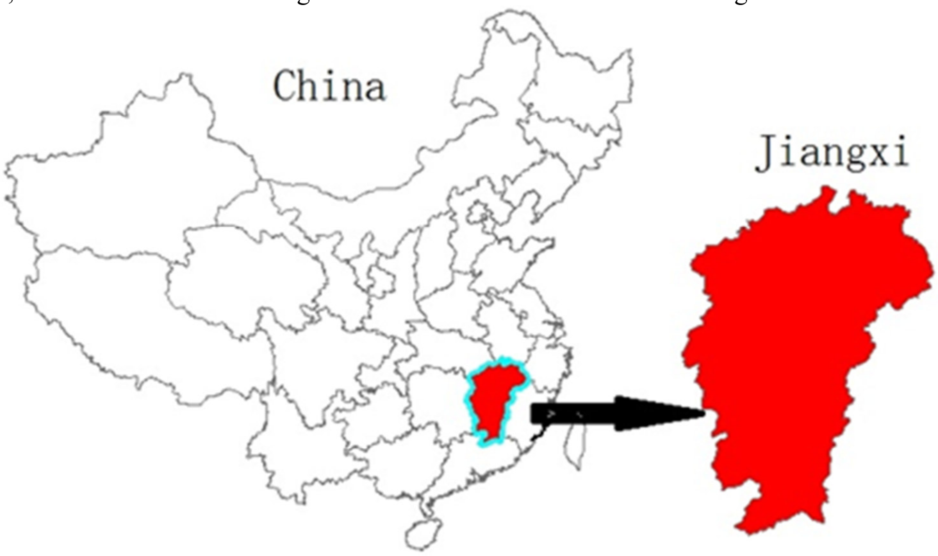


Figure 1. Location of Jiangxi Province in China.

Jiangxi Province covers an area of 166,900 km^2 and ranges from 24° 29′ 14″ to 30° 04′ 41″ N and from 113° 34′ 36″ to 118° 28′ 58″ E. Jiangxi Province is in the upper half of the industrial middle stage, and with the recent, rapid development of the Poyang Lake ecological economic zone, it has become the most economically active area in South China. In particular, the Poyang Lake ecological economic zone was included in the national strategy in 2009, since it has further accelerated the economic development of Jiangxi. Consequently, there are new requirements for the expansion of quantity and quality improvement in the industrial sector in Jiangxi.

2.2 Definition of factor decomposition in industrial wastewater discharge

According to Sun (1998), changes in China's industrial wastewater discharge can be attributed to effects associated with production, structure, intensity, and pollution abatement. In this paper, we refer to the basic LMDI model (Ang 2005), where the aggregate industrial wastewater discharge is expressed as a summation of all sectors, and decomposed using the impact index as follows:

$$\mathrm{S} = \sum_i S_i = \sum_i Q \times \frac{Q_i}{Q} \times \frac{E_i}{Q_i} \times \frac{S_i}{E_i} = \sum_i Q \times C_i \times I_i \times T_i \qquad (1)$$

where S denotes the total amount of industrial wastewater discharge; the subscript i represents diverse sectors; S_i refers to the industrial wastewater discharge of sector i; t is the time in years; Q is the gross output value of industry; Q_i is the output value of sectors i; E_i is the total water use by sectors i; C_i is the proportion of sector i output value; I_i refers to the intensity of wastewater discharge by sector i; T_i is the proportion of wastewater discharge by sectors i to total water use of sectors i, and represents the governance effect.

2.3 LMDI Decomposition Method

LMDI decomposition can be conducted in two ways with the same data from i industrial sectors: the additive form of the direct decomposition of a quantity change is provided in the chosen measurement unit as the factorized effects; while the multiplicative form measures the change by dividing the aggregate intensity of one year, with the factorized effects provided in the indices (Ang 1998). According to the LMDI approach and Equation (1), the additive Equation (2) and multiplicative Equation (3) result in decomposition data being obtained for the base year 0 and target year *t* as follows:

$$\Delta S_{tot} = S^T - S^0 = \Delta S_{act} + \Delta S_{str} + \Delta S_{int} + \Delta S_{tec} \quad (2)$$

$$D_{tot} = \frac{S^T}{S^0} = D_{act} \times D_{str} \times D_{int} \times D_{tec} \quad (3)$$

In Eqs. (2) and (3), ΔS_{tot} and D_{tot} represents the change in industrial wastewater discharge in Jiangxi between base year 0 and target year *t*, and can be decomposed into four effects as follows: (i) $\Delta Sact$ and D_{act} denote the industrial scale effect, and reflect the effects of scale expansion in industrial sectors; (ii) ΔS_{str} and D_{str} denote the structure effect, and reflect the effects of industry structural change; (iii) ΔS_{int} and D_{int} denote the intensity effect, and reflect the effects of the changes in water saving technology and production technology levels in the production sectors; and (iv) ΔS_{tec} and D_{tec} denote the pollution abatement effect, and reflect the effects of the changes in technical progress and environmental protection investment.

In accordance with the additive version of the LMDI decomposition method (Ang 2005), Equation (2) can be described as:

$$\Delta S_{act} = \sum_i \frac{(S_i^t - S_i^0)}{(lnS_i^t - lnS_i^0)} ln\left(\frac{Q^t}{Q^0}\right) \quad (4)$$

$$\Delta S_{str} = \sum_i \frac{(S_i^t - S_i^0)}{(lnS_i^t - lnS_i^0)} ln\left(\frac{C_i^t}{C_i^0}\right) \quad (5)$$

$$\Delta S_{int} = \sum_i \frac{(S_i^t - S_i^0)}{(lnS_i^t - lnS_i^0)} ln\left(\frac{I_i^t}{I_i^0}\right) \quad (6)$$

$$\Delta S_{tec} = \sum_i \frac{(S_i^t - S_i^0)}{(lnS_i^t - lnS_i^0)} ln\left(\frac{T_i^t}{T_i^0}\right) \quad (7)$$

In accordance with the multiplicative version of the LMDI decomposition method (Ang 2005), Equation (3) can be described as:

$$D_{act} = \exp\left(\sum_i \frac{\frac{(S_i^t - S_i^0)}{(\ln S_i^t - \ln S_i^0)}}{\frac{(S^t - S^0)}{(\ln S^t - \ln S^0)}} \ln\left(\frac{Q^t}{Q^0}\right)\right) \quad (8)$$

$$D_{str} = \exp\left(\sum_i \frac{\frac{(S_i^t - S_i^0)}{(\ln S_i^t - \ln S_i^0)}}{\frac{(S^t - S^0)}{(\ln S^t - \ln S^0)}} \ln\left(\frac{C_i^t}{C_i^0}\right)\right) \quad (9)$$

$$D_{int} = \exp\left(\sum_i \frac{\frac{(S_i^t - S_i^0)}{(\ln S_i^t - \ln S_i^0)}}{\frac{(S^t - S^0)}{(\ln S^t - \ln S^0)}} \ln\left(\frac{I_i^t}{I_i^0}\right)\right) \quad (10)$$

$$D_{tec} = \exp\left(\sum_i \frac{\frac{(S_i^t - S_i^0)}{(\ln S_i^t - \ln S_i^0)}}{\frac{(S^t - S^0)}{(\ln S^t - \ln S^0)}} \ln\left(\frac{T_i^t}{T_i^0}\right)\right) \quad (11)$$

2.4 Data sources and descriptions

Jiangxi's industrial sectors have been divided into 37 sub-sectors based on the National Industrial Classification of all Economic Activities (GB/T4754-2002). However, considering the data integrity, consistency and availability, some service sectors have been merged and the number of sectors was reduced from 37 to 32 in this paper (Table 1). The data for 2004-2015 on industrial wastewater discharge and industrial water use are collected from the Statistical Yearbook. The data for gross industrial output values and industrial sector output values were also taken from the Jiangxi Statistical Yearbook and provided as 10^8 CNY at a constant 2002 price. Definition of variables are as follows: (1) Sector scale (namely, sector output values) is expressed by the total output value of industrial sectors; (2) wastewater discharge intensity of industrial sectors is measured by the discharge amount of wastewater produced by the unit output value of each industrial sector; (3) sector structure is measured by the proportion of output value of each sector to gross output value of the industrial sectors; and (4) pollution abatement effect is expressed through the proportion of sector wastewater discharge to sector water use.

Table 1. Classification of industrial sectors in 2002

Sectors	Description	Abbreviation
1	Mining and Washing of Coal	MWC
2	Mining and Processing of Ferrous Metal Ores	MPFMO
3	Mining and Processing of Non-Ferrous Metal Ores	MPNFMO
4	Mining and Processing of Non-metal Ores	MPNO
5	Processing of Food from Agricultural Products	PFAP
6	Manufacture of Foodstuff	MF
7	Manufacture of Wine, Beverages and Refined Tea	MWBRT
8	Manufacture of Tobacco	Mto
9	Manufacture of Textile	MTe
10	Manufacture of Textile Wearing Apparel, Dress	MTeWAD
11	Manufacture of Leather, Fur, Feathers and Related Products and Footwear	MLFFRPF
12	Processing of Timber, Manufacture of Wood, Bamboo, Rattan, Palm, and Straw Products	PTMWBRPSP
13	Manufacture of Paper and Paper Products	MPPP
14	Printing & Reproduction of Recording Media	PRRM
15	Manufacture of Articles for Culture, Education, Artwork, Sport Activity and Amusement	MACEASAA
16	Processing of Petroleum, Coking, Processing of Nuclear Fuel	PPCPNF
17	Manufacture of Raw Chemical Materials and Chemical Products	MRCMCP
18	Manufacture of Medicines	MM
19	Manufacture of Chemical Fibers	MCF
20	Manufacture of Rubber and Plastics	MRP
21	Manufacture of Non-metallic Mineral Products	MNMP
22	Smelting and Pressing of Ferrous Metals	SPFM
23	Smelting and Pressing of Non-ferrous Metals	SPNFM
24	Manufacture of Metal Products	MMP
25	Manufacture of General Purpose Machinery	MGPM
26	Manufacture of Special Purpose Machinery	MSPM
27	Manufacture of Railway, Shipping, Aerospace and Other Transport Equipment	MRSAOTE
28	Manufacture of Electrical Machinery and Equipment	MEME
29	Manufacture of Computers, Communications and Other Electronic Equipment	MCCOEE
30	Manufacture of Measuring Instruments and Machinery for Culture, Activity and Office Work	MMIMCAOW
31	Manufacture of Artwork and Other Manufacturing	MAOM
32	Production and Supply of Electric Power and Heat Power	PSEPHP

3. Results and Discussion

3.1 Changes in industrial *wastewater* discharge and *water consumption per ten thousand yuan of industrial output in Jiangxi*

The industrial wastewater discharge and water consumption per ten thousand yuan of industrial output in Jiangxi for the period 2004-2015 is presented in Figure 2. The industrial wastewater discharge trend exhibited an inverted-U and U-type shape from 2004 to 2015, and then increased to 71454.57 × 10^4 t in 2015. The water consumption per ten thousand yuan of industrial output showed a U-type shape from 2004 to 2015, and then increased to 387.969 t/10^4 yuan. This far exceeded the national level of China (90 t/10^4 yuan) (Ren 2008). The main reasons for this were due to the fact that total quantity of water resources in Jiangxi province is relatively abundant and there appears to be extensive and unrestrained use. In contrast, the production process is relatively backward and the consumption rate of water resources is low in Jiangxi's industrial sectors, which resulted in high water consumption per ten thousand yuan of industrial output.

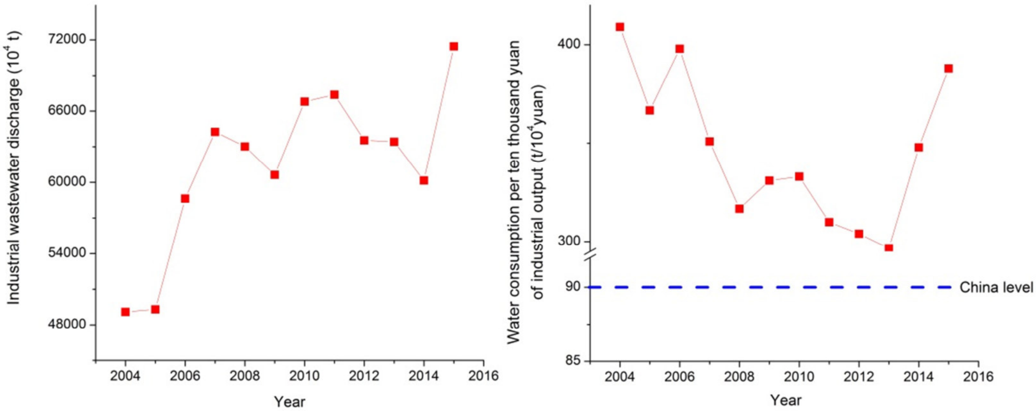


Figure 2. Changes in industrial wastewater discharge and water consumption per ten thousand yuan by industrial output for Jiangxi from 2004 to 2015

3.2 Decomposition of *wastewater* discharge for industrial sectors

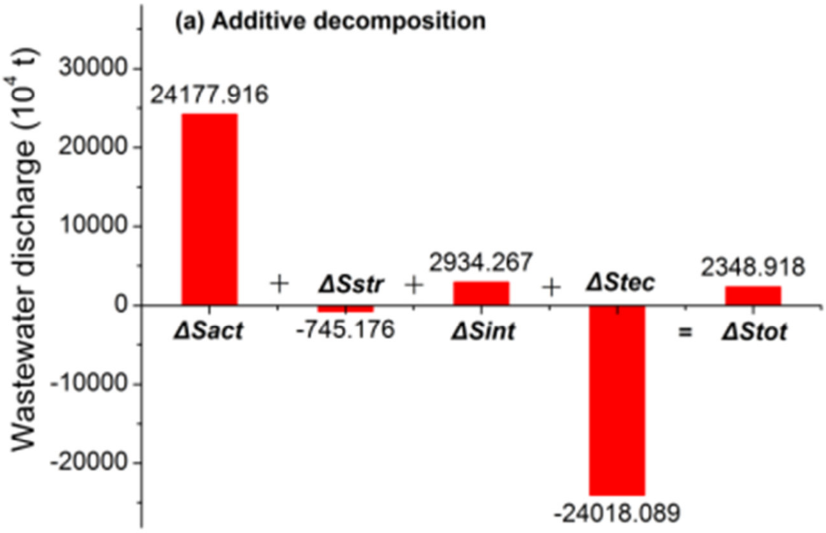
3.2.1 Cumulative effects on decomposition of industrial wastewater discharge during 2004-2015

According to the addition method for decomposition of LMDI, the amount of wastewater discharge for Jiangxi's industrial sectors from 2004 to 2015 are shown in Table 2 and Figure 3a. The changes in the amount of wastewater discharge from Jiangxi's industrial sectors between 2004 to 2015 showed irregular growth and a decreasing trend, where total wastewater discharge increased by 2348.918 $\times 10^4$ t, the sector scale resulted in an increase in wastewater discharge by 24177.916 $\times$ 10^4 t, and sector wastewater discharge intensity resulted in an increase by 2934.267 $\times$ 10^4 t. However, sector structure and pollution abatement technology resulted in a decrease by 745.176 $\times$ 10^4 t and 24018.089 $\times$ 10^4 t, respectively (Table 2). According to the multiplication decomposition of LMDI method in Figure 3b, the total amount of industrial wastewater discharge in Jiangxi decreased 0.939-fold between 2004 to 2015. The sector scale resulted in a 1.392-fold increase in the amount of wastewater discharge, while sector wastewater discharge intensity resulted in a 1.028-fold increase. Sector structure and pollution abatement technology resulted in a 0.996-fold and 0.659-fold, respectively (Figure 3b). These results illustrated that for the period 2004-2015, optimization of industrial sector structure and technical progress was beneficial in reducing wastewater discharge, while this inhibition was offset by the additional quantities of wastewater discharge due to sector scale expansion and sector wastewater discharge intensity. Such activities significantly reduced the pressure on sector scale expansion and sector wastewater discharge.

The decrease in wastewater discharge intensity has had an important positive effect on the control of industrial wastewater discharge. However, in Table 2, it is evident that the discharge intensity of wastewater has caused an unstable change in the total amount of wastewater discharged for the period 2004-2015. Furthermore, this showed that the water resource efficiency, technological capability, funding invested, and management level was relatively low in Jiangxi's industrial sectors. Consequently, the Jiangxi provincial government still needs to take measures to further improve the industrial sector in relation to these aspects.

Table 2. The contribution value of decomposition factors associated with wastewater discharge for industrial sectors in Jiangxi from 2004 to 2015 (Unit: 10^4 tons)

Year	ΔS_{act}	ΔS_{str}	ΔS_{int}	ΔS_{tec}	ΔS_{tot}
2004-2005	4101.878	2232.269	-6131.14692	-6533.114	-6330.114
2005-2006	9916.728	87.829	3810.773	-2760.762	11054.568
2006-2007	3636.709	-756.013	2985.154	-58.737	5807.113
2007-2008	3886.168	252.86	-5709.889	-5643.835	-7214.696
2008-2009	-4418.464	-61.836	2076.05	-1905.978	-4310.228
2009-2010	8874.692	-1390.131	-2131.522	-257.672	5095.367
2010-2011	6979.499	1074.365	-6536.834	-4421.566	-2904.536
2011-2012	-2306.773	-314.832	-1231.855	-1416.727	-5270.187
2012-2013	-948.42	-554.702	1209.452	92.845	-200.825
2013-2014	-1353.441	-473.129	-1538.28	-6608.844	-9973.694
2014-2015	-4190.66	-841.856	16132.365	5496.301	16596.15
2004-2015	24177.916	-745.176	2934.267	-24018.089	2348.918



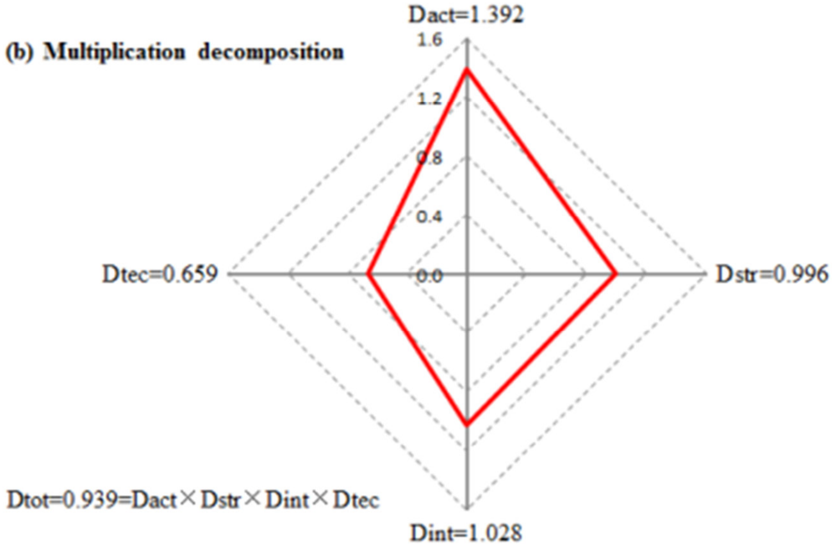


Figure 3. The contribution value and contribution rate graph of decomposition factors associated with wastewater discharge from industrial sectors in Jiangxi Province from 2004 to 2015.

3.2.2. Cumulative effects on decomposition of industrial wastewater discharge at different intervals

The cumulative effects of wastewater discharge in Jiangxi's industrial sectors were analyzed by splitting the study period into three intervals. From 2004 to 2005 (the 10th Five-Year Plan), the total industrial wastewater discharge from Jiangxi province was -6330.114×10^4 t (Figure 4a). Sector scale resulted in an increase in wastewater discharge by 4101.878×10^4 t, while sector structure resulted in an increase by 2232.269 ×10^4 t. However, sector wastewater discharge intensity and pollution abatement technology resulted in a decrease by 6131.147×10^4 t and 6533.114×10^4 t, respectively (Figure 4a).

In Figure 4b, sector scale and sector structure showed a positive role in the 10th Five-Year Plan. In effect, the addition effect was positive and the multiplicative effects were greater than 1. Moveover, sector wastewater discharge intensity and pollution abatement technology showed a negative role. In effect, the addition effect was negative and the multiplicative effects were less than 1.

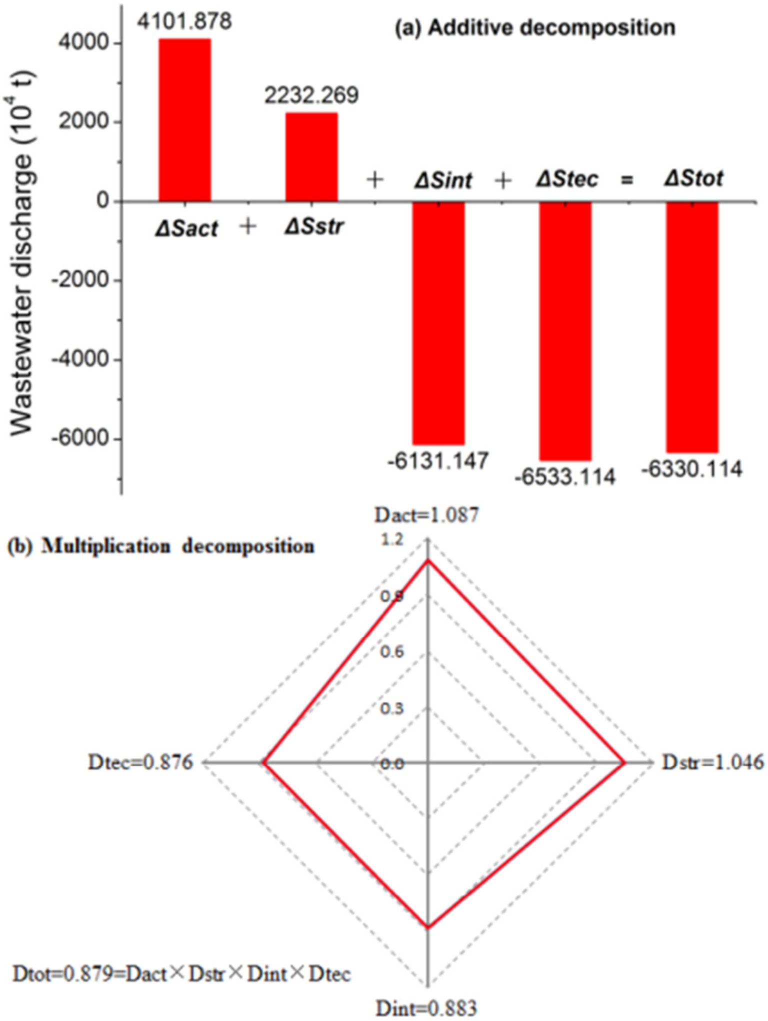


Figure 4. The contribution value and contribution rate graph of decomposition factors associated with wastewater discharge from industrial sectors in Jiangxi Province from 2004 to 2005.

From 2006 to 2010 (the 11th Five-Year Plan), the total industrial wastewater discharge from Jiangxi province was 10432.124×10^4 t (Figure 5a). Sector scale led to an increase in the wastewater discharge amount by 21895.834×10^4 t, while sector wastewater discharge intensity led to an increase of 1030.566 ×10^4 t. However, sector structure and pollution abatement technology resulted in a decrease by 1867.291×10^4 t and 10626.984×10^4 t, respectively (Figure 5a).

In Figure 5b, sector scale and sector wastewater discharge intensity showed a positive role in the 11th Five-Year Plan. In effect, the addition effect was positive and the multiplicative effects were greater than 1. Moveover, sector structure and pollution abatement technology showed a negative role i.e. the addition effect was negative and the multiplicative effects were less than 1. This was attributable to the fact that in 2006, Jiangxi Provincial Government published some policies on adjustments to the industrial structure and the development of an industrial park in Jianxi Province during the 11th Five-Year Plan. Such policies could effectively guide the development pattern and direction of Jiangxi's industrial sectors after 2006, and has had a great significance in transforming the economic model and modifying industrial structure in Jiangxi Province.

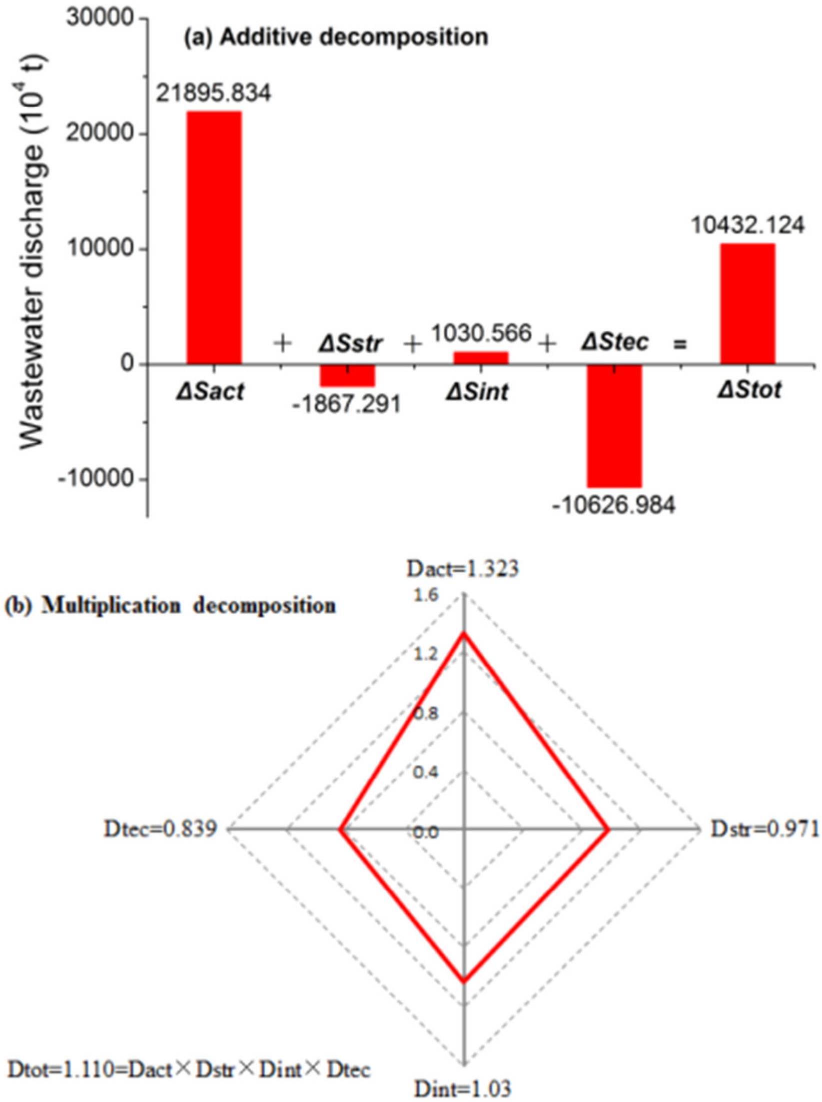


Figure 5. The contribution value and contribution rate graph of decomposition factors associated with wastewater discharge from industrial sectors in Jiangxi Province from 2006 to 2010.

From 2011 to 2015 (the 12th Five-Year Plan), the total industrial wastewater discharge from Jiangxi province was -1753.092×10^4 t (Figure 6a). Sector wastewater discharge intensity led to an increase by 8034.848×10^4 t. However, sector scale, sector structure, and pollution abatement technology led to a decrease of 1819.795×10^4t, 1110.154×10^4 t and 6857.992×10^4 t, respectively (Figure 6a).

In Figure 6b, sector wastewater discharge intensity showed a positive role in the 12th Five-Year Plan i.e. the addition effect was positive and the multiplicative effects were greater than 1. Moreover, sector scale, sector structure, and pollution abatement technology showed a negative role i.e. the addition effect was negative and the multiplicative effects were less than 1. This is likely to be due to the fact that China's State Council published an "Industrial transformation and upgrading plan (2011-2015)" in 2011. In addition, Jiangxi Provincial Government also published a document entitled "Major project planning of the 12th Five Year Plan in Jiangxi province" in 2011 and in 2012, they published a policy entitled "Development program of the 12th Five-Year Plan on industry and information technology in Jiangxi province". These policies can help to control the investment in fixed assets associated with industries that have excess capacity in Jiangxi Province, while they may also limit the expansion of high energy-consuming and high-polluting industries. This would then allow continuous optimization and upgrading of the current industrial infrastructure.

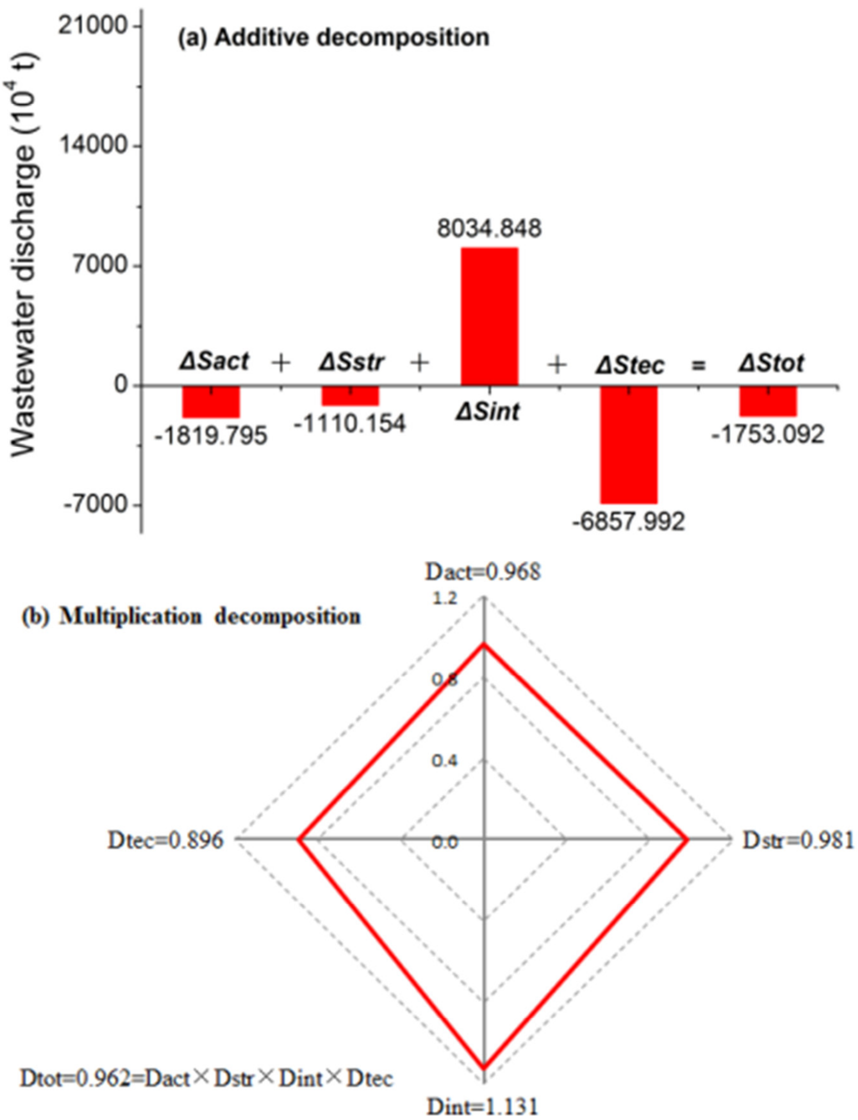


Figure 6. The contribution value and contribution rate graph of decomposition factors associated with wastewater discharge from industrial sectors in Jiangxi Province from 2011 to 2015.

3.2.3. Impact of industrial wastewater discharge to industry

Table 3 showed that during the period of 2004-2015, the other sectors (25 sectors) were associated with an increase in industrial wastewater discharge (increased by 22064.94 × 10^4 t). These included MWC (increased by 1070.279× 10^4 t), MPNFMO (increased by 3267.429× 10^4 t), PFAP (increased by 1484.188× 10^4 t), MTe (increased by 1508.801× 10^4 t), MPPP (increased by 3065.114× 10^4 t), MRCMCP (increased by 2304.592× 10^4 t), MM (increased by 1415.591× 10^4 t), and MCCOEE (increased by 1775.114× 10^4 t). These eight sectors contributed to the largest increase (increased by 15891.11× 10^4 t) and accounted for 72.02% of the increase in the total amount associated with the 25 sectors. This showed that the industrial sectors in Jiangxi Province were still dominated by traditional sectors, where environmental awareness and investment in pollution abatement was relatively weak. In addition, regulation of some of these sectors was more difficult, which had a downstream effect on the total amount of industrial wastewater discharge being greater. MPFMO, Mto, MCF, SPNFM, MSPM, MRSAOTE, and PSEPHP sectors were not associated with an increase in wastewater discharge.

Except for MLFFRPF, MMP, MCCOEE and MAOM sectors, the sector scale effect of the other sectors resulted in an increase in wastewater discharge from 2004 to 2015, and this approximated 19193.6 × 10^4 t. The biggest polluters were MPNFMO (increased by 1669.18× 10^4 t), MPPP (increased by 4632.51× 10^4 t), MRCMCP (increased by 2394.03 × 10^4 t), SPFM (increased by 1744.42 × 10^4 t), SPNFM (increased by 2139.12 × 10^4 t), and PSEPHP (increased by 2176.94 × 10^4 t) (Table 3). This indicated that the proportion of high energy-consuming, polluting industries in Jiangxi Province was greater. Unfortunately, economic development has not improved here, therefore it is difficult to reverse the situation of higher wastewater discharge from the traditional sector in the short term.

During the study period, sector structure effects resulted in a decrease by 745.176× 10^4 t for industrial wastewater discharge. However, the sector structure effect of 15 sectors such as MWC, MPFMO, MPNFMO, MPNO, PFAP, MF, MTeWAD, MLFFRPF, PTMWBRPSP, PPCPNF, MRCMCP, MRP, SPNFM, MCCOE, and MAOM, resulted in an increase in industrial wastewater discharge. MPNFMO and SPNFM were the biggest contributors to this effect with an increase in 6379.2 × 10^4 t (77.37%) for the total amount across the 15 sectors (Table 3). This showed that adjustments and upgrades to the industrial structure had not attained the designated position. Consequently, sector structural pollution control was still not able to cope, resulting in a failure to significantly reduce wastewater discharge.

During the study period, sector wastewater discharge intensity resulted in a 2934.268 × 10^4 t increase in industrial wastewater discharge, among which PFAP, MPPP, MM, MNMP, SPFM, and MCCOE were the biggest contributors to an increase of 18059.39× 10^4 t, that accounted for 73.15% of the overall increase of the responsible sectors (Table 3). MPFMO, MPNFMO, Mto, MRCMCP, SPNFM, MSPM, MRSAOTE, and PSEPHP resulted in an overall increase of 24688.94× 10^4 t. This indicated that the production process and equipment in these sectors in Jiangxi Province were lagging behind, and that the production technology requires further improvement. In addition, the existing economic policies such as pollution charges failed to have an incentive effect in controlling pollution.

Pollution abatement technology for the overall industrial sector led to a decrease of 24018.1× 10^4 t in wastewater discharge from 2004 to 2015, among which MPNO, MWBRT, PTMWBRPSP, MRCMCP, MM, MGPM, and MEME contributed to an overall increase of 2562.238× 10^4 t. This contribution amounted to a total change of -10.67% (Table 3). This showed that environmental protection investment, pollution abatement technology, and water governance facilities in Jiangxi province were sparse, especially in the MRCMCP sector.

From Table 3, it was evident that the MCF sector was able to reduce wastewater by adjusting and optimizing sector structure and advanced pollution abatement technology. The MPFMO and SPNFM sectors were also able to reduce wastewater discharge by means of decreased wastewater discharge intensity and advanced pollution abatement technology. However, Mto, MSPM, MRSAOTE, and the PSEPHP sectors were also able to reduce wastewater by adjusting and optimizing sector structure, wastewater discharge intensity, and advanced pollution abatement technology (Table 3).

Table 3. Factors contributing to wastewater discharge by industrial sub-sectors in Jiangxi (Unit: 10^4 tons)

Sectors	ΔS_{act}	ΔS_{str}	ΔS_{int}	ΔS_{tec}	ΔS_{tot}
MWC	445.694	191.557	759.72	-326.692	1070.279
MPFMO	665.201	426.4	-1087.942	-1089.76	-1086.1
MPNFMO	1669.18	3924.412	-159.307	-2166.85	3267.429
MPNO	204.087	49.904	3.279	83.657	340.927
PFAP	29.965	353.756	1672.779	-572.312	1484.188
MF	190.2	76.562	468.348	-205.524	529.586
MWBRT	272.078	-209.945	755.638	8.993	826.764
Mto	33.0512	-34.042	-190.049	-96.602	-287.642
MTe	493.754	-15.93	720.246	310.731	1508.801
MTeWAD	33.889	5.798	121.383	-60.826	100.244
MLFFRPF	-10.194	80.742	322.392	-1.912	391.028
PTMWBRPSP	82.931	10.94	244.689	2.517	341.077
MPPP	4632.51	-3837.303	5625.185	-3355.28	3065.114
PRRM	5.238	-4.673	63.834	-13.656	50.743
MACEASAA	16.958	-10.082	89.204	-30.525	65.555
PPCPNF	338.924	178.252	344.003	-62.868	798.311
MRCMCP	2394.03	421.957	-2868.318	2356.922	2304.592
MM	262.15	-42.869	1166.669	29.641	1415.591
MCF	444.736	-267.803	963.207	-2621.07	-1480.93
MRP	58.819	9.209	77.252	-87.917	57.363
MNMP	497.52	-102.079	1518.059	-1438.84	474.658
SPFM	1744.42	-2883.185	5477.076	-3541.45	796.856
SPNFM	2139.12	2454.788	-5999.007	-5635.04	-7040.14
MMP	-22.107	-16.035	614.161	-210.536	365.483
MGPM	62.983	-50.419	122.596	25.182	160.342
MSPM	62.673	-46.335	-107.058	-2.23	-92.95
MRSAOTE	172.688	-184.788	-147.96	-183.431	-343.491
MEME	121.474	-276.978	668.574	55.326	568.396
MCCOEE	-63.354	25.095	2599.619	-786.246	1775.114
MMIMCAOW	46.413	-28.045	7.272	-3.846	21.794
MAOM	-8.378	35.391	283.758	-26.063	284.708
PSEPHP	2176.94	-979.428	-11195.034	-4371.59	-14369.1
Total	19193.6	-745.176	2934.268	-24018.1	-2635.41

4. Conclusions and policy implications

4.1 Conclusions

According to the LMDI decomposition method, the changes in wastewater discharge from Jiangxi's industrial sectors showed contrasting trends with irregular growth and decreases in some sectors from 2004 to 2015. However, total wastewater discharge increased by 2348.918×10^4 t. In addition, the sector scale effect, wastewater discharge intensity, sector structure and pollution abatement technology contributions were 24177.916×10^4 t, 2934.267×10^4 t, -745.176×10^4 t, and -24018.089×10^4 t, respectively. According to the LMDI multiplication decomposition method, the total amount of industrial wastewater discharge in Jiangxi decreased 0.939-fold during the period of 2004-2015, among which the increase in sector scale and wastewater discharge intensity was 1.392-fold and 1.028-fold, respectively. Meanwhile, the decrease in sector structure and pollution abatement technology was 0.996-fold and 0.659-fold, respectively. The apparent irresponsible expansion of the industrial sector scale in Jiangxi Province is the main cause for the total increase in industrial wastewater, and sector scale resulted in an increase in wastewater discharge by 2014.826×10^4 t during the period of 2004-2015. Pollution abatement technology effect is the key factor in reducing the total amount of industrial wastewater. This led to an annual average reduction in industrial wastewater by 2001.507×10^4 t during the period of 2004-2015.

Across three intervals, pollution abatement technology effect was the main contributing factor to a reduction in wastewater discharge in the industrial sectors. Based on a comprehensive analysis of contributors of wastewater reduction at different intervals, we noted the following. For 2004-2005, pollution abatement technology, wastewater discharge intensity, sector structure and sector scale was most important; for 2006-2010, pollution abatement technology, sector structure, wastewater discharge intensity and sector scale were most important; while for 2011-2015, pollution abatement technology, sector scale, sector structure, and wastewater discharge intensity were most important. It is therefore apparent that in the future, pollution abatement technology will remain the most important factor in inhibiting wastewater discharge in industry.

The WC, MPNFMO, PFAP, Mte, MPPP, MRCMCP, MM, and MCCOEE sectors were responsible for the largest increase, which accounted for 72.02% of the total amount across the 25 sectors during the period of 2004-2015.

4.2 Policy Applications

According to the aforementioned conclusions, we propose some policy recommendations as follows:

While developing its economy, Jiangxi Province should increase investment in wastewater treatment technology and governance facilities, improve the handling capacity of the governance facilities, and significantly develop the wastewater treatment industry, to reduce the intensity of water resource consumption.

In the absence of major changes in the industrial structure within a short period of time, Jiangxi Province should increase spending on science and technology in industry production, innovation and upgrading of production technologies, scientific management of equipment, improve the utilization ratio of facilities and equipment, which will all help to reduce industrial wastewater discharge. In addition, it is essential for implementation of cleaner production and wastewater reduction, which should be assessed through audit and assessment indicators.

Jiangxi Province should accelerate the adjustment, optimization, transformation, and upgrading of infrastructure in the industrial sector. This would significantly develop the water-saving industry so that there is an ethos of low consumption of water and limited wastewater discharge, resulting in recycling of industrial water and improved treatment rates of industrial wastewater.

Finally, Jiangxi Province should continue to strengthen environmental law enforcement, environmental governance, and environmental impact assessments for the traditional water pollution industries of MPNFMO, MPPP, MRCMCP, SPFM, SPNFM, and PSEPHP. A mandatory threshold should be established for approval and record-filing of high discharge projects; this would limit and eliminate the irresponsible development of industrial construction projects that discharge significant quantities of wastewater. Advanced technology should be adopted to transform and upgrade traditional industries.

Acknowledgments

This work was financially supported by the National Natural Science Foundation of China (grant numbers 21367013, 21407069, 71463020), the Jiangxi Provincial Natural Science Foundation of China (grant numbers 20142BAB203024, 20151BAB203034), the Humanities and Social Science Research Project of Colleges and Universities in Jiangxi Province (grant number JC1420).

Author Contributions

Fucai Lu contributed to conception of the project idea; Mianhao Hu conceived and designed the research; Yunling Hu collected data and analyzed the data; Mianhao and Juhong Yuan wrote the paper. All authors have read and approved the final manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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