Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 17 | No. 1 | pp. 123-129 | 2018

Original Research Paper | Open Access

Characteristics and Influencing Factors of Industrial Pollution Discharge: A Case Study of Anhui, China

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 16-12-2017
Accepted: 18-01-2018

Key Words:
Industrial pollution
Discharge characteristics
Influencing factors

ABSTRACT

The development of industrial economy is the major force behind the rapid development of national economy. However, industrial pollution exerts huge pressure on the environmental carrying capacity with its largest share of environmental pollution. In this study, the characteristics of industrial discharge in Anhui of China were analysed to further understand its pollution discharge characteristics and major influencing factors. Its influencing factors were also analysed through Grey relative analysis, and the grey-relation degree between industrial pollution and each factor was quantitatively measured. Results reveal that in the period of 2005-2016, the total discharge of industrial wastewater in Anhui Province has shown a gradual, but unstable increase; the exhaust gas emission also has increased annually with a growth of 364%; and the common industrial solid waste has increased by 200%, whereas its rate of multipurpose utilization has been constantly improved. Grey relational coefficients indicate that the five industrial indicators are closely correlated according to the three indicators, including GDP per capita, industrial proportion and the number of environmental researchers. This finding indicates that rapid economic growth, unreasonable industrial structure and incompetence in environmental control are the major influencing factors. The conclusion is of great reference value to further understand the current situation of industrial pollution in China, optimize the industrial structure, reduce the discharge of pollutants, and explore the law between environmental protection and pollution effect.

INTRODUCTION

China's environmental pollution is serious. The traditional growth mode featured by high investment, high consumption, and heavy pollution is not transformed fundamentally. Economic growth depends on industrial development, which requires large amount of resources. Resources being consumed produce large amounts of pollutants, such as industrial wastewater, waste gases and solid waste, all of which are a great threat to the environment once their discharge goes beyond the environment's self-cleaning capacity.

Over the past 10 years, Anhui of China has witnessed a speeding economic growth. Given its strategy of "promoting economy through developing industry", its economic growth has been mainly driven by industrial development as presented in Fig. 1. Industrial economy on one hand has contributed to the rapid development of national economy, but on the other hand has caused serious environmental pollution. Wan-Jiang demonstration area has been built in Anhui and has allowed the entrance of industries from Yangtze River Delta region. Most of these are enterprises causing serious pollution. The environment in this area is consequently faced with huge pressure. Similar to the mutual relation between economy and environment, different sector structures, organization structures, and technological structures in the regional industry also influence the environment. Industrial engineering needs high investment, consumption, and heavy pollutant discharge and hence can greatly harm the environment. This study aims to help achieve a sustainable development on the future path of industrialization. This sustainable development is significant in guiding and promoting environmental protection, optimizing economic development, and achieving a harmonious and coordinated development in Anhui of China.

EARLIER STUDIES

Abundant theoretical and empirical studies were conducted on the characteristics and influencing factors of industrial pollution discharge. Concerning the characteristics, Pargal (1996) analysed the features of industrial pollution and informal control measured in Indonesia as a developing country. Brooks et al. (1997) studied the distribution and features of air pollution in communities. The current situation, traits and improvement space in cities of China were investigated by He et al. (2002). Cole et al. (2005) analysed the relationship between the features of industrial pollutants discharge and environmental legislation and air pollution based on the case study of British manufacturing industry. He (2006) studied the features of emitting SO_2 in China and calculated the influence of direct foreign investment on China's environment. Wang et al. (2010) analysed the emission of air pollutants during Beijing Olympics in 2008 and also proposed some control measures. The characteristics of major pollutant discharge in Yangtze River Delta, China were studied by Fu et al. (2013). Hettige et al. (2000) re-examined the industrial pollution characteristics and influencing factors through Environment Kuznets Curve. The influence of direct foreign investment on environmental pollution was analysed, and control measures were put forward by Jorgenson (2009). Li et al. (2014) conducted a time-space analysis on the air quality through air pollution indicators in Guangzhou, China from 2001 to 2011 and explored its temporal relation with meteorological factors. Miao et al. (2015) analysed the potential influencing factor of industrial water pollution in China, showed that the imperfect administration system for environmental pollution caused the frequent break-out of air pollution, and proposed some control methods. Lin et al. (2016) showed that the smog in Beijing was deteriorated by industrial pollution, from which heavy metal pollution greatly harmed the human health. A system dynamics model was proposed by Vafa-Arani et al. (2014), who also estimated the factors influencing the air pollution in Teheran and revealed that air pollution was closely connected with road construction, fuel and transportation control, and development of public transportation infrastructure. Qing et al. (2015) collected 115 samples of surface soil in Anshan, China to assess the harm of heavy metals to human health and revealed that common industrial materials, such as Cu, Zn, Pb, and Cd, were the major sources of heavy metal pollution in iron-steel industry regions. By using the spatial correlation model of economy-energy pollution, Liu G. et al. (2017) analysed the situation of river pollution and believed that the scale of GDP per capita and amount of industrial wastewater discharge were the influencing factors of river pollution. Using Spatial Econometrics, Liu H. et al. (2017) analysed the factors influencing smog in urban China and revealed that the smog mainly results from population gathering, industrial development, inter-regional trade, urbanization, and exhaust gases. Thus, the industrial pollution discharge varies in terms of time and space, and its influencing factors are mainly related to economy, environmental control technology, and policy-making. Using the sample data from 2005 to 2016 on the discharge in Anhui, China and based on previous studies, this study analyses the characteristics of industrial pollution over the past 10 years firstly, followed by the calculation and measurement of major influencing factors through Grey relation analysis. The study's finding can provide references to improve environment state, reduce pollutants discharge, increase the efficiency of utilizing resources, and alleviate environmental pollution.

CURRENT SITUATION OF INDUSTRIAL POLLUTION DISCHARGE IN ANHUI

Industrial wastewater discharge: From 2005 to 2015, the total amount of industrial wastewater discharge increased gradually from 634.87 million tons to 714.36 million tons with the economic development in Anhui. The amount in 2016 began to reduce due to industrial restructuring (Fig. 2).

Situation of waste gas emission: Fig. 3 shows that the emission amount generally follows an increasing trend. In 2005, the emission was only 696 billion m^3 with an increase of 3041.1 billion m^3 in 2011. However, this amount decreased in 2012. The emission in 2016 increased by 364% of that in 2005. Since 2005, the growth rate of waste gas emission has increased by a large margin as a result of rapid economic development. After 2011, pollution control has reduced the emission, and negative growth has been achieved since 2012.

Industrial SO_2 and powders are the major pollutants among waste gases. With the implementation of energy conservation and emission reduction, these two pollutants also showed negative growth (Fig. 4).

Solid waste discharge: Solid waste refers to the solid or semi-solid objects abandoned in the production, consumption, life and other activities of humans. In 2005, the discharge of common industrial solid waste was only 41.96 million tons, which increased by 200%, or to 126.53 million tons, in 2016. The storage and disposal amounts have consistently increased annually. With the advancement of recycling and disposing technology, comprehensive utilization efficiency is improving, thus reflecting the effectiveness of industrial pollution control over the recent years.

METHODOLOGY

Model: Grey relation analysis (GRA), a major part of the Grey System theory, is the basis for analysis, predication, and decision-making and is a qualitative and quantitative analysis method based on the micro or macro geometric approximant of behavioural factor sequences. This technique is used to analyse and determine the influencing degree between factors or contribution of factors on the major behaviour. By analysing the intimacy of major behaviour factors to relevant behaviour factors, GRA can help determine the major factors and secondary factors motivating the system development. The geometric approximant degree of time series curves of relevant factors is used to judge the closeness of the relationship between factors, the simi-

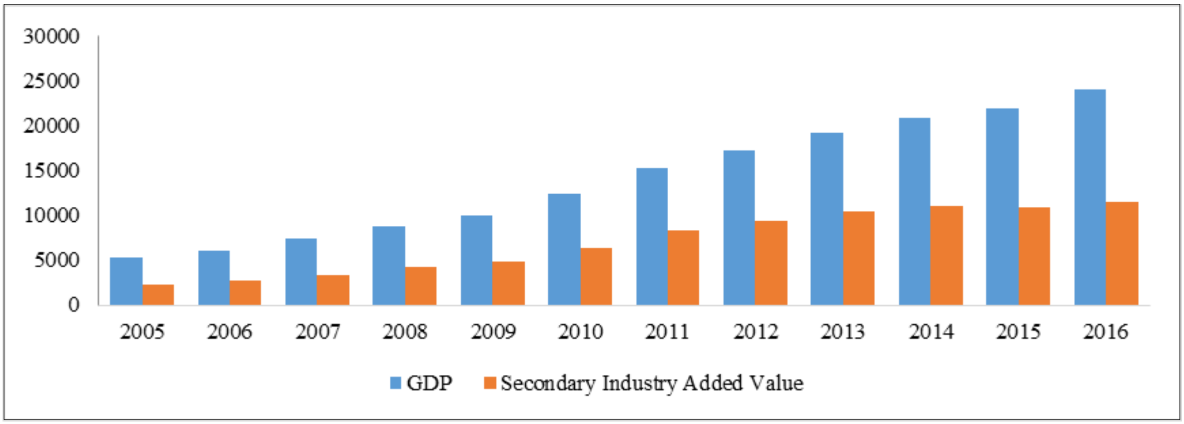

Fig. 1: Economic growth in Anhui Province during 2005-2016 (100 million/RMB).

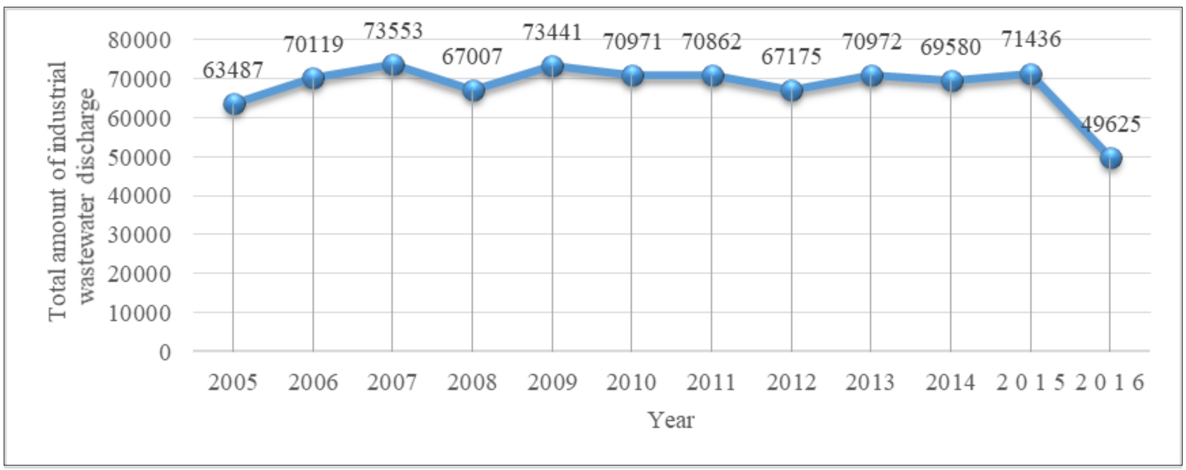

Fig. 2: Total amount of industrial wastewater discharge in Anhui during 2005-2016 (10,000 tons).

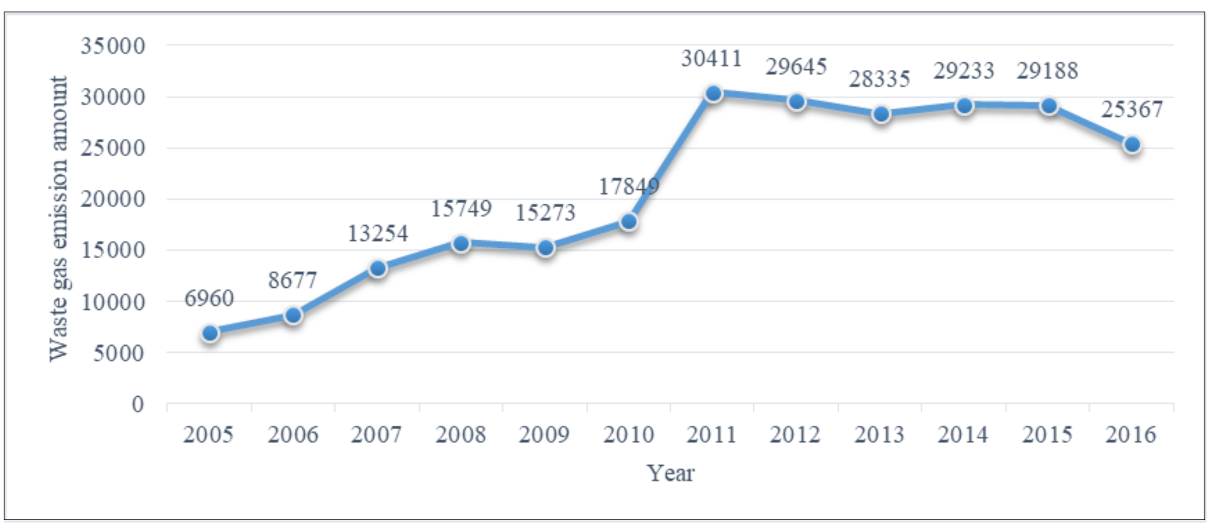

Fig. 3: Industrial waste gases emission in Anhui during 2005-2016 (100 million standard cubic meters).

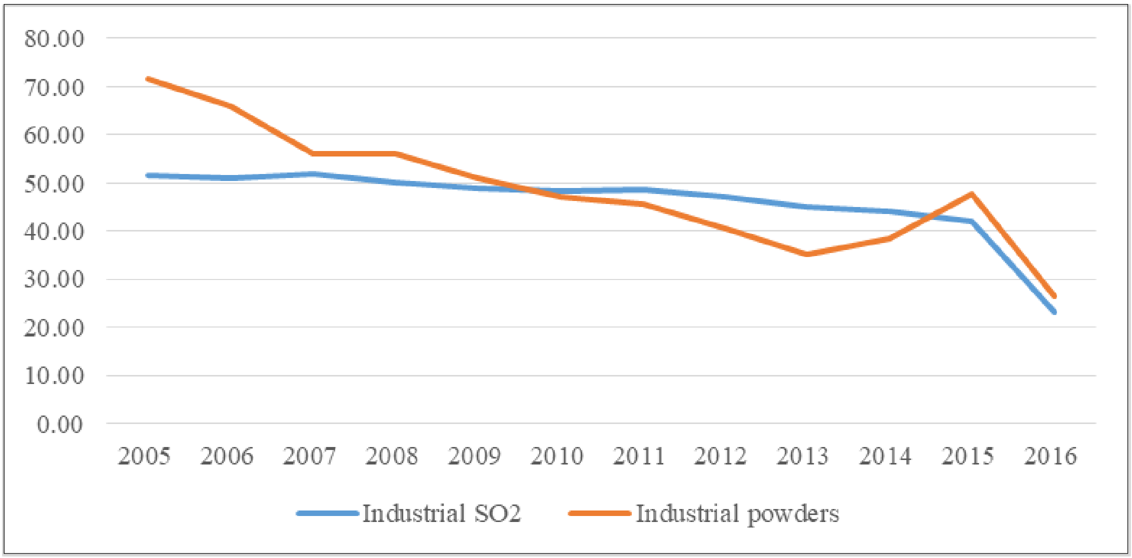

Fig. 4: Total emission of industrial SO_2 and powders in Anhui during 2005-2016 (10 thousand tons).

larity of the geometric shape of curves, and the close correlation of the sequences and vice-versa. The calculation steps are as follows:

Supposing *n* objects to be assessed, and each one has *p* indicators; hence, the description of assessment object *i* is:

$$x_i' = \{x_{i1}', x_{i2}', ...x_{ip}'\} \quad (i=1, 2, \dots, n) \qquad ...(1)$$

Among the assessment objects, the optimal value of each indicator was selected to form the reference sequence, which is:

$$x_0 = \{x_{01}, x_{12,....} x_{0p}\} \qquad ...(2)$$

The real value of indicator is nondimensionalized as:

$$x_{ij} = \frac{x_{ij}'}{x_{0j}} \quad (i = 1, 2, ..., n, j = 1, 2, ...p) \qquad ...(3)$$

When the optimal value of each indicator is 1, the optimal reference sequence will be $x_0 = \{1, 1, ...1\}$. Calculating Δ(max) and Δ(min) requires the absolute difference sequence of the assessment object sequence to the optimal reference sequence through formula (4):

$$\Delta_{ij} = |x_{ij} - 1| \quad (i = 1, 2, ..., n, j = 1, 2, ...p) \qquad ...(4)$$

Therefore:

$$\Delta(\max) = \max_{1 \le i \le n} \max_{1 \le j \le p} (\Delta_{ij}) \qquad ...(5)$$

$$\Delta(\min) = \min_{1 \le i \le n} \min_{1 \le j \le p} (\Delta_{ij}) \qquad ...(6)$$

Δ (max) and Δ (min) can be obtained. Finally, the correlation degree is calculated through:

$$\xi_{ij} = \frac{\Delta(\min) + \rho\Delta(\max)}{\Delta_{ij} + \rho\Delta(\max)} \qquad ...(7)$$

The above formula can help calculate the correlation coefficient. ρ is the resolution ratio, and 0<<1. The correlation degree of *i* to the optimal reference sequence can be determined according to $r_i = \frac{1}{p}\sum_{j=1}^{p} \xi_{ij}$, where the comprehensive assessment coefficient $E_i = r_i \times 100$ will be obtained. $E_i > E_j$ indicates that sample *i* is better than sample *j* and vice-versa. Each of the assessment object is calculated and compared with each other.

Indicator selection and data: Affected by many factors, such as nature, economy and society, regional environment is a complicated open system that is full of dynamic traits and uncertainty. Economy is the most powerful influencing factor, because the influence of society and nature can be reflected through the economy. Industrial pollutants are the major cause of environmental pollution. There upon, industrial wastewater discharge, industrial waste gas emission, industrial SO_2 emission, industrial smoke emission, and industrial solid waste discharge were used to reveal the characteristics of pollution behaviour in Anhui. Indicators such as the scale and level of economic activities, industrial structure, development of environmental protection technology, investment on environmental control and protection, urbanization, specifically GDP gross, GDP per capita, indus-

Table 1: Discharge of industrial waste during 2005-2016.

Time	Output of common industrial solid waste (10,000 tons)	Comprehensive amount of common industrial solid waste (10,000 tons)	Comprehensive utilization rate of common industrial solid waste (%)	Storage amount of common industrial solid waste (10,000 tons)	Disposal amount of common industrial solid waste (10,000 tons)
2005	4196	3357	79.32	360	519
2006	5030	4124	82	419	509
2007	5960	4909	82	418	643
2008	7569	6326	83	451	862
2009	8471	7227	83	544	923
2010	9158	7849	84.55	518	916
2011	11473	9366	78.7	616	2241
2012	12022	10266	81.5	895	1705
2013	11937	10462	83.99	933	1374
2014	12000	10466	84.44	893	1079
2015	13059	11763	88.48	518	1049
2016	12653	10830	82.62	1113	1182

Table 2: Grey correlation coefficients.

Correlation factors	Main industrial pollutants				
	Industrial waste water	Industrial waste gases	Industrial SO_2	Industrial smoke	Industrial solid waste
GDP gross	0.723	0.816	0.712	0.694	0.765
GDP per capita	0.726	0.836	0.736	0.694	0.777
Industrial proportion	0.924	0.665	0.912	0.878	0.769
Tertiary industrial proportion	0.921	0.667	0.901	0.846	0.804
Number of environmental researchers	0.852	0.785	0.835	0.866	0.854
Investment on industrial pollution control	0.612	0.723	0.667	0.675	0.642
Proportion of urban population to the total	0.835	0.821	0.801	0.765	0.889

trial proportion, tertiary industry proportion, number of environmental researchers, investment volume on industrial pollution control, and proportion of urban population to the total were selected to study how these factors lead to industrial pollution (GDP gross and GDP per capita were used to measure the scale and level of economic activities, industrial proportion, and tertiary industry proportion for measuring industrial structure, number of environmental researchers for the development of environmental protection technology, the investment volume for investment on environmental control and protection, and the proportion of urban population to the total for the process of urbanization). Data are mainly from the China Statistical Yearbook, China Statistical Yearbook on Environment and Anhui Statistical Yearbook.

RESULT ANALYSIS

The Grey relation model between main industrial pollutants discharge and each influencing factor was established according to the Grey modelling theory and procedure. The correlation degrees are presented in Table 2.

The correlation coefficients in Table 2 reveal the closest correlation between industrial proportion and industrial wastewater discharge, implying that the industrial structure is the dominant factor affecting the discharge of industrial wastewater. Therefore, the industry must be restructured to reduce the discharge, optimize industrial layout, and change step-by-step the current situation in the direction of a sustainable development both for the economy and environment. Table 2 also shows that the industrial waste gases emission is most closely related to GDP per capita, reflecting the positive correlation between emission and economic growth and the increase in urban population and expansion of urban scale. Industrial SO_2 emission is affected mainly by industrial proportion, indicating an unreasonable industrial structure in Anhui where the industrial output is increased at the cost of the environment. The industrial smoke emission is most correlated with industrial structure, followed by the number of environmental researchers, revealing that the unscientific industrial structure deteriorates the environment. The backward environmental protection technology leaves the pollution unsettled in a short period. Urbanization is the major cause of industrial solid waste discharge, implying that the expansion of urban scale and sharp growth of urban population are the biggest factors leading to large amounts of industrial solid waste discharge and can be the starting point for the control of solid waste.

POLICY SUGGESTIONS

Increase investment in environmental protection and R&D and promote energy conservation and emission reduction: Improving the efficiency of environmental control requires increasing environmental protection and improving the technology. Diverse mechanisms of investment and financing for environmental protections should be established. These mechanisms should involve governmental investment, market financing, and mass investment. Additional investment must be allotted on R&D of environmental protection from diverse channels to advance wastewater disposal technology and equipment, technology of cycling toxic industrial wastewater, key techniques of removing nutrients from the water body, technology of utilizing and disposing industrial solid waste, technology of manufacturing environmental monitoring equipment, technology of environmental control over agricultural point and area sources, and technology of applying extra heat and pressure. Enterprises must take part in energy conservation and emission reduction to push forward the overall control over regional environment. Coordinated and innovation platforms of key technology for environmental protection must be built by the joint efforts of universities, scientific research institutes and high and new technology enterprises. Financial and policy support from the state should be prioritized to raise funds for R&D of environmental protection.

Build a joint mechanism of prevention and control for regional pollution and optimize the regional industrial structure: Participating in the environmental pollution control in the Yangtze River Delta urban agglomerations must be encouraged. The boundary of administrative districts in Anhui must be replaced with a coordinated mechanism to monitoring, checking, assessing, administrating, and coordinating the regional pollution, thus promoting the integrated administration over environmental protection. The integration of industry planning, that of large project approval, integration of water body improvement, integration of air pollution prevention, integration of noise pollution prevention, integration of harmless disposal of municipal solid waste, and integrated control over hazardous chemical transfer and discharge, must be pushed forward. Elimination of backward production capacity, industrial restructuring, technology upgrading, and pollution reduction must be hastened. Industries with outdated production capacity, including small thermal power plants, cement production lines in shaft kilns, iron, and steel, and engineering must be eliminated first. Profit margin needs to be narrowed down by perfecting price and taxation mechanisms to facilitate the close-down or upgrading of high-consuming and heavy-polluting enterprises and help improve the efficiency of utilizing resources to reduce the pollution from production.

Raise regional environmental standard and promote upgrading of industrial technology: The environmental standard in some regions has not been raised with the progress of social and economic development. The current layout and development of main functional areas require updated standard to protect the environment. In terms of the standard of industrial environment, the industries in Anhui, such as paper-making, textile printing and dyeing, fermentation, chemical engineering, and tanning, must be upgraded and transferred. Standard of new emission and discharge, clean production, and backward production capacity must be implemented to enhance the level of industrial techniques and optimize development modes. Concerning regional environmental standard, water environment and discharge standard must be revised. An anti-driving mechanism must be formed by improving regional environmental standard to ensure constant upgrading of regional industrial structure to high end.

Vigorously advocate moderate consumption and develop industries of environmental protection: The integration of environmental protection into improving livelihood must be maintained, moderate consumption must be vigorously advocated, and the production mode and consumption pattern that greatly harm the environment must be changed. For the seriously polluted functional area, the transfer payment should be strengthened to accelerate the local development of livelihood and social development of the people. High and new technology industries in the field of industrial pollution control, environment-friendly production, environmental protection services, and comprehensive utility of waste sources, natural ecological protection, production of low-pollution products, and clean production must be developed. Complete environmental supervision, environmental auditing, environmental law consultation, environmental trade, and financial services must be implemented. Supporting mechanisms of policy must be improved to reinforce the supervision over enterprises, the operation efficiency of pollution control facilities must also be enhanced to install sewage pipe network in urban area, safeguard the fund for a smooth operation of pollution control facilities, and propel the development of environment-friendly industries.

CONCLUSION

The industrial development mode featured by high investment, high consumption, and heavy pollution has caused severe pollution. As a result, industrial pollution has become the major cause of environmental pollution. In this study, the industrial pollution in Anhui Province, China was investigated, the characteristics of industrial pollution discharge were analysed, and various factors influencing industrial pollution were determined through Grey relation analysis and the correlation degree of the industrial pollution with each factor. Result shows the following during 2005-2016, the total discharge of industrial wastewater in Anhui has showed a trend of gradual increase with a total of 364%; the discharge of common industrial solid waste has increased about 200%, and whereas the comprehensive utility rate has kept growing. Three indicators including GDP per capita, industrial proportion, and number of environmental researchers are closely related to industrial pollution, confirming that rapid economic growth, unscientific industrial structure, and incompetent pollution control are the major factors affecting the discharge. These findings are of great reference value to control new pollution at the pollution source, facilitate a reasonable regional industrial layout, reduce industrial pollution output to carry forward clean production auditing, and develop a recycling economy. These aspects must be studied to calculate the loss caused by environmental pollution, the efficiency of pollution control, the economic contribution of environmental investment, and the occurrence of spatial agglomeration of pollution.

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