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Original Research Paper

Heterogeneity Analysis of the Relationship Between Economic Growth and Water Environmental Pollution in Beijing, Tianjin and Zhengzhou of China

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ABSTRACT

Given the rapid development of the industrial economy, the environmental problems caused by water resource pollution have increased in severity. Thus, the optimal use of various natural resources and the reduction of water environmental pollution are important to promote the healthy development of the social economy and the environment. In this paper, the 2001-2013 time series data of discharged volumes of industrial wastewater, industrial chemical oxygen demand, and GDP are employed to analyse the relationship between the water environmental pollution and economic growth of Beijing, Tianjin and Zhengzhou. First, two models are established for the F test and T test on the relationship between GDP per capita and water pollutant discharge. A complete decomposition model is then adopted to analyse the effects of economic scale, industrial structure, and technological progress on water environmental pollution. Investigation results indicate that the relationships between the industrial wastewater discharge and economic growth of Beijing, Tianjin and Zhengzhou show reverse N-shaped curves instead of reverse U-shaped curves. At present, higher economic growth leads to more industrial water pollution. Economic scale and technological progress are the major influencing factors of water pollutant discharge. Therefore, the overall regional water environmental quality can be substantially improved only by enhancing the cooperation between Beijing, Tianjin and Zhengzhou to improve the capacity and efficiency of regional pollution control.

INTRODUCTION

Environmental issues have gradually become a major global problem and everyone's concern. Along with the economic development of countries, the consumption of natural resources is continuously growing, leading to the severe deterioration of the ecological environment. The frequency of regional and worldwide environmental problems and crises, particularly water pollution, has increased. Improving water environmental quality is related to balancing the relationship of economic development with ecological environment and resources. In recent years, China has suffered from frequent and serious water pollution accidents, which result in considerable economic losses. Therefore, water problems are related not only to ecology, but also to production and development planning. The deterioration of the water environment in China has been an important limiting factor in the current economic growth. Thus, awareness of water environment protection and ecological construction should be raised to commensurate to the height of Chinese strategic development. A study of the relationship between water pollution and economic growth could be of considerable value in guiding the process of economic development. China is in the stage of rapid economic development, which requires considerable human power, material resources, and financial resources. This situation magnifies and amplifies the conflict between the economy and the environment. If appropriate measures to effectively balance the relationship between the economy and the environment are not implemented during the process of promoting industrialization and modernization in China, environmental problems will inevitably be the biggest obstacle to China's future economic development. Water pollution is a crucial factor in all the aforementioned problems.

Beijing, Tianjin and Zhengzhou are among the regions with rapid economic growth and high urban densities. These three super-large cities in the metropolitan areas of North China have accelerated the promotion of their industrialization and urbanization. However, their pollutant discharges also dramatically increase, leading to a high relative concentration of pollution source distribution, high pollution load, and aggravated water environmental pollution. For water environmental pollution, terminal treatment is usually adopted. Owing to regional development imbalance and considerable regional differences in water pollution status and dependent regional water pollution, the overall regional water environmental quality still presents a declining trend, even if each city tries to control the local pollution within its administrative management scope. Change in the status of the water environment is clearly one of the main factors of the social and economic development. In view of the considerable pressure on the water environment of the metropolitan areas of North China and the overall gravity and complexity of water environmental pollution problems in these areas, an analysis of the evolutionary mechanism of the regional economy-water environment is imperative to help promote a more effective water environment management.

The studies on the relationship between water pollution and economic growth are abound in China and abroad. The environmental Kuznets curve is extensively used to prove such relationship. Its theoretical basis was developed in the early 1990s. Grossman & Krueger (1992) first empirically demonstrated that, in the initial stage of rapid economic development, the situation of environmental pollution is not obvious, however, with the continuous improvement in people's living standards, pollution severity is also enhanced. Panayotou (1993) empirically obtained a reverse U-shaped curve for the correlation between economic development and per capita income, which is named environmental Kuznets curve (EKC curve hereafter); he proved the existence of EKC. Martinez-Zarzoso & Bengochea-Morancho (2004) suggested that N relation exists between CO_2 waste gas and economic growth. Lee et al. (2010) verified the water EKC and found that the United Kingdom presented a reverse U-shaped correlation between water environment and GDP per capita, whereas Africa, Asia, and Oceania presented different EKC curves. Masson & Petiot (2009) studied the relationship between water pollutant discharge and economic growth and proved that both have a significant relationship. Reddy & Behera (2006) indicated that high-level water pollution had adverse effects on the health of people and livestock and crop growth but at the same time explicitly promoted economic growth. The study of Harbaugh & Wilson (2002) demonstrated that the selection of statistical samples and the standardization of the empirical process were of great importance in the study of the correlation between water pollution and GDP; the rapid economic growth intensifies water pollution. Tsuzuki (2009) found that a total flow EKC curve existed, whereas an EKC curve for total nitrogen and biological oxygen demand in wastewater was nonexistent; he also found that sewage discharge was caused by economic development. Du et al. (2012) analysed the relationship between water pollution and economic growth in Zhangweinan River Basin in China, and demonstrated the detrimental effect of economic growth on water pollution. On the basis of environmental Kuznets theory Du et al. (2012) and Yang & Zhu (2013) established a measurement model for the relationship between the economic growth and wastewater discharge of Jiangsu Province, the results indicated that the relationship between the economy of Jiangsu Province and water environment had a benign development trend, and water pollution was weakening, realizing a win-win scenario between the economy and the environment. The study of Zhao et al. (2012) showed that an improvement in environmental quality does not automatically occur with economic growth; the agricultural environment in Zhejiang Province still faced threefold pressure from rapid economic growth, environmental quality improvement, and environmental risk prevention. Through a co-integration analysis, Song et al. (2011) found that the Xinjiang's economic growth significantly influences water environmental pollution and leads to a considerable increase in the discharged volumes of industrial wastewater and chemical oxygen demand (COD) in wastewater. Yang & Dong (2013) put forward a General Progress Indicator (GPI) index and found a fluctuating negative correlation between GDP and GPI on the whole, and GPI could measure the situation of urban economic development and environmental pollution.

Although numerous studies on EKC have been conducted in China and abroad, the measurement index system for water EKC is not perfect. Moreover, EKC models seldom consider the influences of the adjustments in the current economic and social structures on the environment, even if some scholars introduce technology, regulations, and population density in the model. Finally, specialists and scholars have suggested the causes of EKC characteristics by analysing the actual situation in the research areas. However, only few studies examine the causes of inflection point changes before and after model modification. On the basis of the existing literature, the heterogeneity problem in the relationship between water pollution in North China metropolitan areas and economic growth in the industrialization process is further examined in the present study. At the same time, a holistic decomposition model is established to analyse the effects of economic scale, industrial structure, and technological progress on water environmental pollution. Such model aims to clarify the linkages in the developmental construction of Beijing, Tianjin and Zhengzhou and provide scientific bases for the harmonious development of the economic society, population, and environmental resources. This study could also serve as a reference for the sustainable development of the similar provinces and cities in China.

RESEARCH METHODS AND DATA SOURCES

Research Methods

EKC model: Assuming different conditions and considering different dominant factors, researchers have designed equations of economic growth and environmental pollution. The most common equations are quadratic and cubic equations. The quadratic equation presents a U-shaped or reverse

U-shaped curve, whereas a cubic equation presents an N-shaped or reverse N-shaped curve. The following regression models are evaluated and specified for three cities to verify the shape of the EKC curves for Beijing, Tianjin and Zhengzhou.

$$\ln y_t = \beta_0 + \beta_1 \ln x_t + \beta_2 (\ln x_t)^2 + \varepsilon_t \quad ...(1)$$

$$\ln y_t = \beta_0 + \beta_1 \ln x_t + \beta_2 (\ln x_t)^2 + \beta_3 (\ln x_t)^2 + \varepsilon_t \quad ...(2)$$

Where, y_t represents the discharge of pollution load in stage *t*, β_i represents the coefficient vector, x_t represents the GDP per capita, and ε_t represents the random error term. In model (1), if β_1>0 and β_2<0, a reverse U-shaped curve is generated for the relationship between economic growth and environmental pollution. That is, in the early stage of economic growth, environmental pollution is inevitable. However, when economic growth reaches a new level, the environmental quality will gradually improve. In model (2), if β_1>0, β_2<0, and β_3>0, a reverse N-shaped curve represents the relationship between economic growth and environmental pollution.

Decomposition analysis: Decomposition analysis is used to analyse the contributions of various possible factors to pollution changes and quantitatively study the relative importance of various influencing factors. According to Grossman's pollutant discharge decomposition theorem, the decomposition formula for industrial water pollutant discharge can be expressed as:

$$E_t = \sum_{j=1}^{n} Y_t \times ((Y_{jt} / Y_t) \times (E_{jt} / Y_{jt})) = \sum_{j=1}^{n} Y_t \times S_{jt} \times I_{jt} \quad ...(3)$$

Where Y_t represents the GDP in stage *t*, and the changes in E_t caused by the changes in *Y*, are called economic scale effects. The water pollutant discharge of city *j* in stage *t* is denoted by E_{jt}, the GDP of city *j* in stage *t* is denoted by Y_{jt}, and the GDP share of city *j* in stage *t* is represented by S_{jt} ($S_{jt}=Y_{jt}/Y_t$). Changes of E_t caused by S_{jt} are called structure effects. $I_{jt}= E_{jt}/Y_t$, representing the discharge intensity city *j* in stage *t*. The changes in E_t caused by I_{jt} are called technological progress effects. Ang (2005) proposed the Logarithmic Mean Divisia Index, which effectively solves the residual problems in decomposition. The following are derived from this method:

$$\Delta E_{sca} = \sum_{i=1}^{n} L(E_i^T - E_i^0) \times \ln(Y^T / Y^0) \quad ...(4)$$

$$\Delta E_{com} = \sum_{i=1}^{n} L(E^T - E^0) \times \ln(S_i^T / S_i^0) \quad ...(5)$$

$$\Delta E_{Int} = \sum_{i=1}^{n} L(E^T - E^0) \times \ln(I_i^T / I_i^0) \quad ...(6)$$

In Formula (4)-(6), $L(E^T - E^0) = \frac{E^T - E^0}{\ln E^T - \ln E^0}$, ΔE_{sca} denotes the economic scale effects, ΔE_{com} denotes the structure effects; and ΔE_{Int} denotes the technological progress effects.

Index Selection and Data Processing

Considering data availability and the fact that industrial sewage is the leading cause of urban water pollution, discharged volume of industrial wastewater, industrial COD discharge, and GDP per capita are selected as indicators of water environment and economic growth. In this study, 2010-2013 time series data of Beijing, Tianjin and Zhengzhou are employed. The specific data are obtained from Beijing Annals of Statistics, Tianjin Annals of Statistics, and Henan Annals of Statistics. A smoothness index-based method is adopted to eliminate the influences of price and other factors on GDP per capita. Finally, the log-transformed analytical data of the three indices are adopted eliminate heteroscedasticity without changing the properties of and relationships among the analytical data. The analytical data in this paper are natural logarithms of the selected data. MATLAB2012b and Eviews 7.0 software are used in the analysis of the data.

EMPIRICAL INVESTIGATION

Water Environment and Economic Development Status in Beijing, Tianjin and Zhengzhou

Since 2001, the industrial wastewater discharges of Beijing, Tianjin and Zhengzhou have presented rapidly fluctuating rising trends. Recently, the industrial COD discharges of Zhengzhou and Tianjin has generally tended to decrease, as shown in Fig 1.

As shown in Fig 2, the industrial COD discharges initially exhibited rapidly fluctuating rising trends in a period but has recently presented a decreasing trend. The water environments in Beijing, Tianjin and Zhengzhou have improved; however, the deterioration of the water environment status is not restrained entirely, and the situation remains severe. The current pollution load has led to the degradation of environmental functions, including those of the water environment, and poor overall water quality. The total pollutant discharge is considerable, especially those of total nitrogen and total phosphorus, which have far exceeded the water environmental capacity.

As shown in Fig. 3, the economies of Beijing, Tianjin and Zhengzhou, have been rapidly developing since 2001. The total GDPs of Beijing and Tianjin, being municipalities, are greater than that of Zhengzhou. The GDP growth rate of each city is roughly distributed between 8% and 15% and the high-speed economic growth of each city causes an

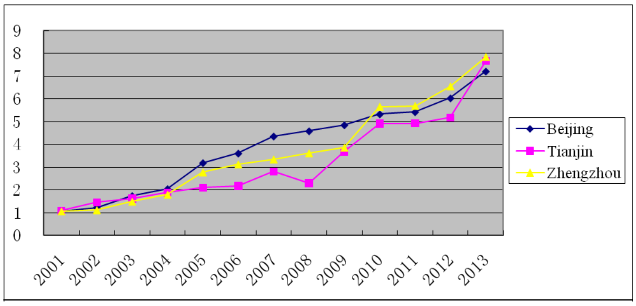

Fig. 1: Industrial wastewater discharges of Beijing, Tianjin and Zhengzhou (100 million tons).

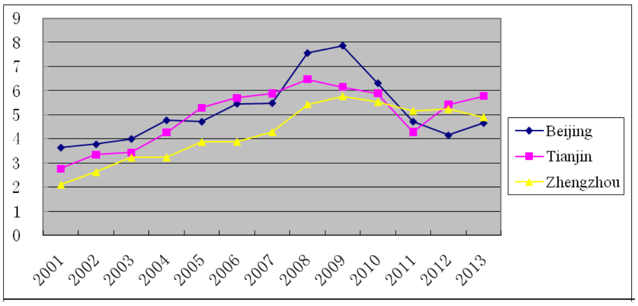

Fig. 2: Industrial COD discharges of Beijing, Tianjin and Zhengzhou(10,000 tons).

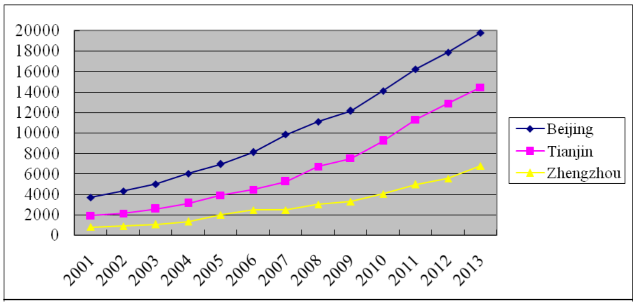

Fig. 3: GDPs of Beijing, Tianjin and Zhengzhou (100 million yuan(RMB)).

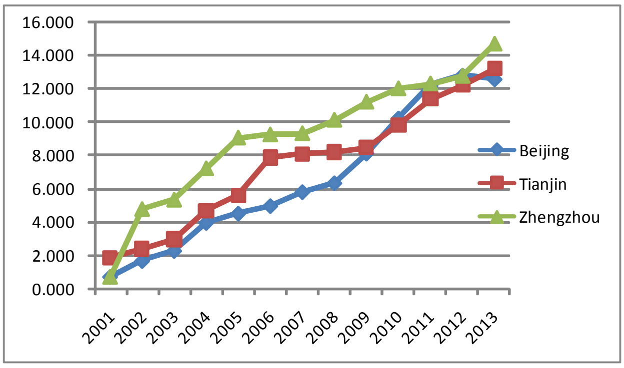

Fig. 4: Decomposition diagram of economic scale effects in Beijing, Tianjin and Zhengzhou.

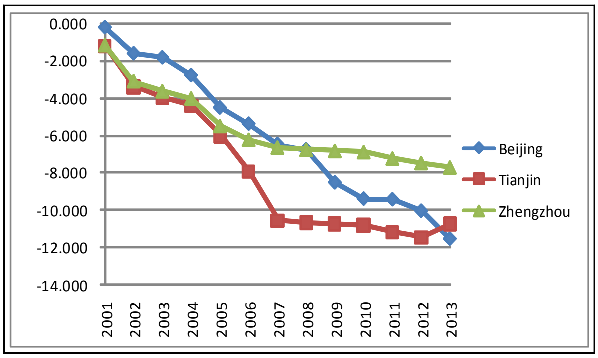

Fig. 5: Decomposition diagram of technological progress effects in Beijing, Tianjin and Zhengzhou.

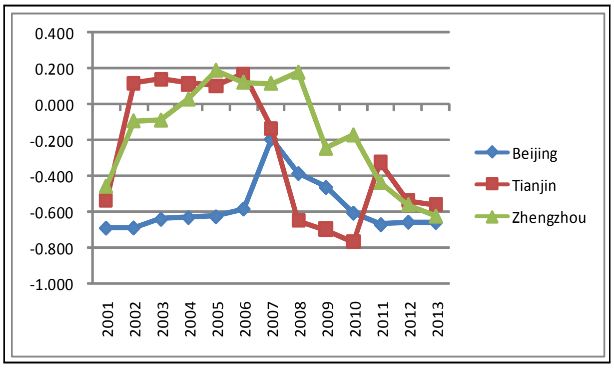

Fig. 6: Decomposition diagram of industrial structure effects in Beijing, Tianjin and Zhengzhou.

increasingly serious pollution load and continuously increasing pressure on the water environment.

EKC Curve Verification of Water Environmental Pollution and its Difference Analysis

Curve verification: Table 1 shows the regression results based on the environmental economic regression model and the simulation of experimental data of GDP per capita and water environment pollutant discharges of Beijing, Tianjin and Zhengzhou. The results indicate that a cubic curve, instead of reverse U-shaped curve, represents the relationship between the economic growths of the three regions and wa-

Table 1: Regression results of water environmental pollutant discharges and economic growths of Beijing, Tianjin and Zhengzhou.

Cities	Model absorption				Model test				
	β_0	β_1	β_2	β_3	R^2	F test	t_{test}		
							β_1	β_2	β_3
Beijing	-0.28	3.98	-29.06	298.23	0.87	0.041	0.031	-19.23	1983
Tianjin	-0.12	12.75	-126.78	187.39	0.91	0.012	0.023	-12.37	1728
Zhengzhou	-0.36	10.27	-108.74	382.91	0.84	0.023	0.018	-14.29	1346

ter environment pollution. The F test rejects the initial assumption at 5% significance level and accepts that a reverse N-shaped curve represents the relationship between water environmental pollution and economic growth. The three models differ in model coefficients; thus, a t test is used to determine the overall level of the model. In the models of these three cities, quadratic and cubic coefficients are significant at 5% statistical test level, and the parameter coefficients of the model are reliable. Therefore, the model in Formula (2) is more suitable for Beijing, Tianjin and Zhengzhou than the model in Formula (1). After the relatively small inflection point, the water environment tends to deteriorate. However, after a certain period of economic development, the water environment tends to improve after relatively large inflection point. The reverse N-shaped curve indicates that the economic growths of the cities significantly influence water environmental pollution, clearly demonstrating that Beijing, Tianjin and Zhengzhou have recently exceeded the inflection point of severe water pollution deterioration. The mitigation of industrial water pollution resulting from economic growth is related to the upgrading of the industrial structures of the three cities and the emigration of some enterprises that pose serious pollution problems.

Model fitting: The relationships between the economic growth of Beijing, Tianjin and Zhengzhou and water environment pollution present reverse N-shaped curves. However, the GDPs per capita at the inflection points of the three cities differ significantly. The GDP per capita of Zhengzhou at a relatively small inflection point is 6,869, whereas that at a relatively large inflection point is 8,236. The GDP per capita of Tianjin at a relatively small inflection point is 12,654, whereas that at a relatively large inflection point is 15,236. The GDP per capita of Beijing at a relatively small inflection point is 14,678, whereas that at a relatively large inflection point is 19,853. These statistics indicate that the economic growths of Beijing, Tianjin and Zhengzhou are not the only reason for the improvement of environmental quality. The economic development models, industrial development periods, urbanization levels, and environmental policies of the different cities have different influences on the water environment. The simulation results show that when the economic level reaches a certain level, the deterioration of the water environment can be minimized by certain means. The current pollutant discharges of Beijing, Tianjin and Zhengzhou tend to decrease with economic growth, indicating that after the economic developments in Beijing, Tianjin and Zhengzhou reach a certain level, these cities have enough funds to reduce their pollutant discharges. However, the capacity of reducing pollutant discharges varies across regions. The pollutant discharge of the whole region can be reduced by enhancing regional cooperation to alleviate the deterioration of the water environment.

Comparative analysis of influencing factors of water pollutant discharge: A factor decomposition model is utilized to analyse the water pollutant discharges of Beijing, Tianjin and Zhengzhou, and the results of which are shown in Fig. 4, Fig. 5 and Fig. 6. The economic scale effects, results in the rapid increasing trend in industrial wastewater discharge and has negative influences on water environment. The economic scale effect of Zhengzhou is the maximum, whereas that of Beijing is the minimum. The technological progress effects exert positive influences on water environment, reducing water pollution and helping improve the status of the water environment. The technological progress of Beijing and Tianjin rapidly reduces industrial water pollution, and the effects of such technological progress are better than that of Zhengzhou; as a result, the water environment pressure caused by the economic scale effects is significantly relieved. The industrial structures of each city vary over time with an aim to improve the water environment status. Thus, industrial structure adjustments and factor input changes have positive influences on water environment. The fluctuations in the industrial structure effect of Tianjin are the most significant and present a reverse U-shaped curve, indicating the city's drive to improve water environment. Thus, the economic scales of Beijing, Tianjin and Zhengzhou are the key factors in increasing their industrial wastewater discharges, and technological progress is an important factor in discharge reduction. Owing to the differences in the economic development imbalances and wastewater discharge patterns of the three cities, their water pollutant discharges also differ significantly. Under the joint action of optimizing industrial internal structure and enhancing technological progress, the water environment in three cities is continuously improved.

Analysis of Results

In this study, the water pollutant discharges and economic data of Beijing, Tianjin and Zhengzhou for the period 2001-2013 are selected, and the regression model and complete decomposition model are utilized to study empirically the relationship between water environmental pollution and the economic growths of Beijing, Tianjin and Zhengzhou. The major results are as follows:

Industrial wastewater discharges and economic growths of Beijing, Tianjin and Zhengzhou present reverse N-shaped curves, instead of reverse U-shaped curves. At present, industrial water pollution tends to improve with economic growth. No EKC curve is generated for the industrial COD discharges with respect to the economic growths of the three. This result indicates that the economic growths of Beijing, Tianjin and Zhengzhou significantly influence water environment pollution, but economic growth is not the only means to improve the status of the water environment.

The results of the decomposition analysis of the influencing factors indicate that economic scale and technological progress are the main influencing factors of water pollutant discharge. The economic scale effect is the major factor increasing the wastewater discharge, whereas the technological progress effect is the major factor decreasing the wastewater discharge. Although industrial structure effect may result in fluctuations in wastewater discharge, its influences are not significant.

The GDP per capita at the inflection point of the reverse N-shaped curve of the relationship between water environmental pollution and economic growth significantly varies across regions; thus, other factors, including the economic growth modes, industrial development periods, urbanization levels, and environmental policies of the three cities have different influences on water environment quality. In terms of the key influencing factors, the economic scale effect of Zhengzhou is the maximum, whereas the economic scale effect of Beijing is the minimum. The technological progress effects of Beijing and Tianjin are obviously better than that of Zhengzhou. The current pollutant discharges of Beijing, Tianjin and Zhengzhou tend to decrease with economic growth. Because of their high economic levels, all three cities have the capacity to reduce pollutant discharges. However, the capacity of pollutant discharge reduction varies across regions. Therefore, the improvement of the overall regional water environment quality requires the enhancement of the cooperation of Beijing, Tianjin and Zhengzhou in promoting the regional pollution control capacity and efficiency.

POLICY PROPOSALS

Enhancing the campaign on water environment protection and raising water protection awareness: Specifically for enterprises with small-scale and relatively poor technology, the status of their surrounding water environment and the water pollution situation can be publicized occasionally and supervised publicly to promote the reduction of industrial wastewater discharge. At the same time, advanced technology and equipment for wastewater discharge reduction can be introduced actively to increase the fund proportion of environmental management and protection. Water pollution compensation mechanism should be perfected and implemented as soon as possible, strictly adhering to the polluter-pays principle and focusing on supervising enterprises significantly contributing to the deterioration of the water environment. The corresponding amount of water environment prevention and control funds are levied to provide financial support to future water environment management and recovery programs and reinforce industrial wastewater discharge standards. Projects related to water environment protection should be actively introduced. Upgrading and servitizing industrial structures and improving water usage in the tertiary industry significantly increases domestic water. The drainage of water to the sea aggravates urban water environment pollution. Therefore, the urban sewage treatment capacity should be enhanced, the sewage treatment rate improved, population development strategies firmly implemented, and population in these three cities strictly controlled. Moreover, water environment protection campaign should be strengthened to improve water environment protection awareness and water environment protection knowledge can be popularized.

Adhering to new industrialization roads and reducing pollutant discharge: The adjustment of the internal structural proportion of industries in the three cities, together with proving information to industries towards industrialization development, may result in the introduction of new technologies that could reduce industrial wastewater discharge and produce higher-value outputs so as to increase GDP mainly from new development directions of water resource inputs. In terms of industrial adjustment, industries with low industrial level but huge unit water resource consumption are eliminated. In environmental access systems, higher demands should be imposed to strengthen the verification of enterprises and exclude enterprises with high energy consumption, high pollution, and high wastewater discharge. Wastewater discharge can be reduced from the source. The industrial structure should be reasonably laid out. Zhengzhou in particular should positively promote the development of the tertiary industry with low negative environmental effects. An investment operating mechanism conforming to the market economic criterion and international practice should be established, investment and financing systems that allows for the investment, subject to decide, should be formed, various financing methods and powerful macroeconomic control by the government should be implemented. At the same time, administrative supervision should be required on current sewage treatment stations of the surrounding industrial and mining enterprises, and measures should be taken to guarantee normal operation. After the criteria are met, sewage should be discharged. New enterprises and new projects should be strictly supervised and monitored, and sewage treatment stations should be established for sewage treatment.

Optimizing industrial structures and transforming economic development modes: The governments of these three cities should provide policy-type supports. The water resource and environmental property right systems should be perfected, and scientific and reasonable water environmental compensation mechanisms should be put in place. The financial and taxation system should be improved to provide tax preference, financial support, and credit support for the development of strategic emerging industries and new services. Technical support should be provided to promote research and development and transformation of agricultural science; improve the contribution rate of agricultural, scientific, and technological progress; and advance agricultural modernization to realize both economic development and water environment protection. Positive effects should be increased, and negative effects should be decreased to fully and effectively exert the role of the economic core of Beijing and Tianjin in the social development. The urbanization macroscopic readjustment and control should be strengthened. Zhengzhou should strive to develop its tertiary industry. A switch from growth-oriented methods to plan-oriented methods is necessary to adjust and control the status quo and development of urban water resource utilization. Projects that are quality and benefit oriented, scientifically and technically guided, resource saving, and environment friendly should be advocated and developed. Projects with high energy consumption, huge resource wastage, and severe pollution should be controlled from the root in these three cities.

CONCLUSIONS

In this study, 2001-2013 time series data of discharged volumes of industrial wastewater, industrial COD and GDP are utilized to establish two regression models to verify the relationship between GDP per capita and water pollutant discharge. The data are also used in the *F* test and *t* test conducted. A complete decomposition model is then established to analyse the effects of economic scale, industrial structure, and technological progress on water environmental pollution. The empirical investigation indicate that the relationships between industrial wastewater discharges of Beijing, Tianjin and Zhengzhou and their economic growths present reverse N-shaped curves, instead of reverse U-shaped curves. At present, with enhanced economic growth, industrial water pollution tends to improve. Economic scale and technological progress are major influencing factors of water pollutant discharge. The three cities should strengthen the campaign on water environment protection, raise water protection awareness, adhere to new industrialization roads, reduce pollutant discharge, optimize their industrial structures, and transform economic development modes. The overall regional water environmental quality can be effected only by enhancing the cooperation between Beijing, Tianjin and Zhengzhou to improve the capacity and efficiency of regional pollution control.

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