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RESEARCH ARTICLE

Analysis of the relationship between economic growth and industrial pollution in Zaozhuang, China—based on the hypothesis of the environmental Kuznets curve

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Abstract In Zaozhuang, economic development affects the discharge amount of industrial wastewater, chemical oxygen demand (COD), and ammonia nitrogen (NH_3-N). To reveal the trend of water environmental quality related to the economy in Zaozhuang, this paper simulated the relationships between industrial wastewater discharge, COD, NH_3-N load, and gross domestic product (GDP) per capita for Zaozhuang (2002–2012) using environmental Kuznets curve (EKC) models. The results showed that the added value of industrial GDP, the per capita GDP, and wastewater emission had average annual growth rates of 16.62, 16.19, and 17.89 %, respectively, from 2002 to 2012, while COD and NH_3-N emission in 2012, compared with 2002, showed average annual decreases of 10.70 and 31.12 %, respectively. The export of EKC models revealed that industrial wastewater discharge had a typical inverted-U-shaped relationship with per capita GDP. However, both COD and NH_3-N showed the binding curve of the left side of the "U" curve and left side U-shaped curve. The economy in Zaozhuang had been at the "fast-growing" stage, with low environmental pollution according to the industrial pollution level. In recent years, Zaozhuang has abated these heavy-pollution industries emphatically, so pollutants have been greatly reduced. Thus, Zaozhuang industrial wastewater treatment has been quite effective, with water quality improved significantly. The EKC models provided scientific evidence for estimating industrial wastewater discharge, COD, and NH_3-N load as well as their changeable trends for Zaozhuang from an economic perspective.

Keywords COD pollutant · NH_3-N pollutant · Industrial wastewater discharge · Per capita GDP · Zaozhuang

Introduction

In recent years, the water quality of lakes in China has decreased (Edwin et al. 2010). Relevant studies (Xu et al. 2009, Yang et al. 2010, Zheng et al. 2008) have shown that the water quality did not meet standard requirements in, e.g., Taihu Lake and Dianchi Lake, which have close relationships with neighboring cities. Many cities still superficially pursue economic development and neglect the environment, which results in industrial pollutants flowing into rivers, then affecting the water quality of lakes. Industrial pollution is a significant contributor to water pollution and remains one of the main threats to regional environment health (Yao et al. 2015).

The influence of regional economic development on environmental quality has aroused widespread concern all over the world. Boulding (2010) pointed out that the unreasonable economic activities of human beings would cause serious damage to the earth's environment by analyzing the relationship between economic system and environmental system (Boulding 2010). The developmental history of developed countries has shown that there are some relationships between economic development and environmental pollution. Using

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economic indicators to analyze and forecast changes in environmental pressure indices has also been studied and discussed by researchers. Hettige, et al. (2000) studied the relationship between economic development and environmental quality by industrial wastewater pollution and found the degree of wastewater pollution was increasing with the development of economy.

The EKC is a well-known method which was first used to study the relationship between economic growth and environmental pollution by Crossman and Krueger in 1991 (Gui and Li 2010). Compared to the mid-1930s, Grossman and Krueger (1991) found that the environmental pollution of some developing-country cities (such as Mexico and Bangkok) was more serious in the early 1990s, but the environmental quality of some developed-country cities was getting better. Therefore, they put forward a typical inverted-U-shaped relationship between economic development and environmental pollution according to empirical data. The results of Crossman and Krueger indicate that environment quality deteriorates during the initial period of economic development (Farhani et al. 2014). When economic development is above a certain threshold, it can automatically reduce or even eliminate the destructive effect on the environment. Therefore, the EKC between industrial wastewater emissions and economic growth is an inverted U-shaped curve.

Empirical studies abroad have shown that the inverted U-shaped curve was universal existence in period of industrialization of developed countries and newly industrialized countries (e.g., America, Western Europe, Korea, Japan, and Singapore) (Grossman and Krueger 1991, Tan 2014). Fodha and Zaghdoud (2010) have also confirmed the existence of U-type relationship between industrial pollution and economic growth in Tunisia. However, many scholars have found that the relationship between economic growth and environmental pollution was more complicated due to different regional economic development characteristics and uncertain implementation of environmental protection policies. As a result, not all EKC studies have shown an inverted U-shaped curve. Many EKC studies have also shown an N-shaped, an inverse N-shaped, a U-shaped, an inverse U-shaped and even a linear relationship (Yu and Chen 2012). Barua and Hubacek (2008) analyzed the relationship between per capita income and water pollution in 21 city states of India and found one of the 17 cities showed linear, N-shaped or U-shaped relationship. Lee et al (2010) has also verified the EKC of the water environment, the results indicated that the relationship between water environment and per capita GDP in the USA and UK was "inverted U" relationship, while Africa, Asia, and Oceania were a curve that is different from the traditional EKC. The reliability of the EKC is affected by sample size, data accuracy, and model selection. So, Farhani (2014) thought the case

study of specific countries and regions was superior to the overall analysis of the international regions. The EKC curve is of great significance to the analysis of the natural, economic, and social development of a region or country.

In Zaozhuang, there are a large number of highly polluting industries, including the papermaking industry, textile industry, and chemical industry (Zhu 2014, Zhao 2012), which pose a threat to water quality of city rivers(Fig. 1). Zaozhuang is located in the Nansi Lake Basin, which acts as a buffer lake of the South-to-North Water Diversion Project (east route) (Xu 2014, Zhao et al. 2006). Therefore, the water quality of the Nansi Lake Basin is important for the health of people in many cities. Water quality was less than class V (the Environmental Quality Standards for Surface Water (GB3838-2002)) in the Nansi Lake in 2002 (Sun et al. 2011) when the South-to-North Water Diversion Project was implemented, which was related to urban pollution discharge in the basin. Compared with Jining and Heze, Zaozhuang poses a higher risk to the water quality of the Nansi Lake (Sun et al. 2013); economic growth is a significant factor. Developing industries could increase the risk of water pollution.

In recent years, the water quality of the Nansi Lake Basin has changed significantly, reaching class III levels outlined by the Environmental Quality Standards for Surface Water (GB3838-2002) upon completion of the eastern route of the South-To-North Water Diversion Project in 2013. As the city with higher pollution, Zaozhuang took measures to positively control water pollution for ensuring the successful implementation of the South-to-North Water Diversion Project (east route). Zaozhuang has shut down many heavily polluting enterprises (Tang 2007) and improved the discharge standard of industrial wastewater. However, it is unknown whether, with respect to the typical inverted-U-shaped relationship between economic development and environmental protection, the turning point of EKC has occurred, thereby improving the water environmental quality without hindering economic development. Therefore, this study focused on the change and response relationship between the economy and wastewater COD and NH_3-N discharge by utilizing EKC models and analyzing the internal causes, which can provide the basis for water pollution control and sustainable development of Zaozhuang. In addition, the targeted coordination with environmental protection in various aspects of economic development can be implemented, to achieve a win-win situation for economic development and environmental benefits.

Materials and methods

Study area

Zaozhuang (116° 48′–117° 49′ E, 34° 27′–35° 19′ N), located in Shandong Province China, is a famous coal-mining city. It
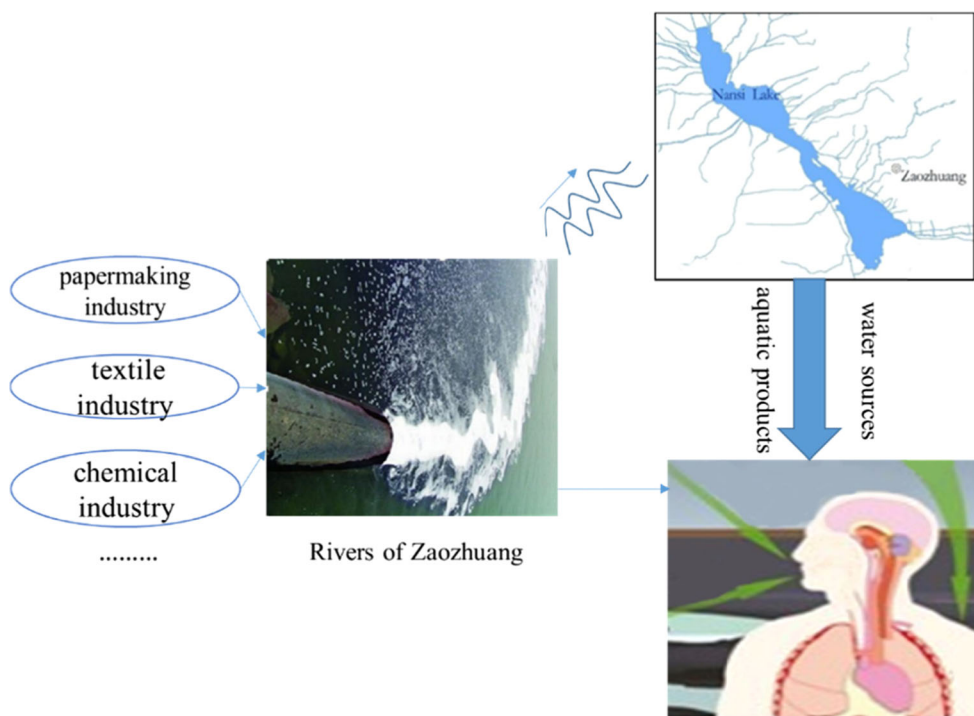
Fig. 1 The importance of Zaozhuang

consists of five districts (Taierzhuang District, Yicheng District, Shanting District, Shizhong District, and Tengzhou City) and a county-level city (Tengzhou City) (see Fig. 2). The total area is 4563 km^2, accounting for 2.97 % of the Shandong Province (He et al. 2013). Zaozhuang lies in the Nansi Lake basin which acts as a buffer lake of the South-to-North Water Diversion Project (east route). There are a total of 24 major rivers in Zaozhuang, in addition to 8 large rivers (Jiang et al. 2007). Zaozhuang is in an important strategic position as the first station of the south-to-north water transfer area in Shandong.

Resources will be exhausted with industrial economic development, which could cause environmental degradation (Daly 1980). The development of industrial production was bound to increase the amount of pollution emissions, which posed a threat to water quality. And, the concentration of pollutants in industrial wastewater was higher. The water pollution incidents of the Rhein River and Songhuajiang River were also due to rapidly advancing industrial. In addition, the papermaking industry around the Nansi Lake, Chaohu Lake, and Dongting Lake was closed, which resulted in greater improvement of water quality. Zaozhuang has formed a

Fig. 2 Zhaozhuang city
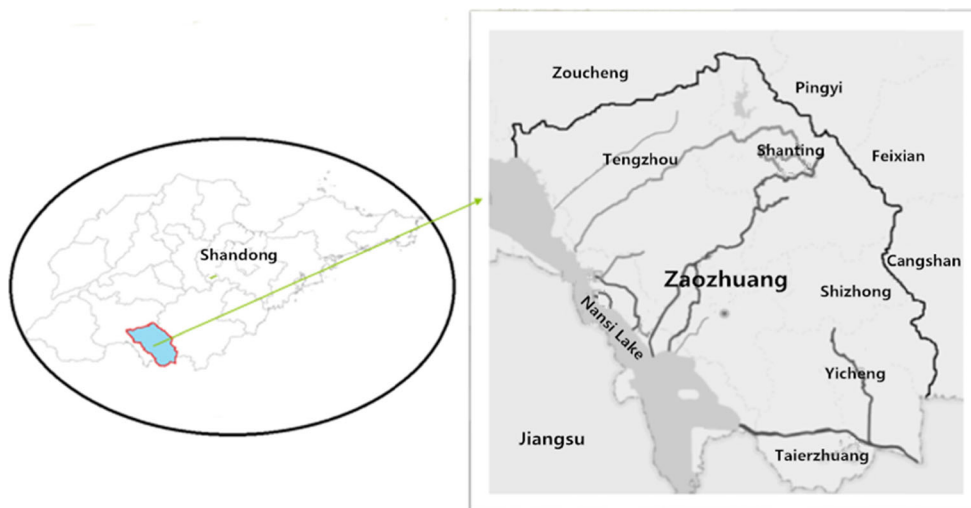
complete industrial system. As of 2012, the number of over-scale enterprises reached 2000, each of which deposits harmful wastewater into the city rivers (Liu et al. 2004). Due to the drastic increase in the number of enterprises, this region produces approximately 6.00×10^5 t of industrial wastewater daily, which has caused a great threat to water quality of the Nansi Lake basin (Xu 2009).

Data sources and processing

In this study, most of the data sets were downloaded from the websites Shandong Province Environmental Protection Authority (http://www.sdein.gov.cn/), and Shandong Province Statistical Bureau (http://xxgk.stats-sd.gov.cn/), including economic data, industrial wastewater, COD and NH$_3$-N discharge, and the water quality of the monitoring section. The data were processed using Excel 2013 and SPSS.20.

Constructing a model for the relationship between economic development and industrial pollution emissions

The theoretical equation of the EKC between environmental pressure and economic income is

$$y_{it} = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \varepsilon_{it} \qquad (1)$$

where i is the studied region, t is the year, y is the environmental pressure indicator, α is a constant, β is the estimated coefficient, x is the per capita GDP, and ε is the error term.

When β is 0, Eq. (1) is the equation of a typical inverted U-shape. The turning point of the EKC is $x = x = -\beta_1/(2\beta_2)$.

The relationship between economic development and environmental quality can be very complicated. In this study, the per capita GDP was selected as the indicator which reflected the economic development level of Zaozhuang. In Zaozhuang, there are a large number of highly polluting industries (including papermaking industry, textile industry, and chemical industry).

Therefore, the emission of industrial wastewater, COD, and NH$_3$-N was selected as the indicator which responded to pollution level of Zaozhuang.

With the help of SPSS software, economic growth (as the horizontal axis) and environmental quality (as the vertical axis) were fitted by linear, quadratic, and cubic models. The results indicate that the cubic model can better reflect the relationship between pollutant emission and per capita GDP. Therefore, the relationship between economic growth and environmental quality were fitted by the cubic regression curve model (Table 1).

From the regression model of per capita GDP of Zaozhuang with industrial wastewater emission, COD, and NH$_3$-N, it can be seen that the regression coefficient (R^2) of per capita GDP with COD and NH$_3$-N emission was over 0.7. However, the fitting effect of per capita GDP and industrial wastewater emission was not ideal. The R^2 of the linear and quadratic models were 0.093 and 0.545, respectively, which was less than the R^2 (0.623) of the cubic model. So, the cubic model was selected to fit the relationship between per capita GDP and industrial wastewater emission. At this time, the industrial wastewater coefficient of 62.3 % can only be explained by the per capita GDP due to affecting the discharge of industrial wastewater by other factors (environmental policy, laws, supervision, etc.).

Results and discussion

Economic development of the Nansi Lake watershed

From 2002 to 2012, the economy of Zaozhuang has developed rapidly. The total GDP increased from 313.86 billion yuan to 1702.92 billion yuan, a 5.43-fold increase, with an average annual growth rate of 16.62 %. In addition, the per capita GDP increased from 8687 yuan to 45,262 yuan (Fig. 3), an increase of approximately fivefold, with an average annual growth rate of 16.19 %. As we can see from Fig. 4, the proportion of the three industries (the primary industry, the secondary industry, and the tertiary industry) was adjusted from

Table 1 The analysis results of regression model

Environmental index (Y)	Model summary					Regression equation
	R^2	F	df1	df2	Sig.	
Emission of industrial wastewater	0.623	3.863	3	7	0.064	$Y = 10915.407 - 0.33X + (3.116E-5) X^2$
Emission of industrial COD	0.956	50.833	3	7	0.000	$Y = 29380.868 - 1.633X + (5.050E-5) X^2 - (5.700E+10) X^3$
Emission of industrial NN$_3$-N	0.806	9.082	3	7	0.008	$Y = 10791.811 - 0.932X + (3.005E-5) X^2 - (3.250E+10) X^3$
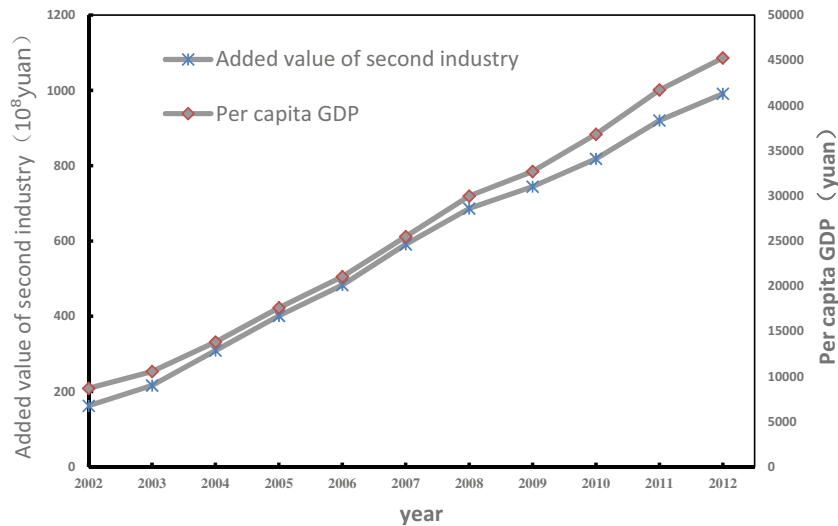
Fig. 3 The added value of industrial GDP and per capita GDP in the Nansi Lake basin during 2002~2012

14.58:51.68:33.74 in 2002 to 7.81:58.21:33.98 in 2012. The proportion of the secondary industry was still larger. From 2002 to 2012, the added value of industrial GDP increased rapidly from 162.20 billion yuan to 991.33 billion yuan, an increase of approximately sixfold, with an average annual growth rate of 17.89 %.

In summary, the proportion of the three industries was gradually optimized. However, the secondary industry still occupied a leading position in the economy of Zaozhuang. The water environment in Zaozhuang directly experienced deterioration due to the irrational proportions of the three industries. Hence, environmental protection needs a reasonable model of economic development.

Eco-environmental changes from 2002 to 2012 in Zaozhuang

As we can see from Figs. 5, 6, and 7, not all the EKCs of industrial wastewater COD and NH3-N emission showed an inverted U-shaped curve in Zaozhuang.

The EKC of industrial wastewater emission and per capita GDP in Zaozhuang showed an inverted U-shaped curve (Fig. 5). According to the traditional EKC, the turning point of EKC industrial wastewater emission occurred at the per capita GDP of 5.4×10^4 yuan. However, the turning point of EKC has occurred at the per capita GDP of 3.7×10^4 yuan, counter to EKC projections. The result was similar to that of
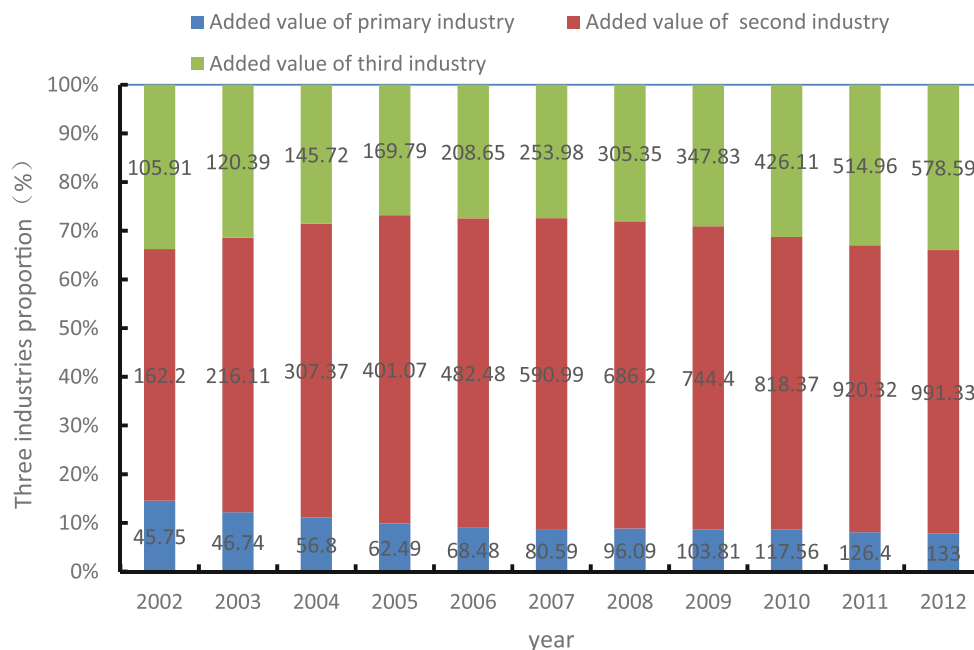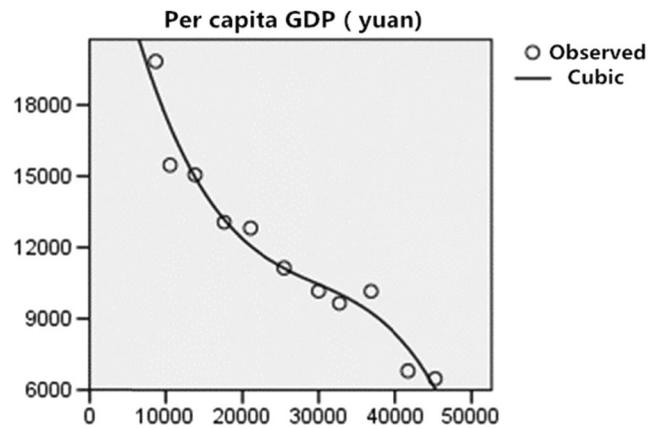

Fig. 4 The proportion of three industries which occupied with total GDP (2002~2012)

Fig. 5 The fitting curve between industrial wastewater emission and per capita GDP
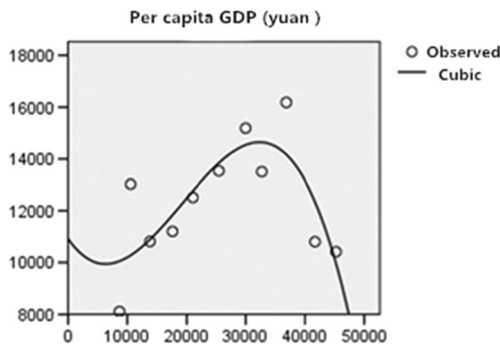
Fig. 7 The fitting curve between industrial COD emission and per capita GDP

the Circum-Bohai Sea zone (Xu et al. 2011), Puyang City (Li et al. 2015), and Hefei City (Zhang 2012): the relationship of industrial wastewater emission and per capita GDP matched the inverted U-shape EKC. The economy in these areas had been at the fast-growing stage with low environmental pollution, according to the industrial pollution level. The main reasons were that these cities took measures to control environmental pollution by increasing environmental protection investment and optimizing industrial structures, improving the discharge standard of industrial wastewater and enacting a series of statutes and policies, etc. However, the industrial wastewater emission still showed an increasing trend in some other areas, such as Guangdong (Li 2015) and Guangxi province (Yao et al. 2011). These cities pursued economic rapid development and had many polluting industries, which was caused by the irrational industrial structure, the little degree of

environmental supervision, and the lack of strict environmental protection standards. Therefore, the industrial pollution was still serious.

As we can see from Fig. 6, the industrial wastewater emission showed a fluctuation from 2002 to 2012. The year 2010 was a turning point: before 2010, the industrial wastewater emissions showed an increasing tendency, an increase of about two times, with an average annual growth rate of 6.48 %. After 2010, the industrial wastewater emissions started to decrease gradually, with a decline of 35.67 % in 2012 compared with 2010, which has confirmed the results of the EKC of industrial wastewater emission and per capita GDP.

Fig. 6 The total emissions of industrial wastewater, COD, and NH$_3$-N in the Nansi Lake basin during 2002~2012
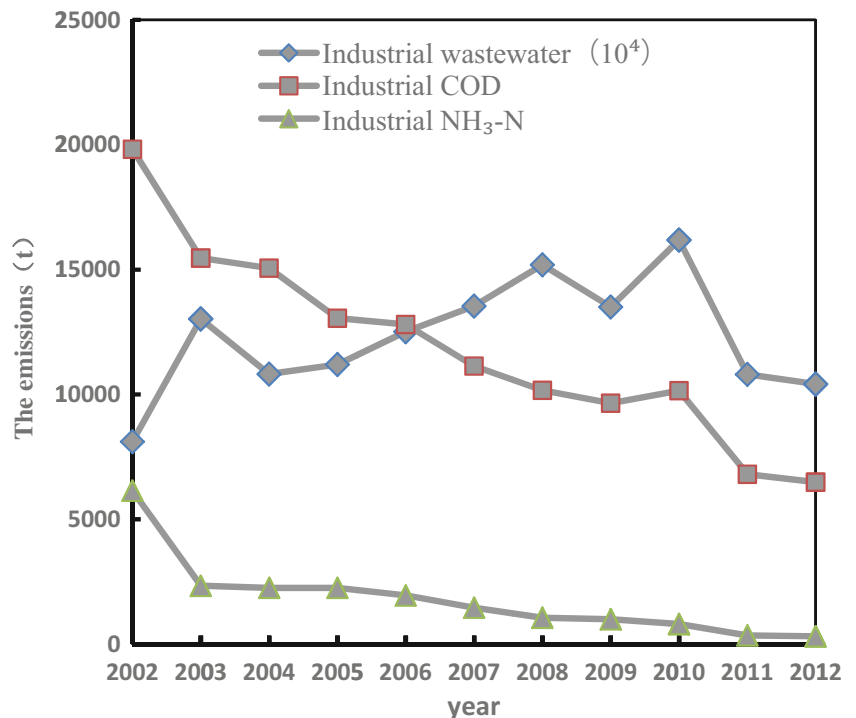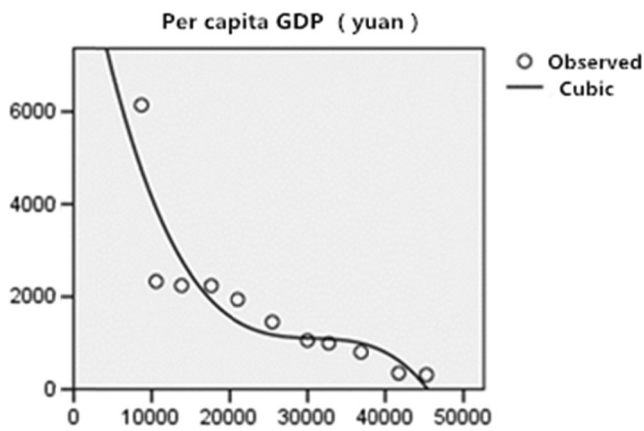
Fig. 8 The fitting curve between industrial NH_3-N emission and per capita GDP

The EKC of the per capita GDP with industrial COD and NH_3-N emission showed the binding curve of the left side of the "U" curve and left side U-shaped curve (Figs. 7 and 8). It indicates that the industrial COD and NH_3-N emission was still in declining stage from 2002 to 2012 in Zaozhuang.

The main reason was that Zaozhuang increased the standard of pollution treatment (Ni 2013). Therefore, many enterprises employed advanced wastewater treatment projects, which resulted in a reduction in the emissions of COD and NH_3-N. COD emission showed an overall decreasing tendency with an average annual decrease of 10.70 %; NH_3-N emission showed a significant decrease, with an average annual decrease of 31.12 % from 2002 to 2012 (Fig. 6). In addition,

compared with 2002, the sewage treatment rate had an increase of 10 % in 2012. Also, there were nine sewage treatment plants in Zaozhuang, which achieved a comprehensive treatment of industrial wastewater. Zaozhuang has passed the primary stage where economic growth had caused the deterioration of the water environment and has been in the second stage of fast growth with low environmental pollution, according to the industrial pollution level, due to technological progress and the environmental protection policy (see Fig. 9).

The intensity of control on heavily polluting enterprises and the situation of the water environment of city rivers in Zaozhuang

Zaozhuang has 40 provincial control enterprises. Among them, ten enterprises belong to the papermaking industry and three enterprises were closed; ten enterprises belong to the petroleum processing, coking, and nuclear fuel processing industry, one of which was shut down; nine enterprises belong to the textile industry, and two enterprises were closed; six enterprises belong to the food manufacturing industry, one of which was closed; five enterprises belong to the manufacture of raw chemical materials and chemical products. After 2002, Zaozhuang has increased the intensity of control on heavily polluting enterprises. In recent years, many heavily polluting enterprises have been halted in production, resulting in a significant decline in industrial pollutant emission. Additionally, the standard for pollution treatment was increased in Zaozhuang; the standardized discharge rates of

Fig. 9 The relationship between water environment and economy in Zaozhuang. + positive; − negative
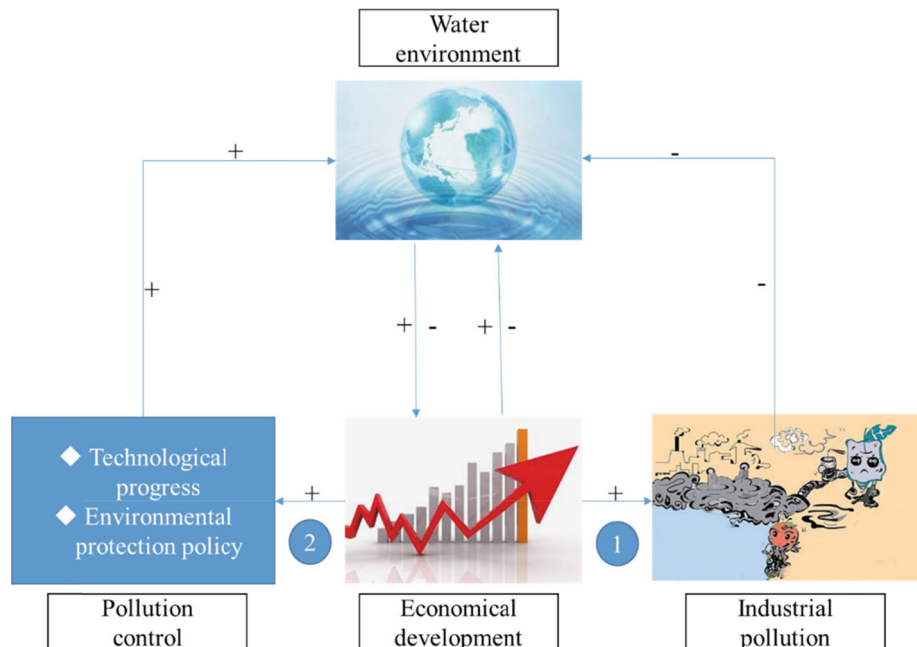
Note: +: Positive ; -: Negative

Table 2 The discharge concentration of COD and NH3-N of key enterprises in Zaozhuang

Enterprise	The discharge concentration of COD	The discharge concentration of NH3-N	The discharge standard of COD	The discharge standard of NH3-N
1	–	–	–	–
2	54.6	–	400	–
3	18	0.2	400	35
4	22.1	–	60	–
5	68.1	–	400	–
6	14.7	–	60	–
7	14.2	–	60	–
8	21.2	–	60	–
9	34.9	0.6	60	10
10	16.8	0.2	450	45
11	40.4	0.9	50	5
12	23.3	–	80	–
13	–	–	450	–
14	120.8	2	400	35
15	–	–	–	–
16	101.3	–	400	–
17	16.9	0.2	50	5
18	20.8	0.5	50	5
19	199.3	0.6	450	25
20	42.7	2	60	10
21	–	–	–	–
22	18.6	0.1	50	5
23	217.8	0.1	400	25
24	15	–	50	–
25	21.3	0.7	60	10
26	174	14	400	45
27	34.7	1.7	50	5
28	78.9	–	50	–
29	17.7	0.3	50	5
30	15.9	0.3	50	5
31	22.3	0.2	60	10
32	–	–	–	–
33	–	–	–	–
34	10.5	–	50	–
35	13.5	0.9	50	5
36	22.5	–	50	–
37	24.2	1.3	60	10
38	–	–	50	5
39	18.9	0.2	400	30
40	13.6	–	50	–

The unit of COD and NH3-N is mg/L. Enterprises are represented by the numbers. If you want to know the name of these enterprises, please log in the website (http://58.56.98.78:8801/webgis_wry/webgis/default.aspx)

Table 3 The water quality of monitoring section in Zaozhuang

Rivers	Monitoring section	The level of water quality	Common fish can grow stably
Hanzhuangyun River	Taierzhuang bridge	II	Standared
Xuechengxiaosha River	Pengkou brake	III	Standared
Xuechengdasha River	Shizihe bridge	I	Standared
Xinxue River	Luofang bridge	II	Standared
Yichengsha River	Jiazhaung brake	I	Standared
Chengguo River	Qunle bridge	III	Standared
Beisha River	Wangchao	Less than IV	No standard

industrial wastewater reached 98 %. Based on relevant enterprises' discharge concentration of COD and NH$_3$-N, it can be shown that effluent water quality reached the discharge standard (Table 2).

As we can see from the water quality of monitored sections in Zaozhuang (Table 3), fish can grow normally, which indicates that industrial wastewater flowing into the river has reached the discharge standard and would not cause serious damage to aquatic organisms of natural water bodies. However, the water quality of the river is different. The water quality of the Xuechengxiaosha and Chengguo rivers reached class III levels. The water quality of the Beisha river reached only class V levels. Overall, water quality has been greatly improved.
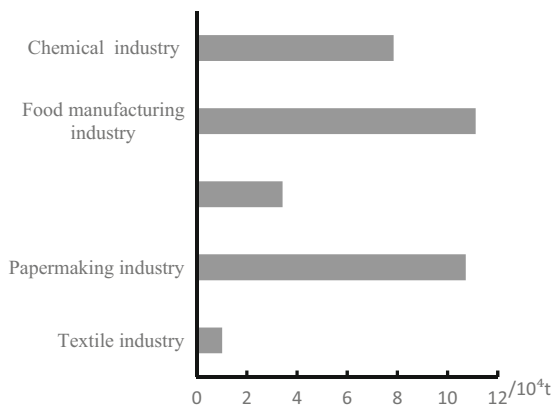
However, the papermaking industry and food-processing industries are still the main sources of pollution in Zaozhuang. In Zaozhuang, a major source of industrial COD is the paper industry. COD emissions from the papermaking industry accounted for 47.18 % of Zaozhuang's total industrial COD emissions (Fig. 10). The textile industry accounts for a
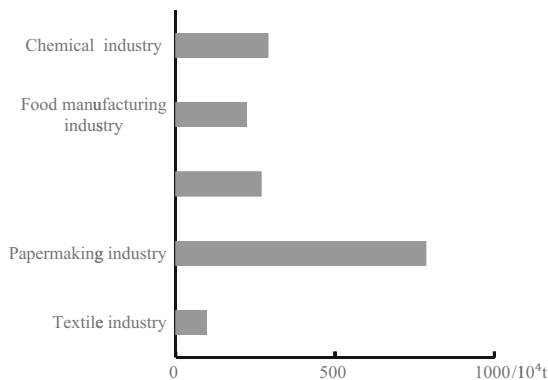
Note：cit ed from " Environment Quality Bulletin" of Shandong (2012）

Fig. 10 The COD emission of key industry of Zaozhuang in 2012.Cited from "Environment Quality Bulletin" of Shandong (2012)

Fig. 11 The NH$_3$-N emission of key industry of Zaozhuang in 2012. Cited from "Environment Quality Bulletin" of Shandong (2012)

large proportion of development in Zaozhuang, but industrial COD and NH$_3$-N emissions account for 5.85 and 2.95 % of emissions. Industrial NH$_3$-N emissions from the food-processing industry had the highest contribution rate, accounting for 2.59 % of the total industrial NH$_3$-N emissions in Zaozhuang (Fig. 11). Other industries accounted for a smaller proportion of emissions. Measures should be taken to control the sources of pollution in the papermaking and food-processing industries.

Conclusions and suggestions

In summary, the relationship between economy and environment was harmonious in Zaozhuang. While maintaining double-digit GDP annual growth during the period from 2002 to 2012, Zaozhuang has managed to significantly reduce industrial COD and NH$_3$-N emission. Overall water quality reached class III levels, which was required by the South-to-North Water Diversion Project. Analysis of a cubic polynomial fit to an Environmental Kuznets Curve demonstrates that the environmental turning points for industrial wastewater COD and NH$_3$-N emissions have occurred. This finding indicates that Zaozhuang has been at the stage of fast economic growth with low environmental pollution.

Although the environmental water quality of Zaozhuang has been greatly improved, there is still much work to be done to address mixed pollution and other pollution channels. In addition, the water quality of Zaozhuang has a huge impact on the water quality of the Nansi Lake basin and normal operation of the South-to-North Water Diversion Project (east route).

Therefore, water quality should be monitored continuously. And, the measures of environmental control and protection should be taken.

Firstly, three industrial structures need to be further optimized. Zaozhuang should adjust the primary department, strengthen the secondary industry, and develop the third industry. It also concludes that we should adjust the industrial structure and develop the low-energy, low-pollution industries. The forced mechanism should be built in order to promote transformation, upgrading and optimization of the polluting industries, and force the transformation of development pattern. The papermaking industry is still the main source of pollution in Zaozhuang, and measures should be taken to control its pollution.

Secondly, the force of environmental response measures should be strengthened to maintain and improve its current grade. The foundation work of the prevention and control of environmental quality should be firmed. It is very effective to improve water environmental quality by propelling the jointly prevention and control of environmental protection and increasing environmental regulation efficiency. The regional green national economic accounting system should be established.

Thirdly, they can combine "treatment, recycling, and restoration (TRR)" model of the Nansi Lake basin and build "TRR" model of small basin, which can promote that the emission reduction of sub-basin pollutants is continuously progressed and the water environment capacity is continuously rising.

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