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Relationship Between Contaminant Flux and Economic Growth at the Pearl River Estuary in Guangdong Province, China

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ABSTRACT

The acceleration of industrialization and urbanization, rapid expansion of population, hysteretic infrastructure construction in cities and towns, and poor domestic sewage treatment in recent years have resulted in increased contaminant flux at the Pearl River estuary and caused considerable pressure on economic growth. The measurement model of the relationship between the emission load of the environmental index and GDP is established by using relevant data about economic growth and environmental quality of cities and counties along the Pearl River in Guangdong Province between 2001 and 2014. The results demonstrate that Kuznets relationship exists between the contaminant emission at the estuary and GDP. Among the contaminants entering the sea, the contents of COD (Chemical Oxygen Demand), nutrient salts (which mainly include ammonia nitrogen, nitrate nitrogen, nitrite nitrogen and phosphorus), heavy metals, petroleum, and arsenic increase with the increasing GDP. Regression analysis shows a close relationship between the contaminant and GDP per capita; U-shaped and reverse U-shaped relationships exist between emission of COD and heavy metals, and between emission of nutrient salts and petroleum and GDP per capita, respectively. Moreover, the relationship between emission of arsenic and GDP per capita presents a relatively weak N curve. Thus, the environmental problem in the Pearl River Basin is serious and needs immediate solution.

INTRODUCTION

Marine environment is a significant subsystem of the entire ecological environment system. Marine resources have indispensable and important strategic effects on the survival and life of humans and social development. With economic development, in particular the emerging economies, increase in population, and change in consumption model, demand for energy and resources has increased. Moreover, the seawater environment at the estuary is also under increasing pressure. The interaction between land and sea has become an important research issue on global environmental change. Given that land activities are key factors that influence the ocean environment, the water quality and contaminant flux have received increasing attention. Pearl River Delta is a decisive zone of economic adjustment and development of Guangdong and even in South China. The zone adjoins HK and Macao and contains abundant resources. The development and utilization along the ocean have reached an unprecedented height. However, protection plan for the ocean has not been developed, and significant environmental problems exist. Emissions produced by industrial and economic sectors along the Pearl River estuary have deteriorated the water environment. Illegal reclamation, dike construction, mineral mining, unscrupulous sea-sand mining, and Mari culture also contribute to water deterioration. Red tide and pollution frequently occur in several aquaculture areas along the Pearl River estuary, and discharges by ships at ports cause serious pollution. The aforementioned activities result in severe contamination in most areas of the estuary, and strategies to reduce water pollution at the Pearl River estuary should be urgently implemented. The rapid development of economy and society in the Pearl River estuary along with great consumption of resources and energies and extensive operation, greatly affect and damage the natural environment because of overexploitation of resources, unrestricted emission of pollutants and wastes, sharp increase of population, urbanization of village, and hysteretic ecological construction. The Pearl River estuary, where most pollutants are received from the entire Pearl River system, has deteriorating water quality. For example, the oxygen demand in the recent 15 years in this area has presented a fluctuating growth trend. Fig. 1 shows that the structure of the entire water ecosystem is imbalance, and biological resources and biodiversity exhibit a sharp decrease.

Cities around the Pearl River are generally industrialized, and heavy chemical industry accounts for a relatively great proportion. The rise of industrial belt of petrochemical industry along the various areas of Pearl River estuary, namely, Nansha Development Zone in Guangzhou, the western area of Zhuhai, and Daya Bay petrochemical zone in

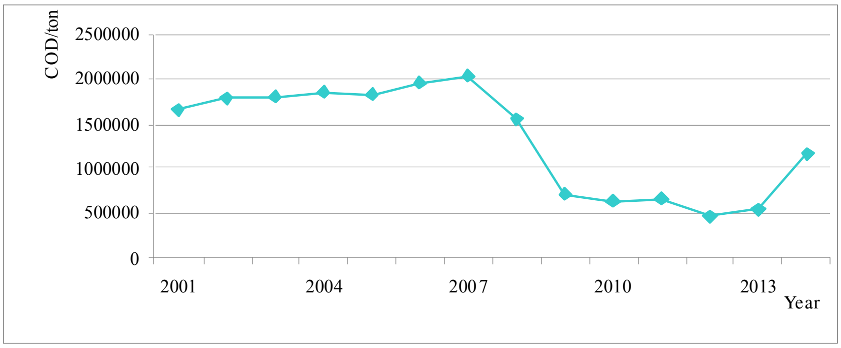

Fig. 1: Graph of COD emission at the Pearl River estuary over the years.

Huizhou, has exerted pressure on the environment. Therefore, we should formulate environmental protection plan for the sea area at the Pearl River and macroscopically delimit the environmental functions of each area to ultimately improve the environmental quality by considering environmental capacity and sewage discharge permission as main management tool. Hence, analysis of the variation trend of contaminant flux at the Pearl River estuary and discussion of the relationship between economic development and variation of surroundings are significant bases to achieve harmonious development of environment and economy at the Pearl River Delta and satisfactory river water quality. These measures provide important reference and are significant for remission of water environment pollution of the river.

STATE OF THE ART

Economic growth pattern should take sustainable development as principle. The quantity of development should be considered, and the quality of development should also be strengthened. Under the premise of maintaining quality of natural resources and provision of service, net earning of economic development shall reach the maximum value. The relationship between the environment and economy, particularly the relationship between water pollution and economic growth, is widely investigated by environmentalists and economists to date. The research on the relationship between social and economic development and environmental pollution in coastal zone firstly attracted the attention of overseas scholars in the 1970s. In 1972, the United States Congress issued Coastal Zone Management Act, indicating that management of social and economic activities in the coastal region is an official activity of the government. Grossman is an American environmental economist who observed the relationship between economic growth and income distribution of numerous countries. He established environmental Kuznets curve (EKC) for the relationship between economic growth and environmental pollution, providing the basis for subsequent research (Grossman & Krueger 1992). Jiang et al. (2001) analysed social and economic development, population increase, and infrastructure construction of a coastal city. They reported that an increasing number of sanitary sewage and industrial wastewater have been directly or indirectly discharged into the sea through the river, drainage system, and other channels, which greatly affect the ecological environment in offshore area.

Muyibi et al. (2008) analysed the close relationship between social and economic development and river pollution in Malaysia and used GDP, industrial production value, and population size as socio-economic indicators. This research indicated that a causal association exists between each indicator and river pollution. Tsuzuki (2009) studied the curvilinear relationship between emission load per capita of relevant factors in water environment and GDP per capita and pointed out that pollutant discharge index and millennium hygienic index must be established to ensure unceasing improvement of human health and life quality. Harbaugh & Wilson (2002) concluded that the relationship between water pollution and GDP is important and that water pollution gets worse with the rapid increase in economy. Tsuziiki (2009) found EKC curve (Environmental Kuznets Curve), but EKC curve of BOD in total nitrogen and waste water does not exist. Sewage discharge is caused by economic development. However, many studies abroad indicated that the changing trend of water pollutants shows a reverse U-shaped relationship with the per capita income of people; this kind of relationship may not exist in several developing countries. For instance, in 2003, Bednar-Friedl & Getzner (2003) carried out a research on the relationship between CO_2 discharge and economic growth in Austria between 1960 and 1999, they concluded that the relationship between the two can be represented by an N-shaped curve, instead of the traditional reverse U-shaped curve.

Perman & Stern (2003) and Coondoo & Dinda (2002) also learned from an empirical research that the relationship between contaminant discharge in the environment and economic indicators does not exist in the EKC curve. In China, many studies on water environment pollution and economic growth have been conducted. Li Xinying (2006) conducted a research by using per capita GDP and discharge data of three industrial wastes of Xinjiang between 1985 and 2003 and concluded that the level of environmental pollution in Xinjiang is at the ascent stage of reverse U-shape of the EKC curve. Danhui Yang & Hongli Li (2011) performed a study by using panel data of 17 cities of Shandong Province between 1995 and 2008 and reported that an N-shape relationship exists between environmental pollution and economic growth of Shandong. Xinying Li (2006) proved through empirical study that the per capita emission load of wastewater in China increases with increasing per capita income and declines thereafter, and has crossed the inflection point of the EKC curve. Zhang Jie & Zhang Yumei (2006) conducted a research on the relationship between economic growth and environmental transition during industrialization in Guangdong; they concluded that an N-shaped curve relationship exists between an emission load of the three industrial wastes and per capita GDP.

All aforementioned studies indicated that EKC is discussed widely in each field and have established a foundation of theoretical analysis. Most investigations on water environment in China focus on the current situation, pollution, and governance of the water environment, whereas those studies abroad, mainly emphasize quality evaluation, water price, and consumption of the water environment. Moreover, few studies on the relationship between water environment pollution and economic growth are available, but investigations on EKC in China and abroad have been increasingly applied. The measurement indicator system of Kuznets curve of water environment is not complete, and few works consider the influence of water environment pollution at the estuary on economic growth. This paper presents an empirical study on the relationship between water environment pollution of the Pearl River and economic development level of the surrounding cities by adopting EKC. The study is based on the response relationship between regional, social and economic development and output of contaminants. This study aims to provide a theoretical foundation to control pollution in Circum-Bohai sea region and formulate policies about the harmonious development of economy and environment in Guangdong.

METHODOLOGY

EKC Model

EKC was first introduced by Grossman & Krueger (1993). This concept reflects the relationship between economic growth and water pollution. EKC curve uses economic indicators, such as abscissa axis, and environmental indicators, such as vertical axis. By assuming different conditions, many researchers consider different factors and several formulas about economic growth and environmental pollution. In this paper, the most common quadratic, cubic, and logarithmic functions are used as follows:

$$E_t = c_1 + c_2 Y + c_3 Y^2 + u_t \quad ...(1)$$

$$E_t = c_1 + c_2 Y + c_3 Y^2 + c_4 Y^3 + u_t \quad ...(2)$$

$$\ln E_t = c_1 + c_2 \ln Y_t + c_3 (\ln Y_t)^2 + c_4 (\ln Y_t)^3 + u_t \quad ...(3)$$

Formulas (1), (2) and (3) are quadratic, cubic and logarithmic functions, respectively. E_t is the environmental pollution index of the surrounding cities at time t, Y_t is the per capita GDP, c_t is the coefficient for temperature, and u_t is a random disturbance term. In the logarithmic model, if $c_2 > 0$, $c_3 < 0$, $c_4 = 0$, $c_2 > 0$, $c_3 < 0$, $c_4 > 0$, $c_2 < 0$, $c_3 > 0$, $c_4 < 0$, then the curve degrees of contamination are U, N, and reverse N shapes, respectively. Both U and N shape curves indicate that the emission indicator of contaminant ultimately decreases in the future with increasing GDP. EKC research includes cross-section, panel, and time series data. Cross-section data can reflect differences in environment-per capita income curve of countries with different developmental levels. Time series data can present the characteristics of environment-economic growth curve of the same country or region at different times. Panel data possess the characteristics of both cross-section and time series data and can reflect comprehensively the influence of variation of per capita income and regional difference on the relationship between environment and economic growth. Considering the differences in economy and culture in different areas in the drainage basin of the Guan River and the difference between environment and economy at each time phase, the panel data model can better determine the shape of environment-economy curve.

Selection of Index and Data Sources

Economic development: Given that per capita GDP can reflect the influence of the true income level on environmental quality, previous studies as well as the present work, use per capita GDP as an index of economic growth. Based on the per capita GDP (presented in RMB Yuan), which indicates economic growth, GDP index in 2001 is taken as a cardinal number in this paper to eliminate the influence of price fluctuations and determine per capita GDP under constant price.

Contaminant flux into the sea: Selecting an environmental index is important in the construction of the measurement model of the relationship between level of environ-

Table 1: Contaminant flux into the Pearl River (Ton).

Time	Chemical Oxygen Demand(COD)	Nutrient	Petroleum Salts	Heavy Metals	Arsenic
2001	1654875	124521	23544	5455	3265
2002	1785645	126845	29874	6856	3105
2003	1794552	135648	32145	6854	2954
2004	1845242	135711	39542	7485	2903
2005	1830000	130800	42400	6808	2840
2006	1954566	124512	46584	7962	2542
2007	2040000	114100	48700	8996	3190
2008	1550000	68100	40200	8813	3760
2009	715510	53768	12544	3308	1019
2010	632016	66808	14045	2934	926
2011	658560	81211	14112	4324	806
2012	464585	184470	9783	3726	725
2013	536180	195452	11288	2888	452
2014	1162800	264512	12240	4781	581

mental pollution and economic development. In view of the availability of data and the feasibility of indexes, COD, nutrient salts (which mainly include ammonia nitrogen, phosphate nitrogen, nitrite nitrogen, and phosphorus), heavy metals, petroleum, and arsenic are selected as indexes based on the contaminant flux into the Pearl River over the years (in ton).

Data sources: Per capita GDP index is obtained from Guangdong Statistical Yearbook (2001-2014). All data on contaminant flux into the Pearl River come from the Guangdong Report on Marine Environment (2001-2014).

EMPIRICAL STUDY

Data of the five indexes of contaminant flux into the Pearl River over the years are obtained by sorting, as depicted in Table 1.

Curve simulation is performed based on the above data and per capita GDP by using Eviews 7.0 software, and the results are presented in Table 2. Based on regression analysis, the simulation results are extremely close, and greater than 0.8. Meanwhile, F indicates that the regression equation of these indexes is significant from the whole.

To analyse the relationship between per capita GDP and contaminant flux in the sea, an EKC curve is presented in a graph, which exhibits a reverse U-shaped curve of the degree of environment pollution. Simulation results are shown in Figs. 2-6.

Figs. 2-6 show the relationship among the five contaminants flowing into the Pearl River. Economic growth generally meets the following conditions for the curve of environmental pollution.

The emission of COD and heavy metals lies in the rising part of the right side of the reverse U-shaped curve, indicating that the emission of COD and heavy metal increases with economic growth. Based on the simulation results and development planning of regional economy, the emission of COD and heavy metals will sharply rise in the next five years. The emission of COD and heavy metals has been efficiently controlled and treated by the government. The EKC curve of COD and heavy metals present a reverse U shape, which indicates initial deterioration followed by improvement. However, the EKC curve shows a linear relationship with increasing emission of COD and heavy metals, and the general condition in the total waste water. This finding reveals that with increasing GDP, the emission of COD and heavy metal increases and high growth and pollution form.

The fitted curve of nutrient salts and petroleum and per capita GDP presents a reverse U shape. This curve indicates that the emission of nutrient salts and petroleum initially increases and then decreases with the development of social economy. With the continuous increase of per capita GDP, the emission of industrial COD also decreases. From 2001 to 2014, the quantity of discharged nutrient salts and petroleum into the sea, presents a fluctuating increase with the increasing per capita GDP. The quantity of nutrient salts and petroleum discharged into the sea shows that the first turning point of the logarithm between the quantity of nutrient salts and petroleum discharged into the sea and per capita GDP is located at the place with per capita of 20500 Yuan and 10500 Yuan, respectively. The curve tends to present a straight climb in the next few years. The city governments have continuously improved the economic development and urbanization along the Pearl River drainage basin during which the population in cities increased yearly, along with water consumption and generated waste water. The emission of sanitary sewage in facilities has exceeded the maximum allowable increase. The lack of water environment awareness and policies in water environment protection has caused the increase of sanitary sewage emission with economic development. Given the continuous improvement of science and technology, enhancement of sewage treatment capacity, and improvement in population quality in the last 5 years, the emission of sanitary sewage in cities and towns has reduced.

A relatively weak N-shaped curve exists between arsenic and per capita GDP. This result is attributed to several aspects, such as industrial structure and environmental policy of the government. The economy in the cities surrounding the Pearl River stably increases and emission of arsenic also rises yearly, but the government has expanded efforts to protect the water environment; thus, the emission of arsenic in the Pearl River Basin maintained a stable trend. However, the

Table 2: Regression results of EKC of pollution at the Pearl River estuary and economic growth.

	R^2			F		
Environmental Index	Quadratic function	Cubic function	Logarithmic function	Quadratic function	Cubic function	Logarithmic function
COD	0.785	0.964	0.698	5451.212	5632.541	2154.012
Nutrient salts	0.796	0.869	0.914	6589.362	6987.546	3654.547
Heavy metals	0.862	0.845	0.863	6987.65	6210.352	5444.398
Petroleum	0.894	0.875	0.769	11125.655	12458.691	9874.654
Arsenic	0.999	0.769	0.864	8745.251	8654.219	11854.682

heavy chemical industry accounts for a relatively great proportion, and enterprises with high energy consumption and high pollution have not been completely rectified and reformed. Moreover, waste water discharges are also increasing.

EKC is a significant reference for the harmonious development of nature, economy, and society of a country or region, although its reliability is affected by sample space, model selection, and data precision. Progress in developed countries indicates that, with economic expansion and rise of per capita income, each region experiences an increase in unit GDP consumption and environmental pollution, which is the cost of resources and environment against rapid accumulation of social capital. The curve between economic growth and environmental pollution does not indicate that it is naturally formed; it is also affected by human factors, especially the requirements of regional development plan and environmental protection policy made by the government. Cities along the Pearl River must coordinate well with the relationship between economic development and environmental protection, take a new approach to industrialization, realize harmonious development of environment and economy in the area around the Guan River, well plan the emission of pollutants into the sea, and protect the environment. Hence, the cities around the Pearl River should consider creating strategic plans that focus on developing pollution prevention, particularly reinforcing pollution prevention in the sea area, coastal land area, and city environment; developing hard regional prevention; practically and effectively improving quality of river emptying into the sea; reducing pollution load entering into the sea; and gradually controlling pollution so that the sea area achieves the index of function division, recovery ecological functions, and environmental index.

POLICY SUGGESTIONS

Transformation of economic growth and development pattern: Economic growth pattern should be transformed, and industrial structure should be optimized. Moreover, circular economy must be developed, and sustainable development should be applied. We should encourage the areas under research to update the technology of enterprises, as well as transform industrial growth pattern and linear growth pattern depending on the energy consumed into circular and economic production patterns that rely on recyclable resources. These suggestions aim to form new economic mode of resource-product-renewable resources, use resources and protect the environment to the greatest extent, and apply a new approach for sustainable industrialization. Considerable effort must also be expended into ecological agriculture by improving intensive production and developing modern agriculture. Promoting optimization and upgrading of industrial structure must be focused. Moreover, developing tertiary industry and technology and capital-intensive high-tech industry; supporting modern service industry with high production, high employment, low pollution, and low energy consumption; and rapidly optimizing and upgrading of industrial structure; and enhancing comprehensive environmental treatment should be practiced.

Strengthening the construction of emergency capacity against environmental pollution accidents: We suggest building linkages among land area, river, and sea in the area under research, as well as strengthening the construction of basic capacity of forecasting and early warning of environment and risk assessment of disaster in the area. Early warning mechanism for key pollution in the land area must be established and enhanced, and rapid and efficient implementation of emergency process by relevant departments should be ensured to reduce loss. Other suggestions are as follows: establishing a perfect monitoring system of marine contamination accident; improving monitoring capacity of contamination accident; strengthening the construction of the risk prevention system for serious environmental pollution in the offshore area; focusing on the establishment of emergency response system for oil spill; and improving emergency capacity against contamination accident, such as oil spills and leakage of toxic chemicals.

Reinforcement efforts in sewage treatment and agricultural pollution: Actively developing environmental impact assessment; arranging productivity; a deepening circular

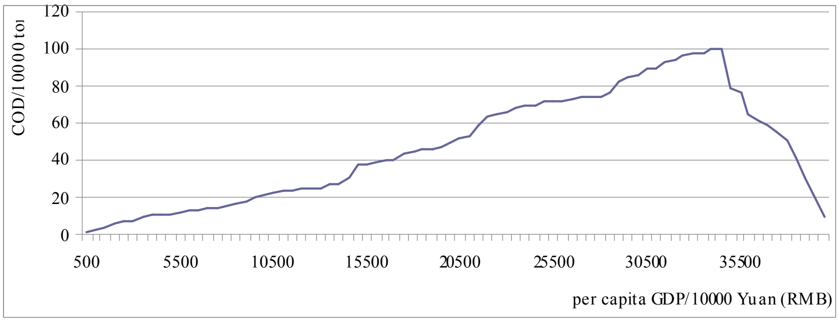

Fig. 2: Regression fit of COD and per capita GDP.

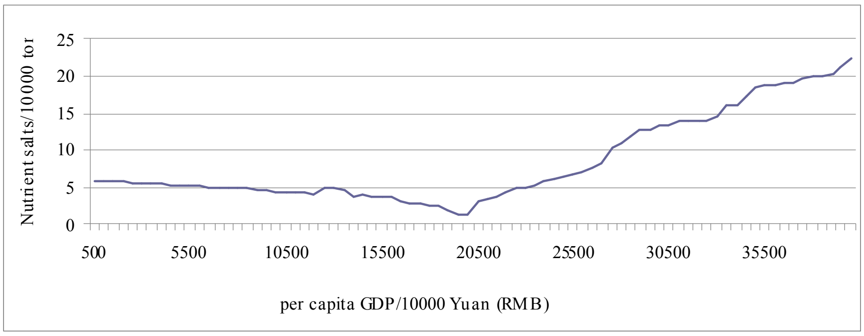

Fig. 3: Regression fit of nutrient salts and per capita GDP.

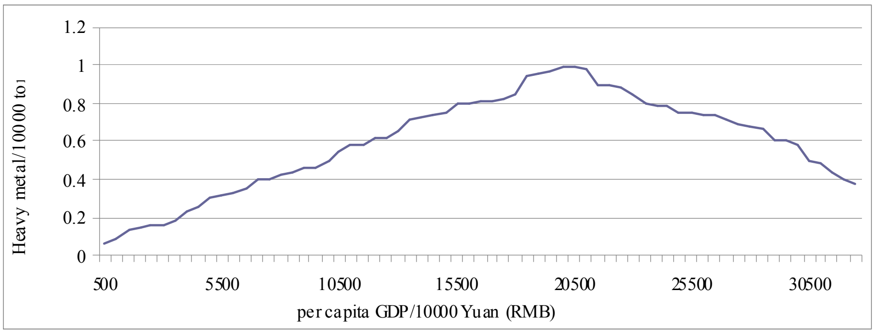

Fig. 4: Regression fit of heavy metals and per capita GDP.

economy based on the principle of reduction, recycling, and reclamation; and requiring a new approach to industrialization should be performed. Upgrading and reconstruction of sewage plant must be rapid. Construction of centralized processing facility for waste water and treatment of sanitary sewage in towns must be focused. Other suggestions are as follows: reinforcing treatment of non-point source pollution in agriculture; constructing effective sewage treatment facilities, including methane project, oxidation pond, oxidation ditch, and wet land by adjusting measures to local conditions; building centralized processing facility for human and animal excreta, such as biogas digester; and setting up prevention and control project against pollution, such as forest buffers made by agricultural surface source, to prevent contaminants from directly entering into the surface water body and control pollutants from migration.

Enhancement of science and technology input and legal construction: Science and technology constitute the primary productive force and contribute greatly to reform of productive forces. Thus, we need to increase science and technology input, and promote scientific improvement. The poli-

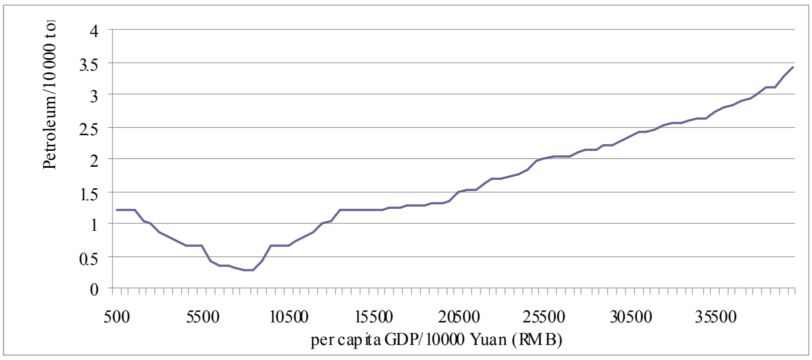

Fig. 5: Regression fit of petroleum and per capita GDP.

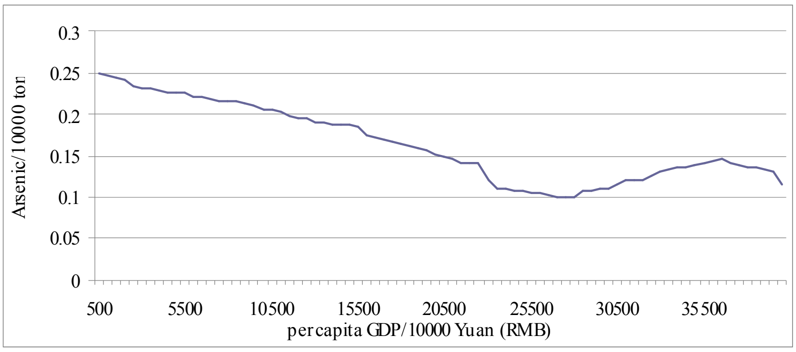

Fig. 6: Regression fit of arsenic and per capita GDP.

cies and regulations of environmental protection should be first improved. In the meantime, we need to constantly enhance the systems and measures in the practical work to make relevant regulations conform to the practice. Communication and cooperation with other provinces, cities, and regions must be strengthened, and institutional innovation should be intensified.

Improvement of financing channels of capital for environmental management: Macroscopic readjustment and control and market governance must be carried out. Moreover, we should establish multivariate investment and financing channels and allow the effect of market on water environment governance. Diversification of the investment subjects for environmental protection should also be emphasized to alleviate the financial burden of the government for environmental protection. We need to gradually promote relevant systems, such as environmental protection tax and ecological compensation against exploitation of mineral resources; allow the market power; absorb social capital by issuing bonds of environmental protection and sewage discharge permission; and establish funds for environmental protection.

CONCLUSIONS

In summary, the relationship between emission load of COD and heavy metal, as well as nutrient salts and petroleum and per capita GDP, is a reverse U-shaped curve, whereas that between arsenic and per capita GDP is a weak N-shaped curve. The following detailed measures are proposed: transformation of the pattern of economic growth and development, reinforcement of construction of emergency capacity against environmental pollution accidents, intensification of efforts in sewage treatment and agricultural pollution, enhancement of science and technology input and legal construction, and improvement of financing channels of capital for environmental management. These measures aim to provide a theoretical foundation to control pollutant that enters the Pearl River, as well as establish relevant policies with respect to the harmonious development of economy and environment in Guangdong.

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