LUMES Master Thesis, 2003/2004

Investigating the Interactions of Economic Growth and Environmental Quality in Shenzhen, China's First Special Economic Zone

Student: Xiaozi Liu*
Supervisors: Prof. Bengt Nihlgard, Dr. Jan Sendzimir
Program: LUMES, Lund University, Sweden

* Corresponding author; Tel.: +46 734-070587; email:xiaoziliu@yahoo.com

Abstract

There is a general perception that environmental degradation is driven by economic growth. In order to know how the economic growth and environmental quality interact with each other empirically, I choose Shenzhen city, the first special economic zone in China. The motivation of the study lies in the unique features of Shenzhen city. The city originated from a small village on the border of Hong Kong, but became one of the most developed regions in China in less than two decades. I have used environmental monitoring data indicating concentration of pollutants in ambient air, main rivers, and near shore waters from 1989 to 2003. The standard Environmental Kuznet's Curve (EKC) regression is applied in the economic analysis. The result of the study showed high correlation between per capita GDP and the environmental quality in a form of natural logarithmic quadratic function. However, only river water quality followed the inverted U shaped EKC curve, while air quality and the quality of near coastal waters in the western side actually followed a U shaped curve. The observed generic trends of environmental improvement with economic growth were interpreted as a result of the government's environmental regulations, which were motivated by their perceptions on maintaining the city's attractiveness to the foreign investment and tourists. The study also showed that, with the economic growth in the city, the industrial production inducing pollution has been mitigated, but consumption inducing pollution is actually increasing due to immigration and more luxury goods consumed.

Table of Contents

1. Introduction
1.1 Background and aim

There is a general perception that environmental degradation is driven by economic growth. The concept of Environmental Kuznets' Curve (EKC) proposes an inverted U shape curve relation between economic growth and environmental degradation. It assumes that environmental degradation will increase when per capita income is at a relatively low level; however, it will decline afterwards when per capita income reaches a certain point, the so called turning point (Grossman, 1995). The significance of EKC hypothesis for developing nations, where per capita income is still at the uphill level, is to learn the lessons from developed nations and adjust development strategies to "tunnel" Munasinghe,1999) through any potential EKC - thereby to achieve an economic and environmental win-win strategy (UNEP, 2002)..

Map 1. Overview of China and Shenzhen.

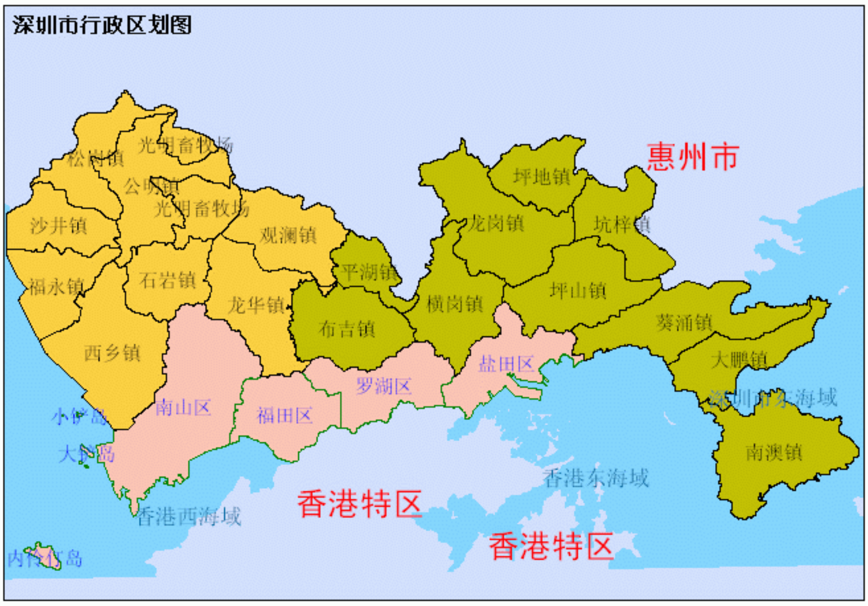
China, as the largest developing country in the world, has seen tremendous economic growth since the nation adopted its reform policy in 1978. Accordingly, the environment has been changed significantly due to urban sprawl and industrialization.

The aim of this paper is to find out how the economic growth and environmental change interacted in the specific context of China. I have chosen Shenzhen, China's first Special Economic Zone (SEZ), as an empirical study area. SEZ is a free-trade area where imported inputs and exports were exempted from duty, and new enterprises operating within them enjoys prolonged tax exemptions (Sen, 2001).

The reason for choosing Shenzhen was because of both its economic achievement and the reputation of the municipal government in reserving local environment. Shenzhen is a natural port city which is located on the border of Hong Kong in South China. See maps 1 and 2. The city is composed of six districts: Nanshan, Futian, Luohu, Yantian, Baoan, and Longgang. The former four districts marked in pink in the map below are inside of the SEZ. Baoan district and Longgang district marked in yellow and dark yellow are located outside SEZ, but still belong to the city.

Before the establishment of a SEZ, Shenzhen was a fishing village. In less than two decades, the city became a substantial agglomeration. It has the highest income in the country since 1990. As a consequence, the city's population is booming from 23,000 inhabitants in the beginning to over 5 million in 2003 mainly due to immigrants (Sen, 2001; NSB, 2003). Meanwhile, Shenzhen is also at the forefront in terms of environmental protection. In 1997, China's State Environmental Protection Agency entitled the city as the first national model city for environmental protection. In 2002, Shenzhen received UNEP's Global 500 Roll of Honor due to its efforts in simultaneously yielding both economic and environmental gains (UNEP, 2002).

Seemingly, Shenzhen city has successfully following the concept of developing the economy without damaging the environment, a so called "win-win" strategy. In order to identify the mechanisms that might link economic growth with environmental improvement, I collected statistical economic data of the city from 1988 to 2003. Also, with the great contribution from Ms Junmiao Chen, from the Shenzhen Environmental Monitoring Center at Luohu District, a series of raw environmental monitoring data was collected, showing ambient air quality, the quality of the major rivers and near shore waters during the same time span in Shenzhen.



Map 2. *Overview of Shenzhen Border (Map in pink is the border for Special Economic Zone (SEZ), and map in light yellow and dark yellow is other two districts of the city but outside the SEZ border)*

1.2 Hypotheses

The hypotheses being tested in this thesis are the following:

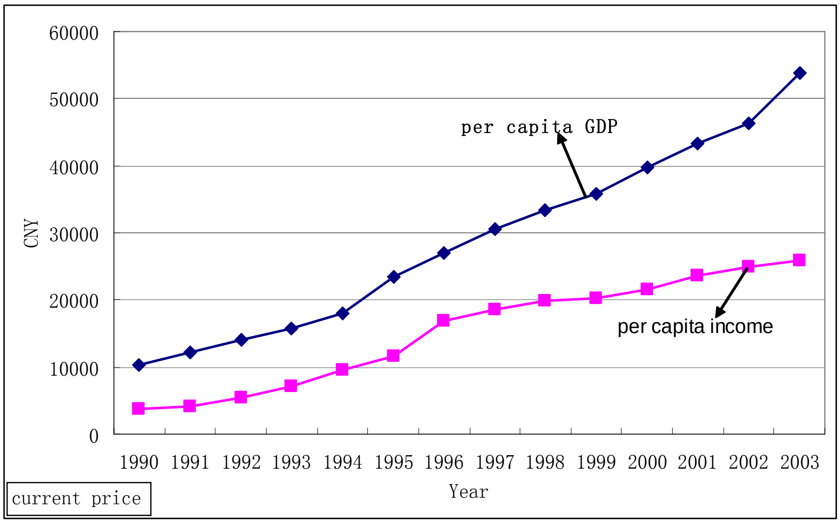
- The relationship between environmental degradation and economic growth in this region has followed an inverted U shaped pattern.
- Under the current economic growth level, per capita GDP is increasing, while the pollutants in air and water are decreasing.

2. Economic Growth & Urban Expansion in Shenzhen

Since Shenzhen was established as the Special Economic Zone (SEZ) in 1980, its GDP has increased by an average annual rate of 32%, with the industrial growth rate at 49%. Even when the Asian economic crisis slowed growth throughout China, Shenzhen continued its exports by an average of 9% annually, and showed an annual growth rate of 18.5% between 1994 and 1999 (Guo and Li, 2000). Graph 2.1 below shows the consistent growth of per capita GDP and per capita income in the city from 1990 to 2003. By the end of 2003, the total nominal GDP in Shenzhen reached 286 billion Chinese Yuan (or 24.7 billion USD[1]). The per capita nominal GDP in the city

[1] The exchange rate of USD to CNY (Chinese Yuan) is based on the rate issued by the Bank of China, which is around 1USD=8.25 CNY.

is over 50000 Chinese Yuan (6532 USD), and the per capita annual income is around 25935 Chinese Yuan (3144 USD), which is two times more than the nation average value.



Graph 2.1 The patterns of Per Capita GDP and Per Capita Income in Shenzhen, from 1990 to 2003 (GDP = Gross Domestic Products)

Source: Compiled from Shenzhen Statistics Yearbooks of various years (1990-2003). Note: GDP and income are calculated in current price.

As for the driving force of Shenzhen's economic growth, as the first SEZ, in the beginning of establishment of SEZ, Shenzhen has gained more favorable tax policy and investments from the central government. Also, its geographical advantage of a port city and bordering on Hong Kong enabled the city to attract large amounts of foreign investment. Foreign direct investments are substantial in Shenzhen. Many industries in Hong Kong were re-located to Shenzhen in order to take advantage of low wages and tax incentives. Towards the end of 2001, over 70 countries and regions had invested in 27,030 projects in Shenzhen (Shenzhen municipal government, 2004).

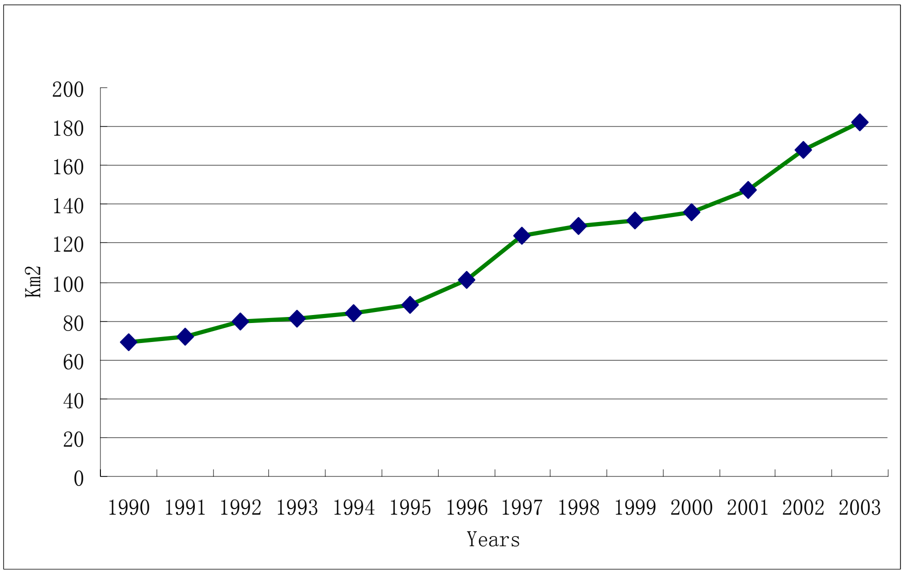
According to national statistics (various years from 1990-2003), the major contributing sectors to Gross Domestic Product (GDP) growth in Shenzhen are the secondary sector of industry[2] and the tertiary sector of industry[3] accounting for 53% and 45% respectively of total city's GDP. The primary sector of industry[4] is very tiny with only about 2% contributing to the total GDP. The pillar industries of the city are computers and software, IT, microelectronics and components, video and audio products, electro-mechanical integration, and key projects of light industry and energy (Shenzhen Municipal Government, 2004).

[2] Secondary sector of industry is manufacturing sector of industry. This sector of industry generally takes the output of the primary sector and manufactures finished goods or products to a point where they are suitable for use by other businesses, for export, or sale to domestic consumers. This sector is often divided into light industry and heavy industry. (TheFreeDictionary.com)

[3] Tertiary sector of industry is also known as the service industry. It involves the provision of services to other businesses or people. Services may involve the transport, distribution and sale of goods from producer to a consumer, or may involve the provision of a service. The goods may be transformed in the process of providing the service. (TheFreeDictionary.com)

[4] Primary sector of industry generally involves the conversion of natural resources into primary products. Most products from this sector are considered commodities or raw materials for other industries. Major businesses in this sector include agriculture, agribusiness, fishing, forestry and all mining and quarrying industries. (TheFreeDictionary.com)

Meanwhile, the industrialization also has facilitated urbanization. Shenzhen has expanded its size from 3 km^2 in the beginning of SEZ's establishment to 180 km^2 in 2003, indicating the increasing economic activity intensity in the city. Graph 2.2 below shows the pattern of the expansion of urban build-up area in Shenzhen city from 1990 to 2003.



Graph 2.2 The Growth in Area of Urban Build-up in Shenzhen

Note: Data are collected from the database of China's economic network at http://www.cenet.org.cn.

3. The Patterns of Environmental Quality over Time

In Section 2 a significant over time economic achievement in the past decades in Shenzhen was shown. It is certainly also substantial to look at over time patterns of the environmental quality of the City, which has evolved from a natural environment of an original small fishing village to another total different environment of a mega city now.

To evaluate the overall environmental quality, I have used the Nemerow pollution index (AHUT, 2004) in the following analysis. The Nemerow pollution index is an index which highlights the contributions of both Maximum and average value of the pollutants. See equation (3-1).

In my studies the Nemerow pollution index has been further classified into "river water" Nemerow index, "air" Nemerow index and "near shore water" Nemerow index. The "river water" Nemerow pollution index accumulates the contributions from COD, BOD_5, Total Phosphorus (TP), CN^-, Pb, Cd, As, Cr^{6+}, Total Petroleum Hydrocarbon (TPH). The "air" Nemerow pollution index is composed of SO_2, NO_x, and Total Suspended Particulates (TSP). The "near-shore water" Nemerow pollution index sums up the contributions from Inorganic Nitrogen, Phosphate, Hg, Cu, Pb, SS.

$$I = \sqrt{\frac{(MaxI_i)^2 + (AveI_i)^2}{2}} \qquad (3\text{-}1)$$

where $I_i=C_i/S_i$
C_i=the observed concentration of pollutant$_i$.
S_i=the municipally set objective of pollutant$_i$, according to national standards.
MaxI_i=the Maximum value of I_i , AveI_i=Average value of the sum of all I_i.

Basically, if I>1, it means the quality does not comply with objectives, if I<1, the quality is better than set objective. And the lower the value of the Nemerow pollution index, the better the environmental quality.

In order to indicate the major pollutants, the parameter of K is further introduced in the studies. K represents the percentage shares of the polluting substance. See equation (3-2).

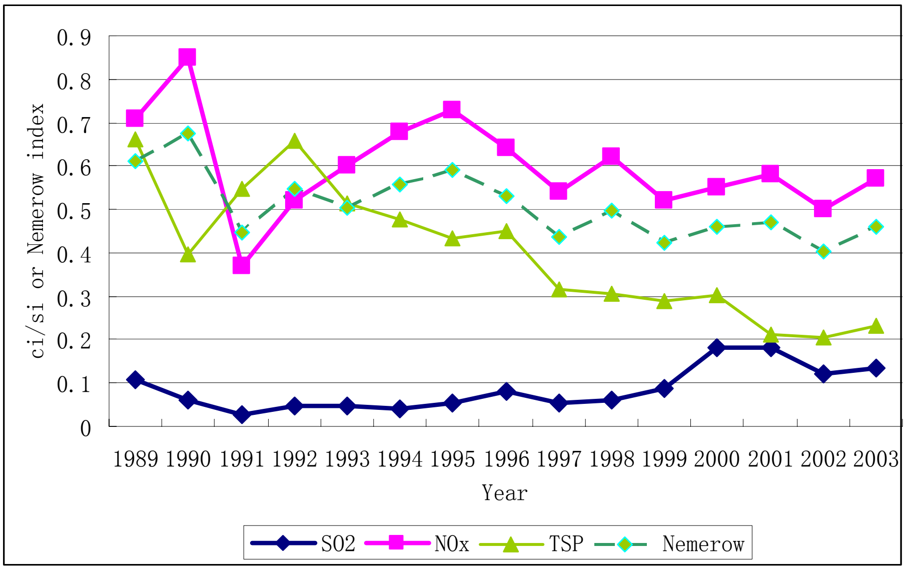
$$K_i= (I_i/I)*100\% \qquad (3\text{-}2)$$

where $I_i=C_i/S_i$
$I=\sum_{i=1}^{n} I_i \ (i=1,2,\ldots..n)$
C_i and S_i indicate the same parameters as in equation (3-1).
Certainly, both I value in equation (3-1) and K value in equation (3-2), are very much determined by the denominator, the set objectives. It is argued that China and many other developing countries have chosen weaker environmental objectives than the EU and USA. Therefore, the rationality of the Nemerow pollution index and K parameter is arguable. To prove that, we referenced sources from the World Bank (see Appendix 1), and compared the ambient air quality standards in China with other countries. It turned out there are no substantial standards differences between China and some developed nations. Actually, in China there are more problems in the standard enforcement rather than the standards themselves.

3.1 Ambient Air Quality

Shenzhen monitors three major air polluting substances: Total Suspended Particulates (TSP), SO_2, and NO_x. TSP represents the suspended particulates with the size of no more than 20 micron in aerodynamic diameter. The air monitoring network comprises 9 sampling points throughout the city. The type of monitored pollutants and the distribution of sampling points follow the guidance of national environmental monitoring which was issued by the State Environmental Protection Agency and being implemented throughout the whole nation. All of these three air pollutants are sampled and analyzed automatically by the ambient air monitoring systems featured by DOAS and TEOM technologies imported from Sweden and the USA (SZEMC, 2000). The ambient air pollutant concentration in this paper indicates annual daily average value.

Looking at the patterns of air quality and pollutants over time at Graph 3.1, we can see a slightly decrease of the “air” Nemerow pollution index in Shenzhen city from 1989 to 2003, indicating neither a significant improvement nor a deterioration of air quality taking place in Shenzhen. Since the “air” Nemerow pollution index is less than the value of 1, the overall air quality in Shenzhen during this period complied with the municipally set objective, which is the second level of the national standard of ambient air.



Graph 3.1. Air Quality Pattern for SO2, NOx and TSP (=Total suspended particles)

Source: compiled raw monitoring data from Shenzhen environmental protection agency, various years (1989-2003); Partly retrievable at http://www.sepa.gov.cn.

Graph 3.1 clearly showed that the major contributor to the "air" Nemerow pollution index is NO_x, since most of the time it is located on the top of the other curves. The graph also shows a significant decrease of TSP concentration from 1992 to 2003. Table 3.1 gives detailed information on the contributory percentage of all three polluting substances. NO_x has a significant increase in its contributory percentage from 48% in 1989 to 61% in 2003, while TSP has decreased its percentage from 45% to 25%. Although, SO_2 still has the lowest contributory percentage among the three pollutants compared to early 90s; in recent years there was a clear increase in percentage. To rank the percentages, the highest is NO_x, TSP is the second, and SO_2 the last.

Table 3.1 *The percentage shares of polluting substances in the ambient air during 15 years.*

Years	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
SO2	7	5	3	4	4	3	4	7	6	6	10	17	19	15	14
NOx	48	65	39	43	52	57	60	55	59	63	58	53	60	61	61
TSP	45	30	58	54	44	40	36	38	35	31	32	29	22	25	25

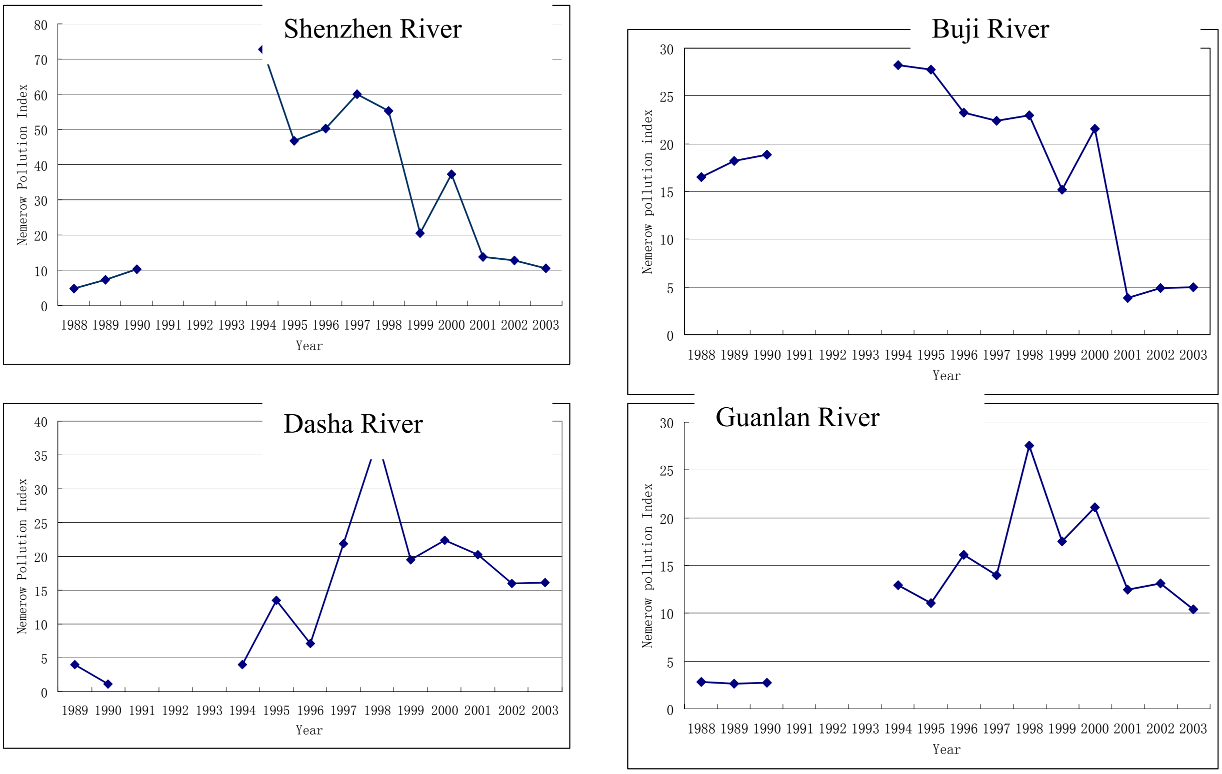
3.2 Major Rivers Quality

There are over 160 rivers and streams passing through the city borders of Shenzhen, since Shenzhen is located in the eastern part of the Pearl River estuary, and the Pearl River is the largest river system in South China. Although, about 82% areas of the city belongs to the Pearl River water catchments, only five of them have more than 100 km^2 catchments areas (SEPA, 2003). Below, we will give the analysis for four major rivers in the city due to the suitability of the data. Among them, the first three rivers are located inside the Special Economic Zone (SEZ), and the last one is outside of SEZ border.

To indicate river water quality, more than 10 indicators are monitored: BOD_5, DO, COD_{mn}, Total Phosphate (TP), CN^-, Pb, Cd, As, Cr^{6+}, Total Petroleum Hydrocarbon

(TPH), and Total Nitrogen (TN). They are sampled three times a year. We excluded total nitrogen in our analysis due to the inconsistency of the data. The water concentration objective was chosen as in the assessment it is the third level of national standard for surface water, as set by China's State Environmental Protection Agency.

Graph 3.2.1-3.2.4 shows the patterns of the "water" Nemerow pollution index for different rivers during the period of 1988 to 2003. From figures below we can see the seriousness of water pollution in all of four rivers since its Nemerow pollution indices are many fold more than the value of 1, with the highest value of over 70 in Shenzhen River and the lowest value of over 25 in all of the other three rivers.



Graph 3.2 The overall water quality over time in different rivers of Shenzhen

Sources: the Shenzhen environmental monitoring center, various years from 1988 to 2003.
Note: No data for the period of 1991 -1993.

Noticeably, all figures in Graph 3.2 showed that the four rivers inside and outside SEZ, had peak concentrations and tended the last years to decrease pollution intensity.

Regarding the major pollutants in the rivers in Shenzhen, Table 3.2 has given the ranks of the contributory percentages of different pollutants in different rivers and years. In all four rivers, there is a rough rank for contributory percentages: TPH is the highest, followed by TP (Total Phosphorus), BOD_5. The polluting substances of CN^- , Pb, Cd, As, and Cr^{6+}, which usually originated from industrial sources, showed zero or lower contribution to overall water pollution in the rivers. Therefore, we can conclude here that the major river pollutants in Shenzhen River are TPH, TP, and BOD_5.

Table 3.2: the percentage shares of polluting substances in four rivers of Shenzhen

1. Shenzhen River

Years	COD_{mn}	BOD_5	CN^-	Pb	Cd	As	Cr^{6+}	TP	TPH
1988	8	17	0	1	0	0	0	57	17
1989	8	19	0	0	0	0	0	49	23
1990	8	17	0	0	0	0	0	49	26
1994	6	27	0	2	0	0	0	27	38
1995	6	23	0	1	0	0	0	29	41
1996	9	24	0	1	0	0	0	21	44
1997	7	19	0	3	1	0	0	28	42
1998	7	19	0	1	0	0	0	28	43
1999	8	19	0	0	0	0	0	36	36
2000	6	19	0	0	0	0	0	32	42
2001	12	32	0	0	0	0	0	52	3
2002	12	31	0	1	0	0	0	50	5
2003	11	27	0	0	0	0	0	42	19

2. Buji River

Years	COD_{mn}	BOD_5	CN^-	Pb	Cd	As	Cr^{6+}	TP	TPH
1988	8	18	0	0	0	0	1	35	37
1989	7	19	0	0	0	0	0	31	42
1990	7	20	0	0	0	0	0	27	46
1994	2	9	0	0	0	0	0	7	82
1995	3	14	0	0	0	0	0	10	73
1996	3	10	0	0	0	0	0	10	76
1997	2	8	0	0	0	0	0	10	79
1998	3	9	0	0	0	0	0	12	76
1999	6	13	0	0	0	0	0	23	57
2000	4	17	0	0	0	0	0	19	60
2001	9	35	0	0	0	0	0	30	26
2002	8	36	0	0	0	0	0	36	18
2003	8	32	0	0	0	0	0	32	28

3. Dasha River

Years	COD_{mn}	BOD_5	CN^-	Pb	Cd	As	Cr^{6+}	TP	TPH
1988	13	22	2	0	0	0	13	11	40
1989	10	16	0	1	0	0	10	18	46
1990	10	13	2	0	0	0	4	39	32
1994	4	12	1	1	0	1	1	26	54
1995	5	10	1	1	0	1	1	30	52
1996	4	10	1	0	0	1	2	28	53
1997	3	7	2	0	0	1	1	31	55
1998	3	8	1	1	0	1	1	26	60
1999	4	12	3	1	0	2	1	30	48
2000	4	11	1	0	0	1	0	35	49
2001	6	18	3	0	0	0	1	61	11
2002	7	21	4	0	0	0	1	56	11
2003	7	25	3	0	0	1	1	52	11

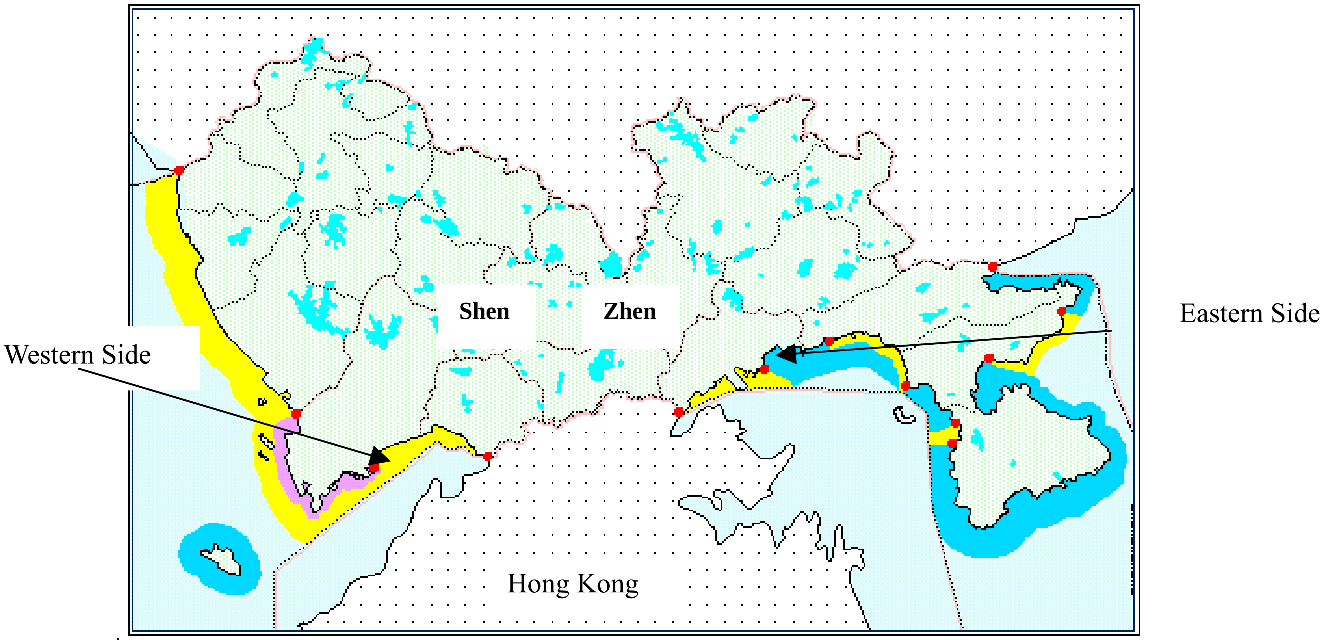
4. Guanlan River

Years	COD_{mn}	BOD_5	CN^-	Pb	Cd	As	Cr^{6+}	TP	TPH
1989	5	11	0	0	10	0	1	3	70
1990	20	16	0	8	13	0	0	17	26
1994	7	9	0	0	1	0	4	10	67
1995	4	5	0	0	1	0	0	10	79
1996	6	11	1	0	1	0	1	19	61
1997	3	6	0	0	0	0	0	10	79
1998	2	4	0	0	0	0	0	69	25
1999	4	12	0	0	1	0	0	14	69
2000	3	11	0	0	1	0	1	32	52
2001	4	9	0	0	0	0	1	24	62
2002	9	16	0	0	0	0	0	50	23
2003	6	16	0	0	0	0	1	41	36

Notes: 1. TPH=Total Petroleum Hydrocarbon, TP=total phosphorus.
2. DO and PH are excluded from our assessments.

3.3 The Near-shore Water Quality

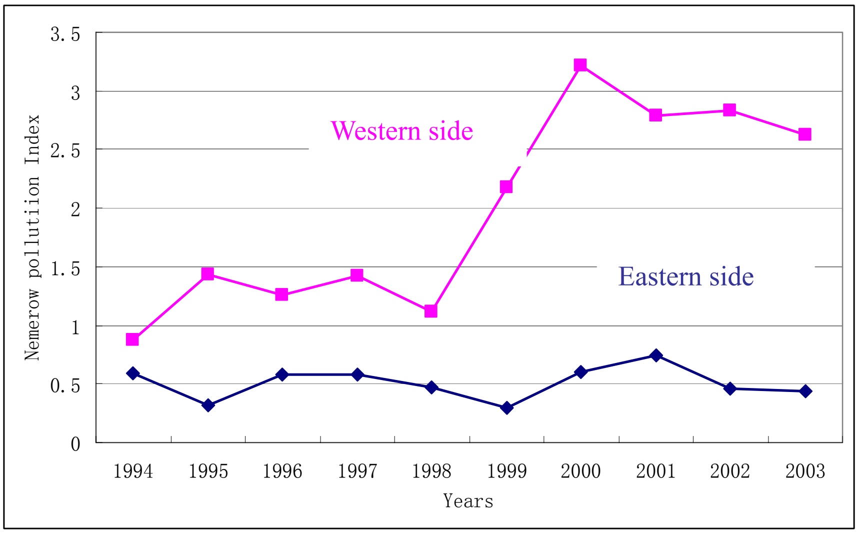
The monitoring network of near-shore waters in Shenzhen was divided into two parts, the eastern side and western side. See map 3 below.



Map 3. The seashore of Shenzhen((The dotted lines in western and eastern side mark the border of Hongkong.)

The eastern side is a well reserved beach area with better primary natural environment. Extensive investments have been taken place on the western side of Shenzhen Bay. Sampling points are placed at the estuary of major rivers. The water is sampled two times every April, July and December, and twice for each month. The eastern side water should comply with the second level of national standards for ocean water, while the western side water should comply with the third level national standards. There are in total 10 indicators monitored in the near-shore waters: Inorganic Nitrogen, Total Phosphor (TP), Total Petroleum Hydrocarbon (TPH), COD_{mn}, Hg, Cu, Pb, Cd, PH value, and SS.

Graph 3.3 illustrates the patterns of the Nemerow pollution index for near shore water from 1994 to 2003. The water quality on eastern side is almost constant, and the value of the Nemerow pollution index is around 0.5, which indicates that the water quality in eastern side can comply with the second level of national standards for ocean water. The western side water has been further deteriorating since 1998, and the water quality is not able to comply with the set national objectives. The Nemerow pollution index peaked at the value of around 3.2 on the western side.



Graph 3.3 Pattern of the near-shore water quality over time

Table 3.3 presents the percentage share of different pollutants on both sides of near-shore waters in Shenzhen. The major pollutants in the eastern side of near-shore waters are TPH, Inorganic nitrogen, and COD_{mn}. On the western side, the major pollutants are Inorganic Nitrogen, and Phosphate.

Table 3.3 The percentage shares of polluting substances in the near-shore waters

Eastern Side

	Inorganic Nitrogen	Phosphate	CODmn	TPH	Hg	Cu	Pb	Cd	SS
1994	**6**	**4**	**19**	**39**	**5**	**18**	**6**	**1**	**2**
1995	**16**	**10**	**21**	**23**	**14**	**6**	**6**	**1**	**3**
1996	**14**	**7**	**16**	**42**	**5**	**5**	**8**	**1**	**2**
1997	**16**	**2**	**18**	**42**	**5**	**5**	**7**	**1**	**3**
1998	**24**	**24**	**15**	**24**	**4**	**3**	**3**	**0**	**2**
1999	**7**	**10**	**21**	**31**	**8**	**6**	**13**	**2**	**2**
2000	**0**	**12**	**14**	**32**	**4**	**7**	**9**	**1**	**1**
2001	**27**	**2**	**18**	**36**	**4**	**5**	**6**	**1**	**1**
2002	**20**	**16**	**15**	**29**	**5**	**3**	**8**	**1**	**3**
2003	**12**	**7**	**14**	**39**	**7**	**10**	**8**	**1**	**2**

Western Side

	Inorganic Nitrogen	CODmn	TPH	Phosphate	Hg	Cu	Pb	Cd	SS
1994	**0**	**18**	**8**	**58**	**5**	**2**	**2**	**1**	**6**
1995	**45**	**7**	**2**	**27**	**6**	**1**	**6**	**0**	**7**
1996	**51**	**7**	**2**	**25**	**3**	**1**	**4**	**0**	**7**
1997	**49**	**7**	**2**	**28**	**2**	**1**	**4**	**0**	**6**
1998	**45**	**8**	**3**	**36**	**3**	**1**	**2**	**0**	**2**
1999	**39**	**6**	**2**	**49**	**2**	**1**	**1**	**0**	**1**
2000	**38**	**6**	**2**	**47**	**1**	**1**	**1**	**0**	**4**
2001	**47**	**7**	**2**	**37**	**1**	**1**	**1**	**0**	**4**
2002	**55**	**5**	**1**	**33**	**1**	**1**	**1**	**0**	**2**
2003	**45**	**4**	**1**	**44**	**1**	**1**	**1**	**0**	**2**

3.4 Section Summary

To sum up the patterns of environmental quality overtime in the ambient air, the overall air quality has been slightly improved and complies with the second level of the national objective. The major pollutant of air pollution in Shenzhen is NOx, which indicates the highest percentage share, followed by TSP and SO_2.

The water quality of all four rivers deteriorated in the beginning of the observed years, and then recently its pollution intensity declined. However, the rivers' water quality is still far away from being able to comply with the set objectives. The main pollutants in the rivers are TPH, TP, and BOD_5.

The quality of near-shore waters shows different trends on the eastern side and on the western side. On the eastern side the quality almost kept constant and can reach the set objectives of the second national level, but the western side water quality has been continuously worsening since 1994 and can not comply with set objectives. The major pollutants of the western side near-shore water are TPH, inorganic nitrogen and phosphate.

4. Economic Framework

There is a general thought that the change of environmental quality is driven by economic growth. As described in the introduction parts, the Environmental Kuznets Curve (EKC) is one of those hypotheses, which proposed an inverted U shaped curved relationship between environmental degradation and economic growth. Therefore, how do these two factors interact with each other in the specific context of Shenzhen City?

To find out their interactions, I chose the pollutant concentrations in ambient air, main rivers, and near-shore waters as indicators of environmental degradation, and I used the per capita GDP to indicate the economic growth level in the city. In our regression analysis, I introduced the standard EKC model (see equation 4-1), where each pollutant's concentration was treated as a dependent variable, and per capita GDP was treated as an in-dependent variable. Regarding the GDP value in the analysis, I used real GDP instead of nominal GDP; since without any adjustment, the GDP calculation would be distorted by inflation.

The earliest EKCs were simple quadratic functions of the levels of income. By the laws of thermodynamics, the use of resources inducing by economic activity inevitably implies the production of waste. Regressions that allow levels of indicators to become zero or negative are inappropriate. Therefore, a logarithmic dependent variable is implemented in standard EKC regression model (Stern, 2004):

$$\mathbf{ln(C)_{it} = b_0 + b_1 ln(GDP/P) + b_2 (ln(GDP/P))_{it}^2} \qquad \mathbf{(4\text{-}1)}$$

where C is the concentration of pollutants and P is population, and ln indicates natural logarithms.

4.1 The Regression Analysis on Ambient Air Quality

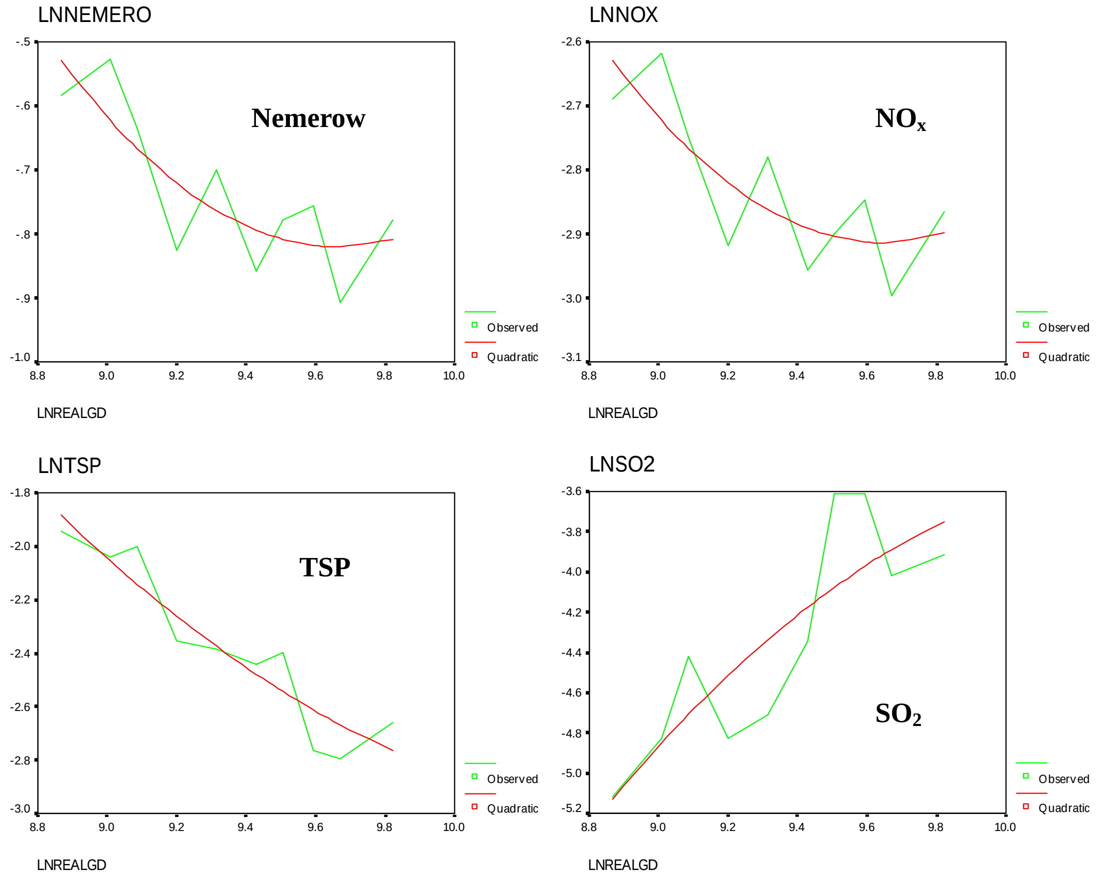
In the unitary-variable regression analysis, the concentration of TSP, SO_2, NO_X are the dependent variables. I made regressions on per capita GDP from 1994 to 2003. See Table 4.1 below:

Table4.1 The Regression Analysis Output Data for Air Pollutants

Dependent	**Mth**	**Rsq**	**d.f.**	**F**	**Sigf**	**b0**	**b1**	**b2**
LNSO2	QUA	.715	7	8.76	.012	-73.245	13.3123	-.6350
LNNOX	QUA	.640	7	6.23	.028	40.8297	-9.0714	.4703
LNTSP	QUA	.875	7	24.59	.001	36.1125	-7.3203	.3423
LNNEMERO	QUA	.662	7	6.86	.022	41.6914	-8.7957	.4550

Notes:
1. Dependent=dependent variables, Mth=mathematic equation, Rsq=R^2, d.f.=degrees of freedom; F=F statistic; Sigf=the statistical significance; bo, b1,b2=parameters in equation (4-1).
2 LNSO2=ln(SO_2), LNNOX=ln(NO_x),LNTSP=ln(TSP), LNNEMERO=ln(Air Nemerow Pollution Index)
3 Independent variable is ln(per capita real GDP).
4. Produced by SPSS V11

Table 4.1 clearly shows that all 4 independent variables have R^2 values above 0.6, indicating good correlations with per capita real GDP. In Graph 4.1 is demonstrated that only SO_2 actually followed the inverted U shaped curve, while the other three variables presented U shaped curve relationships.



Grap 4.1 Natural logarithms (LN) of air pollutant concentrations versus the economic growth (per capita GDP).

Notes: LNTSP=ln(TSP), LNNOX=ln(NO_x), LNNEMERO=ln(Nemerow), LNSO2=ln(SO_2). LNREAGD=ln(per capita realGDP). Green lines are observed values, and red lines are model output.

Moreover, Graph 4.1 was observed that the TSP concentration showed a relatively high correlation with economic growth compared to the other three dependent variables. This proved that in the past decade, the TSP concentration has been declining significantly with economic growth. This might be explained through the increment of vegetation in the urban areas and less industrial emissions in the city.

“Air” Nemerow pollution index pattern actually follows the NOx’s pattern, since NOx is the dominant pollutant of Shenzhen as described in section 3. In the past decade, the NOx concentration decreased with the growth of economy, but, as is clearly shown in the regression model (Graph 4.1), in recent years its pollution intensity tended to increase again. Regarding the reason, industrial sources of air pollutants might have been decreased due to effective treatment measurements. However, when the economic growth reached a certain point, the reduction of NO_x and TSP from industrial sources emission would be offset by the increase of residual luxury consumption, for instance motor vehicles driving, since more people are able to afford to buy cars, emitting NO_x. The SO_2 pattern shows a continuous increase of the concentration. Since SO_2 can be transported through a long distance, therefore, the regression pattern of SO_2 might be very much influenced by other pollution sources outside the city. Thus, when evaluating the effect of local economy on the local environmental quality, the pattern of SO_2 apparently is not an eligible example. We may simply exclude it from our follow-up analysis. More detail information will be presented in the discussion section.

4.2 Regression Analysis on River Water Quality

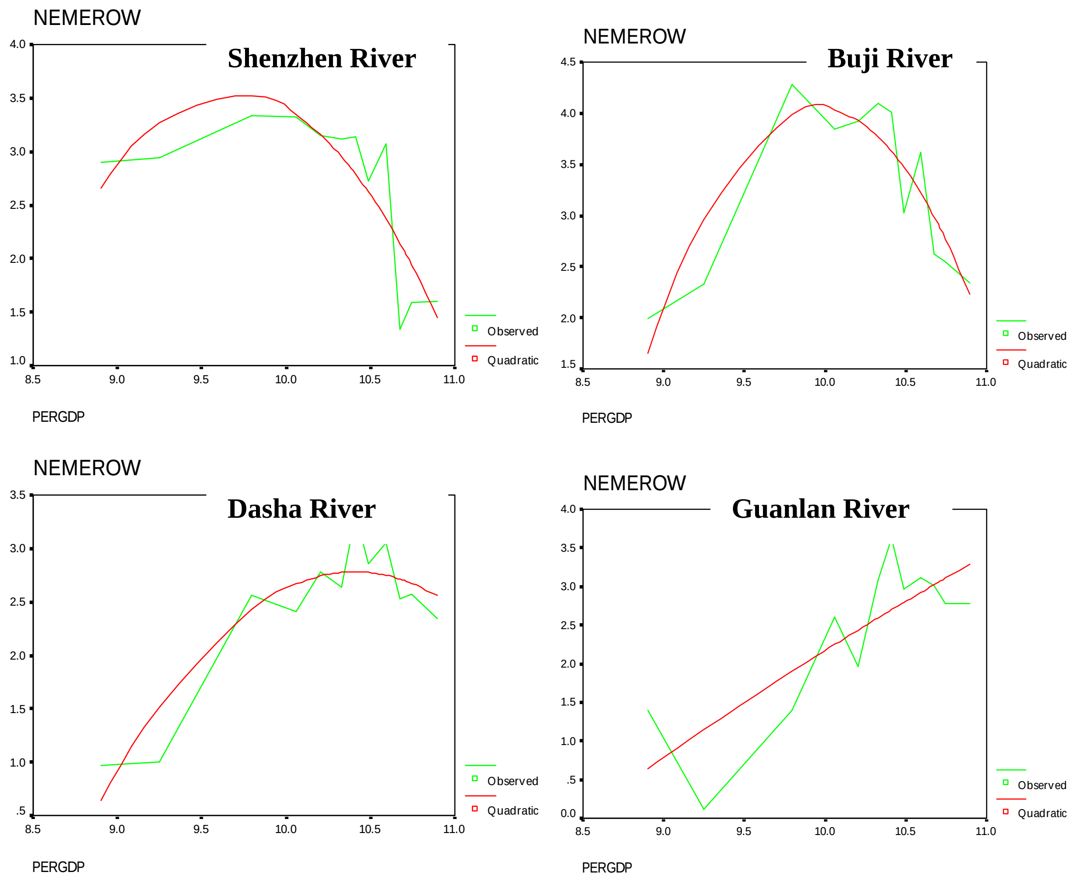
Table 4.2 The Regression Analysis Output Data for River water quality

Dependent Variables	Mth	Rsq	d.f.	F	Sigf	b0	b1	b2
Shenzhen River								
NEMEROW	QUA	.724	9	11.81	.003	-130.96	27.7692	-1.4333
TPH	QUA	.637	9	7.90	.010	-211.78	44.0913	-2.2825
P	QUA	.856	9	26.74	.000	33.6184	-6.1098	.2796
BOD_5	QUA	.599	9	6.72	.016	-26.159	6.2765	-.3338
Buji River								
NEMEROW	QUA	.809	9	19.03	.001	-205.64	42.0794	-2.1111
TPH	QUA	.764	9	14.54	.002	-234.71	47.5883	-2.3973
P	QUA	.838	9	23.36	.000	20.9808	-4.5194	.2485
BOD_5	QUA	.602	9	6.81	.016	-2.8802	.7663	-.0117
Dasha River								
NEMEROW	QUA	.836	9	22.89	.000	-99.598	19.6751	-.9453
TPH	QUA	.574	9	6.07	.021	-219.03	43.9402	-2.2020
P	QUA	.960	9	106.99	.000	-67.876	12.4669	-.5678
BOD_5	QUA	.842	9	24.04	.000	-10.576	1.7225	-.0409
Guanlan River								
NEMEROW	QUA	.657	9	8.61	.008	-18.440	2.8105	-.0749
TPH	QUA	.580	9	6.22	.020	-29.679	4.6400	-.1733
P	QUA	.818	9	20.23	.000	6.5752	-3.9690	.3243
BOD_5	QUA	.944	9	75.52	.000	86.7746	-18.520	1.0006

Notes:
1. Dependent=dependent variables, Mth=mathematic equation, Rsq=R^2, d.f.=degrees of freedom; F=F statistic; Sigf=the statistical significance; bo, b1,b2=parameters in equation (4-1).
2 LNSO2=ln(SO_2), LNNOX=ln(NO_x),LNTSP=ln(TSP), LNNEMERO=ln(Air Nemerow Pollution Index)
3 Independent variable is ln(per capita real GDP).
4. Produced by SPSS V11

Table 4.2 above shows the outputs of the curve estimates for different pollutants in different rivers. Still real GDP is the independent variable of this economic analysis. For each river, we had regression on four different dependent variables: the natural logarithmic of TPH, TP, BOD_5, and Nemerow. As was pointed out in previous section has pointed out, TPH, TP and BOD_5 are three major pollutants of the rivers. Nemerow is the Nemerow pollution index which aggregates all of indicators (except total nitrogen) monitored in the rivers of Shenzhen, including TPH, TP, and BOD5.

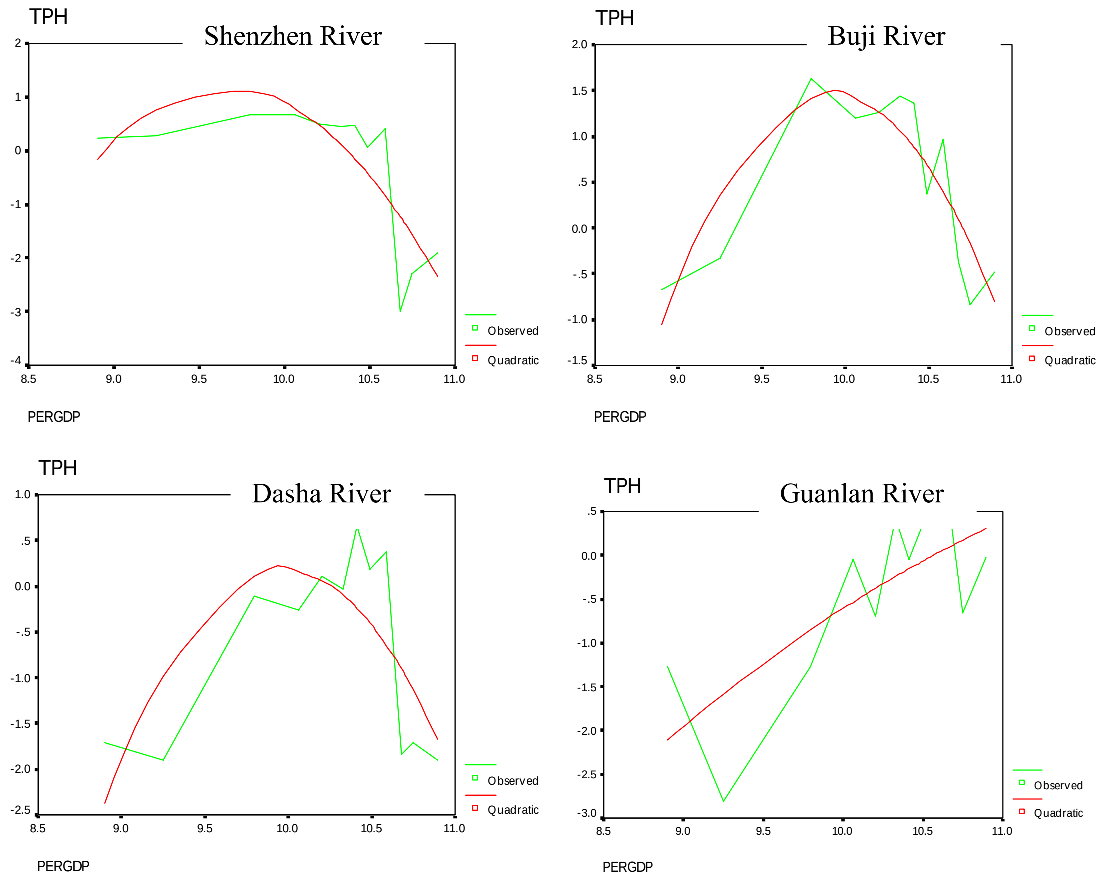
From table 4.2 we can see, all of three major rivers have an R^2 value of over 0.6; that's to say, when estimated in quadratic function, the overall river quality has rather good correlation with economic growth and they all show incomplete inverted U shaped curves. And significantly, from Graph 4.2, all three rivers, Shenzhen River, Buji River, and Dasha River, which are located inside the Special Economic Zone of Shenzhen, have showed the trends of peaking off their pollution intensities, and under current economic growth level, overall water quality is improving. However, the river water quality in Guanlan River, which is the only river observed outside the SEZ in our analysis, is still increasing its pollution intensity and there are no noticeable signals showing it will level off soon.



Graph 4.2 The overall river water quality patterns

Notes: Nemerow=ln ("water" Nemerow pollution index) ; PERGDP=ln (per capita RealGDP)

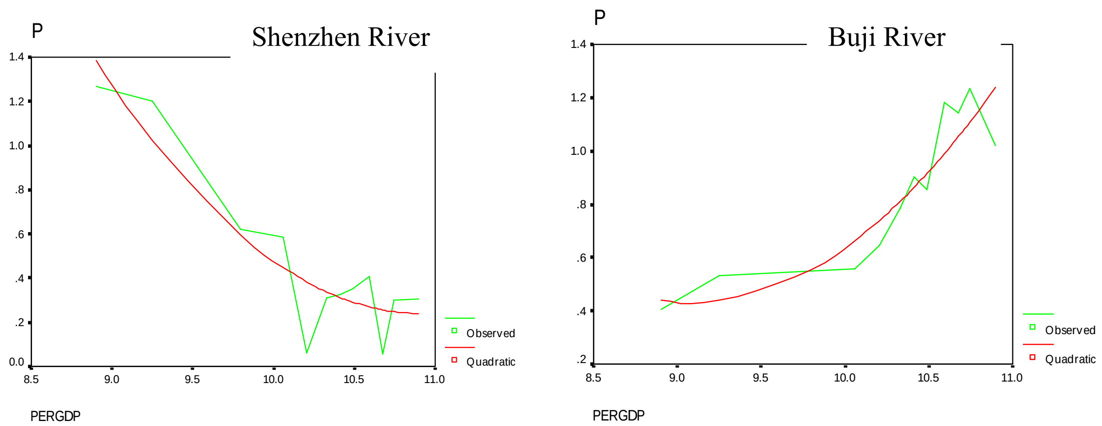
Since TPH concentration is the determinant indicator of the overall Nemerow pollution index for river water, therefore the regression patterns of TPH concentration in four rivers show similar trends as overall water quality. See Graph 4.2.1. This indicated that the pollution intensity of TPH increases first and then declines as economic growth continues.

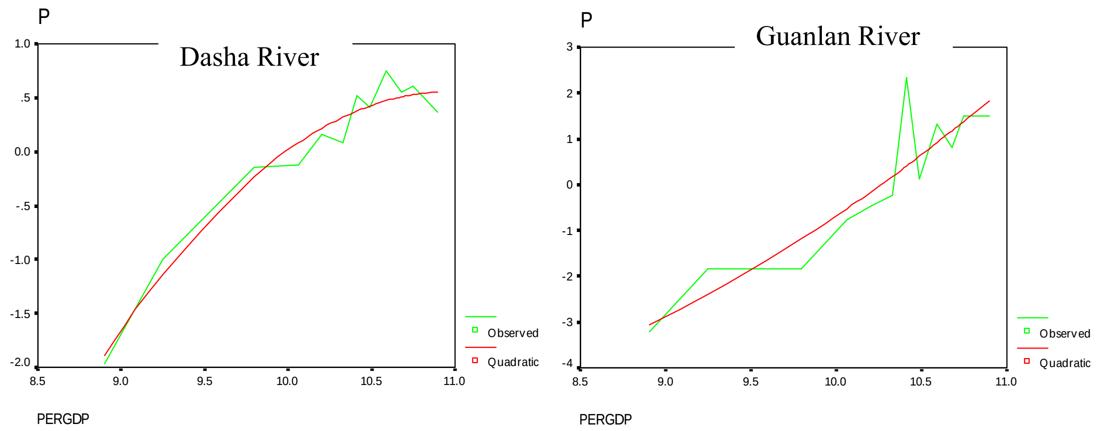


Graph 4.2.1 The regression patterns of Total Petroleum Hydrocarbon (TPH) in the rivers

Notes: Nemerow=ln("water" Nemerow pollution index) ; PERGDP=ln(per capita Real GDP)

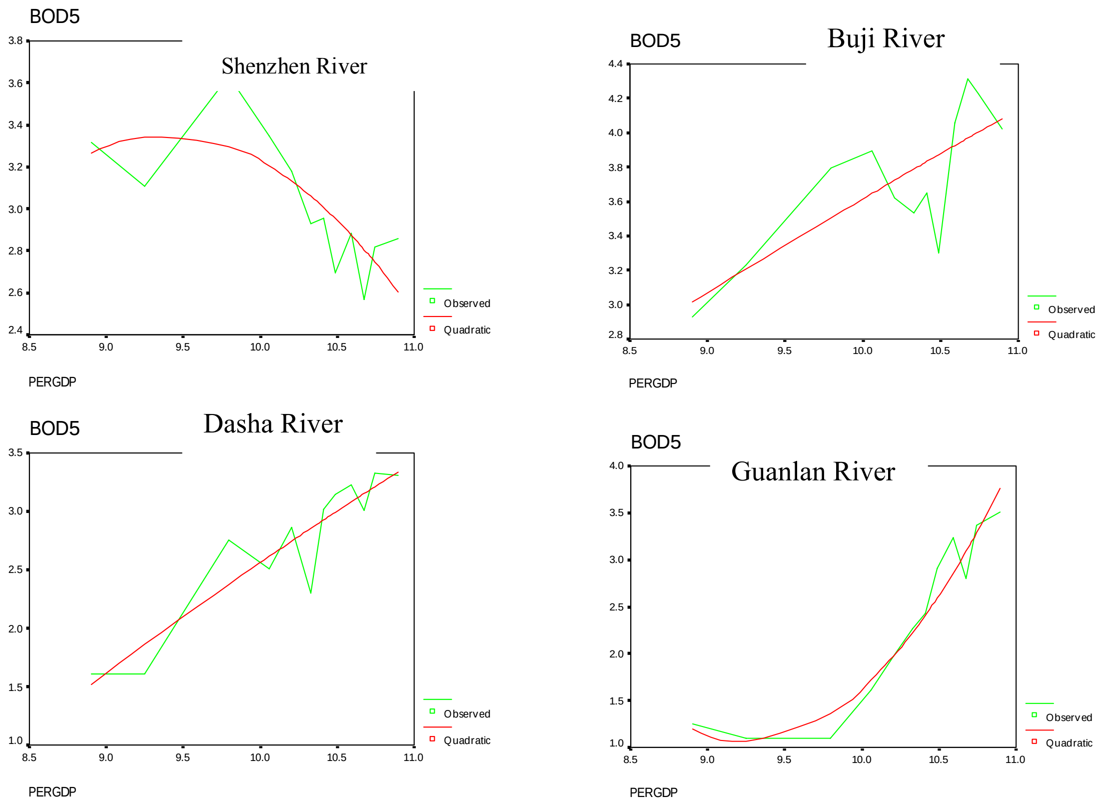
Meanwhile, Graph 4.2.2 shows, the Total Phosphor (TP) concentration is accumulating continuously with economic growth in all four rivers except in Shenzhen River. The regression patterns of TP indicated continuously aggregating trends of nutrients enrichment in the rivers. In Shenzhen River, where intensive water treatments have been going on, we observed decreasing trends of phosphor enrichment.





Graph 4.2.2: The regression patterns of Total Phosphorus in the rivers
Notes: P=ln(total phosphorus); PERGDP=ln(per capita RealGDP).

BOD_5 is another major pollutant in the rivers of Shenzhen. The regression patterns of BOD_5 in graph 4,2,3 showed the similar trends as TP regression patterns. In Shenzhen River, BOD_5 pollution intensity has been diminishing, and its per capita GDP pollution intensity[5] has already leveled off. On the other hand in the other three rivers BOD_5 are increasing in their pollution intensities (Graph 4.2.3), and are still far away from leveling off their pollutant concentrations with the current economic growth. In Buji River and Dasha River, which located inside of the Special Economic Zone (SEZ), it shows an inverted U shaped curve relationship. But in Guanlan River, which is outside of SEZ, it shows U shaped curve. This implies that BOD_5 pollution intensity is almost exponentially increasing.



Graph 4.2.3: The regression patterns (natural logarithms) of BOD_5 in the rivers
Notes:BOD5=ln(BOD_5); PERGDP=ln(per capita RealGDP).

[5] Pollution intensity = ln (C_i or I) /ln(per capita GDP), where C_i=ln (the concentration of pollutant_i), I = ln(Nemerow pollution index for air or water).

4. 3. The Regression Analysis on Near-shore Waters

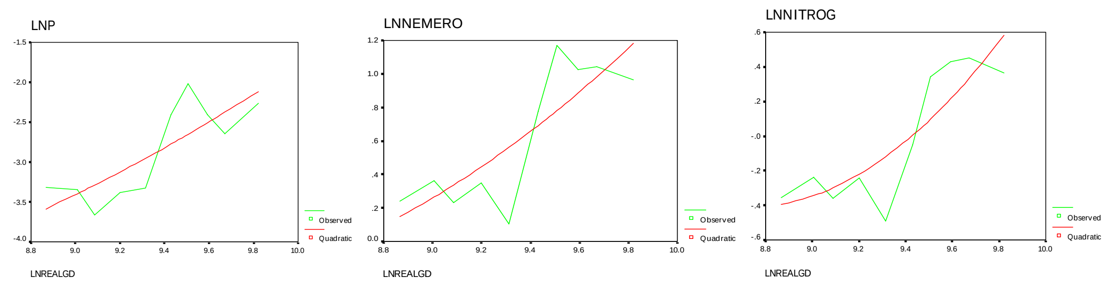
Since eastern water quality in the Shenzhen's near-shore waters can comply with set national objectives, and it almost keeps constant overtime, therefore there is no correlation between the eastern side water quality and city per capita GDP. Therefore, we only had regression analysis on western side water. The results show below:

Table 4.3 Regression Analysis Output for near-shore waters, western side

Dependent Variable	Mth	Rsq	d.f.	F	Sigf	b0	b1	b2
Nemerow	QUA	.679	7	7.41	.019	17.4182	-4.6831	.3085
P	QUA	.658	7	6.75	.023	4.4764	-3.1227	.2496
Inorganic N	QUA	.741	7	10.03	.009	60.1746	-13.924	.7999

Notes:
1. Dependent=dependent variables, Mth=mathematic equation, Rsq=R^2, d.f.=degrees of freedom; F=F statistic; Sigf=the statistical significance; bo, b1,b2=parameters in equation (4-1).
2 LNSO2=ln(SO_2), LNNOX=ln(NO_x),LNTSP=ln(TSP), LNNEMERO=ln(Air Nemerow Pollution Index)
3 Independent variable is ln(per capita real GDP).
4. Produced by SPSS V11

Above Table 4.3 showed, all three dependent variables have rather good correlations with independent variable, per capita GDP in the city, while the inorganic nitrogen presented the highest R^2 value, 0.741.



Graph 4.3 The regression models for Near-shore waters in the western side

Notes: LNNEMRO=ln(Nemerow);LNP=ln(phosphate);
LNNITROG=ln(inorganic nitrogen); LNREALGD=ln(RealGDP).

I have discovered in section 3, the major pollutants of western side water are phosphate and inorganic nitrogen. Their regression models in Graph 4.3 showed that all of the three models fit the inverted U shaped curve and are located on the uphill side of the curve. Therefore, we can conclude that the overall water quality in western side of rivers is still deteriorating, and the major pollutants of Phosphates and inorganic nitrogen are increasing pollution intensity with the growth of economy. Since inorganic nitrogen is the derivational pollutant of algae booming, we can predict that continuous enrichments of nutrients in the near-shore waters of Shenzhen would substantially increase the risk of algae booming.

4.4 Regression Analysis Summaries

Several statements can be summarized from the above regression analysis. First, when estimated in quadratic curve, all of the overall ambient air quality, river water quality, and near-shore water quality in Shenzhen showed good correlations with per capita GDP. However, only rivers water regression curve follow inverted U shaped curve. Both ambient air quality and near-shore water quality actually follow U shaped curves. These implied that water quality in our observed rivers in Shenzhen has been improving. But ambient air quality and near-shore water quality at the western side are tending to deteriorate.

Second, in the ambient air, NO_x is the dominant pollutant. In the past decade, the pollution intensity of NO_x and TSP has been decreased probably by the emission reductions from industrial sources and extensive vegetation. However, in the recent years, NO_x tended to increase its pollution intensity, which to large extent is driven by the increasing emissions from motor vehicles.

Third, in the four observed rivers, TPH, TP and BOD_5 are the major pollutants. Since TPH is the dominant pollutant of the rivers, its regression patterns more or less followed the similar patterns of the overall "river water" Nemerow pollution index. That is, TPH has peaked its concentration in Shenzhen River, Buji River and Dasha River. But in Guanlan River, which is outside of SEZ, the TPH concentration still tends to further increase with the current economic growth. The reason for that is, TPH is mainly emitted from industrial sources. While the economic growth continues, the production costs inside the SEZ get higher, factories started moved out and settled down outside of the SEZ. Also, much stricter industrial measures carried out in the enterprises inside of the SEZ. Another two pollutants, TP and BOD_5 have showed rather different trends with TPH. In Shenzhen River, TP and BOD_5 seem to have been treated effectively and its regression model showed downward trends. But the TP and BOD_5 concentrations in the other three regression models of the rivers are still in the upward hill which implied their concentrations are still increasing while the economy grows. This could be explained as the pollution increment from consumption inducing emission, including residential emission and commercial emission.

Last but not least, in the western side of Shenzhen's near-shore waters, the major pollutants are inorganic nitrogen and phosphate. The regression models of overall near-shore water quality, inorganic nitrogen, and phosphate all showed upward tendencies. These demonstrated, in the western side of near-shore water, there are increasing enrichments of nutrients and therefore high risks of algae booming. .

5. Discussion

My regression analysis is unitary variable based analysis. However in the real life, there are more factors involved in between. Thereby the analysis is somehow weak and limited in explaining the real interactions of economic growth and environmental quality. To compensate, in the section, I further introduced Causal loop diagram (CLD), which is a substantial tool to represent the feedback structure of a dynamic systems (Haraldsson, 2000), to illustrate the functions that might be behind my observations.

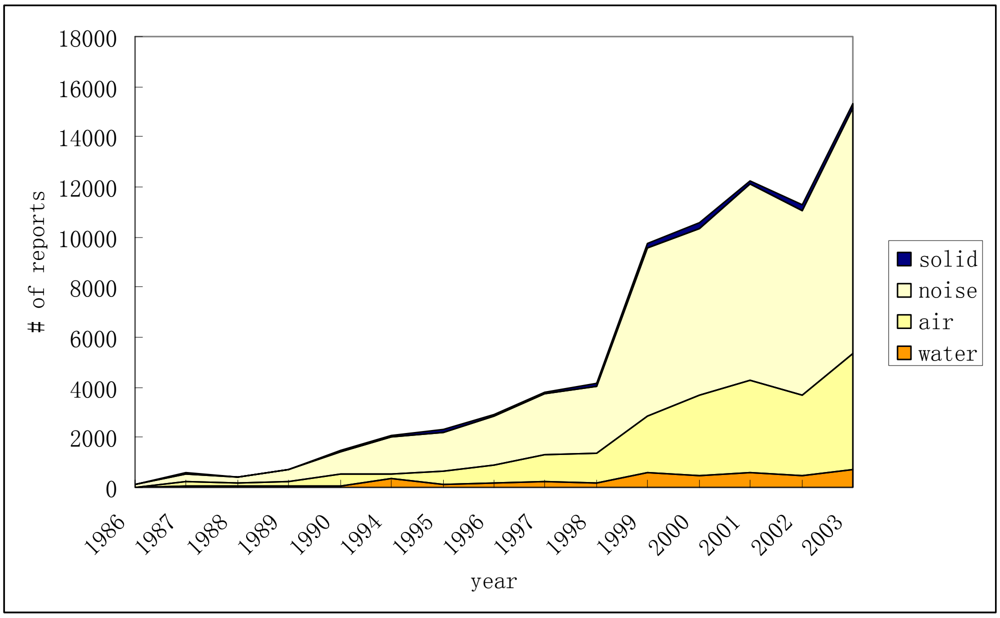
5.1 The municipal government aims at improving environmental quality to facilitate economic growth

In Shenzhen, per capita GDP has been observed rather high quadratic correlations with the environmental quality, which includes overall ambient air quality, main river water quality and near-shore water quality. Moreover, in all of studied rivers, its overall river water quality and per capita GDP illustrated an inverted U shaped curve relationship, which is coherent to EKC hypothesis. In Shenzhen River, both TPH, BOD_5 regression models show inverted U shaped curve (Appendix Ⅱ). And the pollution intensities in all regression models of TPH, TP and BOD_5 are decreasing. The reasons are various and the driving force is arguable.

As pointed out in our introduction part, a good environment is perceived as an asset of the city to attract more foreign direct investment. In order to facilitate local economic growth, Shenzhen government has enforced much stricter regulations on reserving local environment than other cities. Therefore, intensive environmental regulation is argued as the original key factor of this correlation. It is reported, the total environmental budget in Shenzhen in 2003 accounted for 2.16% of total city GDP (Shenzhen environmental statistics yearbook, 2003). Till 2003, the city has built up several waster water plants with the total treatment capacity of over 1,240,000 tons waster water per day. Also, the effectiveness of environmental regulations affects the potential of the appearance of EKC curve. In Shenzhen River, which is called the "Mother River" of the city, municipal government has paid more attention and therefore more intensive treatment projects have been carried out. Consequently, my regression analysis illustrated obviously better pollution abatement in Shenzhen River than other studied rivers.

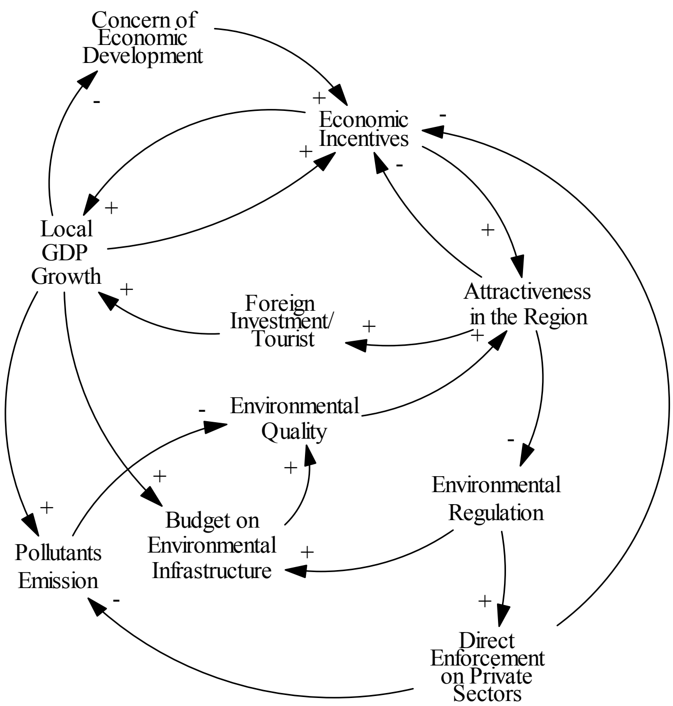
Regarding the driving force of environmental regulation to municipal government, several factors might be concerned: the pressure from upper level governments, the pressure from local residents, and the sustainable growth of city's economy itself. As mentioned before, Shenzhen is one of the first national model cities of environmental protection in China. Being a leading city in environmental protection, its driving force normally is generated internally, instead of externally, which is oriented from central government's pressure.

The pressure from local residents due to the demand on environmental improvement also is doubtable to be regarded as a main force. In Graph 5.1.1 is demonstrated the numbers of environmental pollution cases reported by residents to local government from 1986 to 2003. It shows noise pollution on an average accounted for about 60% of the total cases. The numbers of reports on water pollution and air pollution only account for 7% and 25% respectively. Since noise pollution did not include in our economic analysis, therefore the pressure pushed by local residents shouldn't be the main force of the water and air quality improvements with economic growth, which we observed from our analysis.



Graph 5.1.1 Numbers of Environmental Pollution Cases Reported to Government (1986-2003) Source: *Shenzhen Environmental Protection Agency, Various Years (1986-2003)*

Graph 5.1.2 demonstrated, it is to keep city's attractiveness in the region that essentially drives Shenzhen's government to implement more effective environmental regulations.



Graph 5.1.2 CLD illustrating the motivation of environmental regulation is driven by economic growth itself.
Note: Produced by Vensim3.0

We can see from the Graph 5.1.2, that in order to facilitate the economy, the government tried to build up economic incentives, for instance tax exemptions, and other favorable policies. At the beginning of establishing SEZ, Shenzhen city was offered many unique favorable policies from central government. Consequently, the local economy benefited a lot and grew quickly on one hand. On the other, the economic incentives increased the attractiveness of Shenzhen city in the region, which would attract more foreign investment also tourists into the city, and further speed up local economic growth. More economic growth implies more profits for business, which also is one type of economic incentives to attract external business.

However, from Graph5.1.2 we also knew that higher GDP growth would induce more pollution which deteriorated the local environment directly. When local environmental quality is getting worse, its city will become less attractive for business and tourists. Moreover, the Graph illustrates the attractiveness of the city is determined by two factors, economic incentives and environmental quality. Worthy to note, Shenzhen is losing its regional competitiveness in terms of favorable tax policies since the central government withdrew most of those policies when its economy reached a high level. As the economy is driven by foreign investment, Shenzhen government had to put more efforts in improving local environment in order to compete with other cities and attract more foreign investment,

Basically, there are two ways of environmental regulations ongoing. One is to enforce factories to build up their own treatment facilities and treat the waste properly. However, it will increase the production cost, decrease the profit and somewhat reduce the overall economic incentives and impede economic growth eventually, for instance, some big companies might have to move out to other cities with less stricter environmental enforcement. Therefore, another way of regulation for Shenzhen government is to allocate more budgets on environmental infrastructures, for instance waste water treatment plant, sewage system, etc. Graph 5.1.2 helps us to visualize how the economic growth and the quality of environment have interacted with each other in the reality.

5.2 The production inducing pollution has been mitigated in Shenzhen SEZ.

Several observations can support the point highlighted in this subtitle. In the regression analysis for ambient air, TSP and NO_x showed declined pollution intensity in the 1990s (Graph 4.1). In the water quality of main rivers, TPH in three rivers inside the SEZ has peaked off its concentration. But in the Guanlan River which is located outside of SEZ, its TPH is still increasing pollution intensity (Graph 4.2.1).

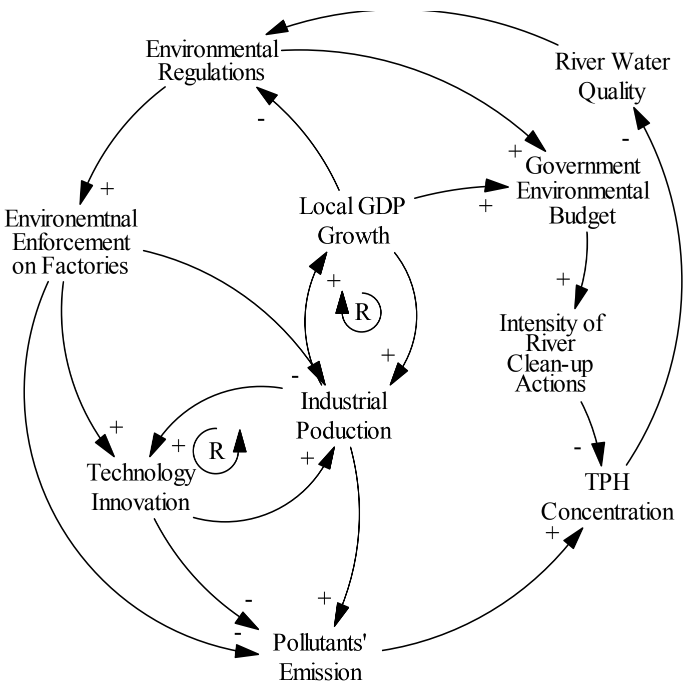
The questions of pollutant's sources, the concentrations of TSP, NO_x TPH to large extent have been influenced by the emission from industrial sources. In the beginning of my studied years, coal and oil burning from industry sector are the major sources of NO_x and TSP, after the treatment measures are carried out in this sector, NO_x and TSP pollution intensities started to decrease. In last years, NO_x tends to increase its pollution intensity, due to the increasing emission from motor vehicles which will be demonstrated as consumption inducing emission in section 5.3.

The sources of TPH are more complicated. TPH is a term used to describe a broad family of several hundred chemical compounds that originally come from crude Total Petroleum Hydrocarbon. It can be released from industry and commercial or private use, for instance as oil & grease discharge, spilled crankcase oil, or solvent use at home. (ATSDR, 1999) In Shenzhen, TPH is mainly released into rivers through oil & grease discharges from industry and boats as well as, leakage from car and trucks. Since petroleum products are widely used as lubricants, solvents in electronic and mechanical industry, one of the pillar industries in Shenzhen, oil and grease discharges from these sectors are generally more than other releases. Besides, our analysis already showed that TPH is not the major pollutant (Table 3.3) on the western side of near shore waters, where there is more likelihood of oil spill and emission from boat and oil tanker transport than in the rivers inside the city.

To sum up, the patterns of regression models for TSP, NO_x and BOD_5 indicate the trend of production inducing pollution (or industrial pollution) in Shenzhen Special Economic Zone.

Industry is an important sector in Shenzhen. It accounts for over 50% of total GDP in the city, in 2003 for instance, it composed 58.9% of total GDP (SNB, 2003). Regarding the industrial pollution abatements in Shenzhen, there are certain figures highlighted here. Utill the July of 2003, a total of 187 factories have been forced to meet national emission objective within a limited time, and over 8,240,000 Chinese Yuan(1,000,000 USD) have been fined. In total, 24,760,000 Chinese Yuan(3,001,212 USD) has been invested by factories in Shenzhen to build up treatment facilities (Shenzhen Commercial Daily, 2003). Shenzhen is regarded one of two best cities in China in controlling industrial pollution.

Graph 5.2 further illustrates how the industrial pollution has increased emission and reduced the pollution intensity afterwards, with TPH as an example.



Graph 5.2 CLD illustrating the Industrial Production Inducing Pollution

Note: Produced by Vensim3.0

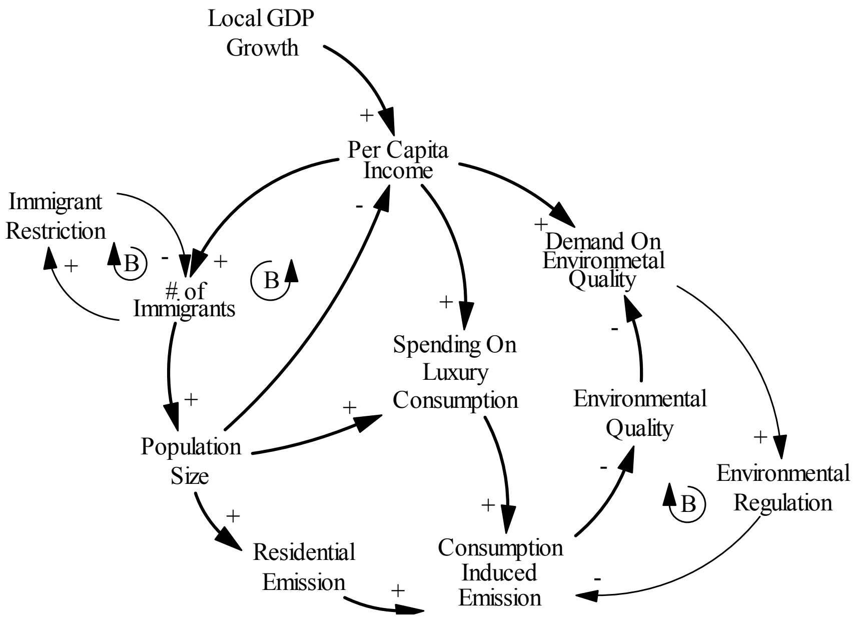
Graph 5.2 suggests that more industrial production will increase the growth of local

GDP, which would reinforce further the growth of industrial production. Unfortunately, industrial production will bring pollutants' emission. For instance, discharging oil and grease into the rivers increases the concentration of TPH and deteriorates river water quality. In order to relieve river pollution, Shenzhen government has to strengthen environmental regulations through, firstly, increase its budget for environmental protection. More environmental budget means more intensive actions of river clean-up would be able to be carried out to dissipate TPH in the rivers. Meanwhile, how much environmental budget Shenzhen government can allocate also depends on the level of local economic growth. Secondly, environmental regulations can also be directly enforced onto the factories which emitted the pollutants. It would certainly reduce pollutant emission due to more treatment facilities built by the factories. Pollution could be further relieved when factories apply technological innovation into production processes. The innovation of technology is originally driven by the factories' willingness to increase their production efficiency and their competitiveness subsequently. It can also be driven by the governmental pressure to eliminate pollution. However, if too strict environmental regulation is set, environmental enforcement on factories could also impede the growth of local economy since the internalized environmental cost would increase production cost of the factory. Also when economic growth reached a certain level, it would be too expensive to settle the factories inside the SEZ, therefore, some factories moved out the SEZ and settled down outside the SEZ, the Guanlan River water catchments for instance. This could be explained as the reason why TPH concentration in Guanlan River is still increasing under the current economy level but already leveled off in other three rivers inside the SEZ.

5.3 Consumption inducing pollution offset the abatement of production pollution

Here consumption inducing pollution refers to pollution from both commercial consumption and residential consumption. In my regression analysis, I observed that NOx tended to increase its concentration again after decreasing in the beginning of our studied years (Graph 4.1). This is because with the economic growth, people can afford to buy more motor vehicles, therefore NO_x from motor vehicles emission increased significantly with the increment of the amounts of cars. The regression patterns of BOD_5, TP in the river water and the regression patterns of inorganic nitrogen and phosphate are other examples supporting this point of increasing emission intensity from consumption side.

In the main rivers except Shenzhen River, TP and BOD_5 have been observed accumulating tendency of pollution intensity (Graph 4.2.2 and 4.2.3). Also, in the western side of near-shore waters, the inorganic nitrogen and phosphate showed the similar tendency of emission intensity accumulation (Graph 4.3). Therefore, in our studies there is one common feature for the emission of NO_x , BOD_5, TP, inorganic nitrogen, and phosphate, they are mainly originated from consumption inducing activities, including residential emission and the emission from service sector. Graph 5.3 has been developed to explain how the consumption inducing pollution can increase emission intensity therefore offset the abatement of production pollution.



Graph 5.3 CLD illustrating the Consumption Inducing Emission
Note: Produced by Vensim3.0

When local GDP grows, the per capita income of Shenzhen is increased subsequently. Higher original income in the city has being attracted to a large amount of arriving immigrants into the city. Some of them are skilled personnel. But most of them are unskilled workers from inner land of the country. They usually works as cheap laborers, and can not afford expensive accommodations inside of the SEZ. Instead they live in so called villages within the city (VWC). There are hundreds of such VWCs which can supply around 1350,000 cheaper rooms for 5000,000 immigrants, and normally there are lack of sewage and waste collection systems (Shenzhen Academy of Social Science, 2004). Since the numbers of immigrant are too large, around 1.21 million people have moved in from 1999 to 2003 (*Shenzhen Statistics Bureau, 1999-2003*), the city government is unable to build up enough sewage systems and other infrastructures to relieve the residential emission inducing pollution. Therefore, there is increasing intensity of residential emissions which ended up in the rivers and oceans of the city and eventually deteriorated the water quality. This is main reason for the accumulation of BOD_5, TP, inorganic nitrogen and phosphate in the river and the western side of near coastal waters.

Graph 5.3 can also explain that lifestyle changed consumption pollution, as Shenzhen has the highest per capita income in China, over 2 times of the nation average income (SNB, various years from in 1990s). Higher income means that people can afford more luxury goods than other parts of the country, car purchased. It is reported, that the number of cars in Shenzhen has been increased by 20% since 2000, and to the end of 2003, there are over 0.62 million automobiles in Shenzhen. Half of them are privately owned cars. In 2003 alone, the net increase of automobiles in Shenzhen is about 0.12 million, which is about the total numbers of automobiles in an inland city at prefecture level (Shenzhen Special Zone daily, 2004).

Meanwhile, when people get wealthy, they have higher demand on local environmental quality. If the real environmental quality can not meet their needs, there will be an increasing demand of environmental quality which will further force Shenzhen government to take more effective environmental regulation. Automobiles emission regulation for instance, stricter exhaust emission standards have been set. From August of 2004, Shenzhen has started to adopt an auto emission standard equivalent to Euro II standard. For all of public transportation, even stricter emission standard. Euro III standard has been adopted since September 2003. Shenzhen is the third city in China adopting Euro II automobile exhaust emission standards and the only city in China adopting Euro III standards (Shenzhen City Automobile Exhaust Emission Inspecting Center, 2004).

6. Conclusions

Since established as the Special Economic Zone in 1980, Shenzhen city has increased tremendously both in terms of economic growth and environmental protection. While economy grows robustly and continuously, the over-time pattern of environmental quality demonstrated various tendencies. The overall air quality has been slightly improved due to reduction from TSP emission. The water quality in four observed rivers has started reducing the concentration of polluting substances, but the water quality is still far away from being able to meet the set objectives. Near-shore water quality in eastern side and western side shows different tendencies, water quality in eastern side almost keeps constant during our studied years, while in western side it showed the tendency of being deteriorated.

The regression analysis aimed at finding out interactions between economic growth and environmental quality, and they showed interesting and abundant results. While estimated in quadratic function, all regression models for the overall ambient air, river-water and near-shore water presented high correlations with R^2-values over 0.6. Good correlations of economic growth and environmental quality could be explained by the reason that the economy, driven by direct foreign investments, had to be improved by the Shenzhen municipal government together with the local environmental quality, in order to attract more external investors to facilitate the economy.

There are another two substantial conclusions could be further drawn from regression analysis. From the regression patterns of NO_x and TSP in the ambient air and the regression patterns of TPH in the major rivers, industrial production inducing emission have been relieved in the Special Economic Zone of Shenzhen. This is mainly due to stricter environmental regulations being carried out and more factories moving out of the SEZ and settled down outside of SEZ (but still within the city borders), when the land rental costs inside of SEZ increased significantly with the economic growth.

Another conclusion is consumption inducing emission have increased and offset the pollution abatement from production side. The regression patterns observed at NO_x in the ambient air, TP, BOD_5 in the rivers, and inorganic nitrogen and phosphate in the near shore water could support this point. The reason is, firstly, the life style has been changed when people get wealthy and can afford to more luxury consumption, for instance cars driving and restaurant catering; secondly, sewage system and other environmental facilities has been far lagged behind the real needs driven by the demands from the huge migrating people in the city.

The overall results principally support my hypotheses, with the exception of some air pollutants and near shore water pollutants indicating the increasing consumption problems.

7. Limitations of Analysis

There are some limitations in my analysis. First, quality of the acoustic environmental in Shenzhen is excluded from the analysis due to the consideration of data validity. However, as graph 5.1 shows, there are increasing complaints from citizens about noise pollution. Second, some important air pollutants which play substantial role in overall air quality are not monitored in Shenzhen, O_3 concentration for instance. Total Petroleum Hydrocarbon, determining the chemical composition of a petroleum release is rather complicated, and in the analysis I did not pay attention to its hydrodynamic, abiotic, and biotic process. Also the possibility exists that the changing of monitoring methodologies during the studied years would affect the consistency of the monitoring data.

Acknowledgements

This thesis was initiated my Young Scientist Summer Program project at IIASA and has been further developed at Lund University. I would thus like to thank Dr. Gerhard Heilig for the excellent supervision and Larry Willmore for helpful advice at IIASA. I would also like to express my special thanks to my M.Sc. supervisors, Professor Bengt Nihlgard in Lund and Dr. Jan Sendzimir at IIASA, for their comments and guidance. Ms Junmiao Chen, from the Shenzhen Environmental Monitoring Center at Luohu District, kindly provided raw data. Also, I would like to give my sincere thanks to Mr. Tom Cochart for his help with language editing. The economic support by FORMAS and LUMES is gratefully acknowledged.

References

AHUT, Anhui University of technology, 2004. Environmental assessment and system analysis. Retrived from http://www.ahut.edu.cn/jpkc/hjpj/hjpj03.ppt.

ATSDR, Agency for toxic substances and disease registry. September 1999. Public statement: Total Petroleum Hydrocarbons (TPH).
Derived from http://www.atsdr.cdc.gov/toxprofiles/phs123.html, on August 30th, 2004

Grossman, G.M., & Krueger, A.B. (1995). Economic growth and the environment. Quarterly Journal of Economics, 110, 353-377.

Haraldsson Hördur V., 2000. Introduction to Systems and Causal Loop Diagrams. System Dynamic course for LUMES, Lund University.

Munasinghe, Mohan.1999. Is environmental degradation an inevitable consequence of economic growth: tunneling through the environmental Kuznets curve. Ecological

Economics, 29, 89-109.

N.L. Nemerow, Stream, Lake, Estuary, and Ocean Pollution 2nd ed.(New York: Van Nostrand Reinhold, 1991) 272-286.

NSB, China's National statisticas bureau, various years from 1989 to 2003.

Sen, Gautam, 2001. Post-reform China and the international economy: economic change and liberalization under sovereign control. International Relations, London School of Economics. Retrievable at http://www.theglobalsite.ac.uk/press/103sen.pdf.

Robert K. Kaufmann, et al., 1998. The determinants of atmospheric SO_2 concentrations: reconsidering the environmental Kuznets curve. Ecological Economics 25, 209-20.

SEPA, Shenzhen Environmental protection agency, 2003. Accessible from http://www. szepb.gov.cn.

Shenzhen Municipal Government, 2004. Shenzhen government online: industry information. Retrievable at http://www.sz.gov.cn/english/gs.

Shenzhen City Automobile Exhaust Inspecting Center, 2004.

Shenzhen academy of social science, 2004. The Blue book of Shenzhen. Social Scientific Documentation Publishing House.

SNB, China's Statistical national bureau. 2003.

Stern, D. I. 2004. The rise and fall of environmental Kuznets curve. The journal of world development, Vol.32, No.8, pp 1419-1439.

Shenzhen Special Zone Daily, 2004. 120000 number net increase of automobiles in 2003 in Shenzhen. Published on 05/19/04.

Guo, Rongjiu, Li Zibin, 2000. Shenzhen: Retaining the lead in Growth. World economic forum. Retrieved from http://www.weforum.org.

Shenzhen City Automobile Exhaust Emission Inspecting Center, 2004. Shenzhen's Environmental friendly automobile list.

Shenzhen Commercial Daily, 2003. Shenzhen becomes the first city in the nation that has achieved the overall industrial pollution emission objectives. Published on October, 11st, 2003.
Retrievable at http://www.shenzhen.net.cn/shishi/s2/200310110013.htm

SEMC, 2000. the introduction of the ambient air monitoring system in Shenzhen. Retrievable from www.api-shenzhen.gov.cn.

UNEP, 2002. Adult Award Winner in 2002: municipal government of Shenzhen. Global 500 forum. Retrievable from http://www.global500.org.

Appendix Ⅰ: Standards of Ambient Air Quality and Emissions in Asian Countries and Others

(Unit: mg/m^3, unless otherwise indicated)

1. SO_2

Country	Annual Average	24-Hour Max	Daily Average
China	0.06	0.50	0.15
India	-	0.03-0.12	-
Poland	0.032	-	0.2
Thailand	0.10	-	0.30
World Bank	0.10	0.5 (outside)	1.0 (inside)
USA	0.06 (0.02 ppm) [c] 0.08 (0.03 ppm) [d]	0.26 (0.1 ppm) [c] 0.365 (0.14 ppm) [d] 1.3 (0.5 ppm) [c, e]	-
Germany	0.14 (0.05 ppm)	-	0.40 (0.14 ppm)
Japan	0.26	0.11 (0.04 ppm)	-

[a] 0.03 mg/m^3 for "sensitive" areas, 0.08 mg/m^s for "residential and mixed use" areas
[b] One-hour average
[c] Secondary based on environmental effects
[d] Primary based on health effects on humans
[e] Maximum of 3 hours once yearly

2. Particulates

Country	Annual Average	24-Hour Max	Daily Average
China	-	1.00 [a] 0.5 [b]	0.30 [a] 0.15 [b]
India	0.1-0.5 [c]	-	-
Poland	0.05	-	0.12
Thailand	0.10	-	0.33
World Bank	0.10	0.50	-
USA	0.065 [e] 0.075 [f]	0.15 [e] 0.26 [f]	-
Germany	0.1 [g] 0.2 [h]	-	0.2 [g] 0.4 [h]
Japan	-	0.20	0.1

[a] Total suspend
[b] Fly dust
[c] 0.1 mg/m^3 for "sensitive" areas, 0.2 mg/m^3 for "residential" and "rural" areas, and 0.5 mg/m^3 for "industrial and mixed use" areas
[d] One-hour average
[e] Secondary based on environmental effects
[f] Primary based on health effects on humans
[g] <10 um
[h] <10 um

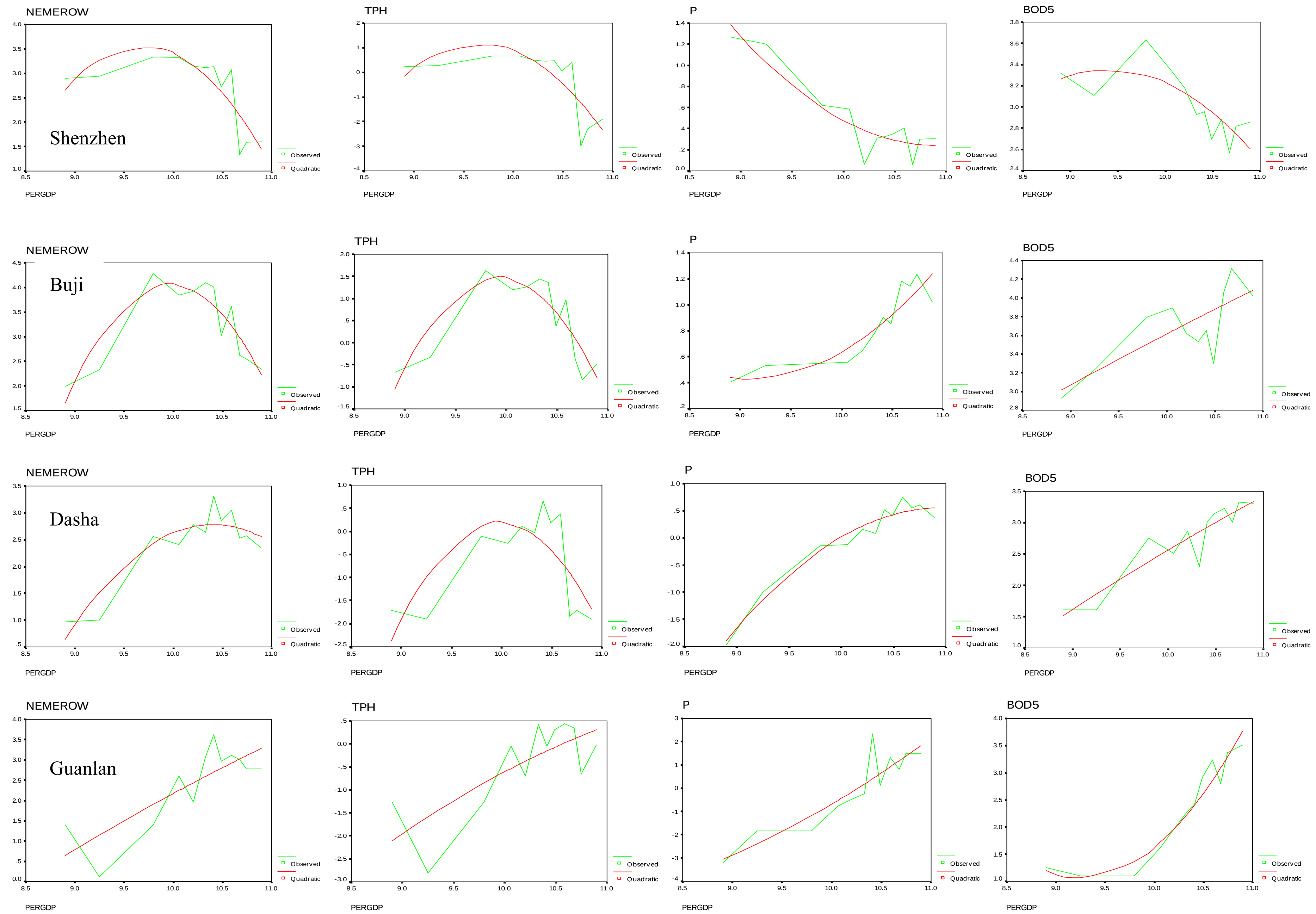
3. NO_x

Country	Annual Average	24-Hour Max	Daily Average
China	0.12	0.15	0.1-0.15
India	0.03-0.12 [a]	-	0.0925
Poland	0.05	-	0.15
Thailand	-	0.32 [b]	-
World Bank	0.1 (0.05 ppm)	-	0.5
USA	0.1 (0.05 ppm)	-	-
Germany	0.1 (0.05 ppm)	-	0.3 (0.15 ppm)
Japan	-	-	0.04-0.06
EU	0.2	-	-

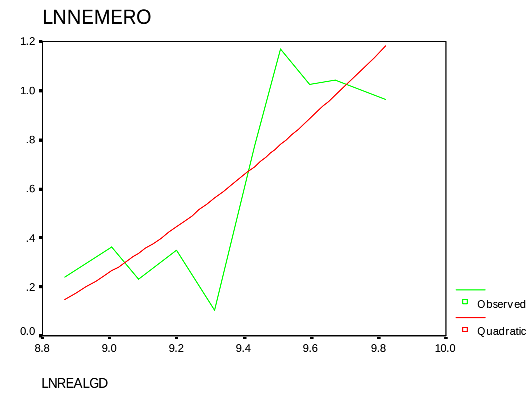
[a] 0.03 mg/m^3 for "sensitive" areas, 0.08 mg/m^3 for "residential and mixed use" areas
[b] One-hour average

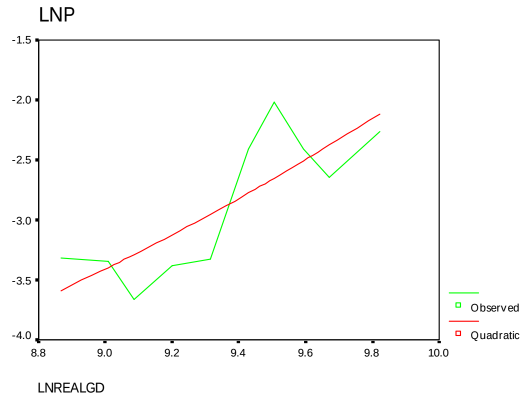
Sources: World Bank, Retrievable from http://www.worldbank.org

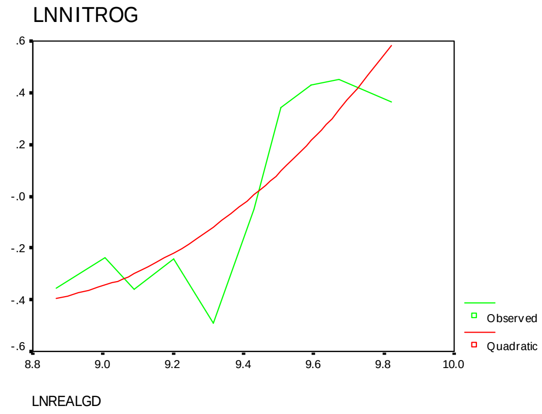
Appendix Ⅱ: Regression models of all rivers in Shenzhen



Regression models of Near-shore water quality on western side







Regression models of Ambient air quality