THE RELATIONSHIP BETWEEN WATER POLLUTION AND ECONOMIC GROWTH USING THE ENVIRONMENTAL KUZNETS CURVE: A CASE STUDY IN SOUTH KOREA

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Title

The Relationship between Water Pollution and Economic Growth

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

This thesis reviews relationships between economic growth and water pollution in South Korea using the Environmental Kuznets Curve (EKC). Both national perspective (pooled data) and regional perspective (each river) are used to reveal the EKC theory. Given that the small sample covers four rivers and the period of 1985-2009, Fixed-effects model with a robust standard error is chosen for removing econometric problems.

Empirical results demonstrate that the EKC theory explains water quality change in South Korea, depending on the types of water pollutants and their generated regional characteristics. The Han River does not show inverted-U shapes for BOD (Biochemical Oxygen Demand) and COD (Chemical Oxygen Demand), but the Geum River (BOD), the Yeongsan River (BOD and COD), and the Nackdong River (COD) show inverted-U shapes. At the national perspective, BOD and COD might show inverted-U shapes; therefore, the EKC relationship cannot always be generalized between economic growth and environmental pollution.

ACKNOWLEDGMENTS

I would like to thank my co-chairs, Dr. Hearne and Dr. Lee, about their sincere supports, guidance and understandings. I appreciate the help from my committee members, Dr. Koo, Dr. Roberts, Dr. Nhoe, and Dr. Chu for their contribution and constructive comments.

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CHAPTER 1. INTRODUCTION

Economic activity produces pollutants, which may lead to environmental degradation. People desire more products as their incomes grow in the process of economic development and industrialization. Increased production and consumption implies that the natural environment is exploited for human desire. Increased pollution may lead to the concurrent increased health concerns, loss of natural habitats, and the potential for decreased quality of life.

In the early 1990's, Grossman and Krueger demonstrated the inverted U-shaped relationship between economic growth and environmental degradation, and proposed the Environmental Kuznets Curve (EKC) (Grossman and Krueger, 1991). They defined this relationship as the EKC hypothesis named after the Kuznets curve hypothesis developed by Kuznets in 1955.

The EKC theory generally assumes an inverted U-shaped relationship between economic growth and environmental degradation. It shows that environmental degradation increases with increase of income, but that it starts to decrease when income reaches a certain point—the so-called turning point. Shafik and Bandyopadhyay (1992), Panayotou (1993), Grossman and Krueger (1995) and Selden and Song (1994) investigated and concluded that each country or region has its own EKC pattern, depending on regressed pollutants, economic, social, cultural backgrounds.

Because the economy of South Korea has grown rapidly in the past 40 years, it is an excellent case study for the analysis of the relationship between economic growth and environmental quality. As a result of the strong desire of the people to be out of poverty and polices that fostered industrialization, growth has been unprecedentedly fast. In the process of the economic growth, water pollution which is strongly connected with water-borne disease and the loss of aquatic ecosystems has been occurred.

However as the nation ascended out of poverty, new priorities led the government to adopt new policies and efforts to improve water quality. The government led to its success with restricting certain types of growth in particular regions like Seoul, Incheon, Daejeon, Daegu, Gwangju, Busan and some provinces around the four rivers (Han River, Geum River, Yeongsan River and NackdongRiver). See Figure 1.1. for an illustration of the study area. However the results for these efforts may be unequal in these four river basins due to regional characteristics and policies that have tended to concentrate certain types of economic activities in certain regions.

Figure 1.1. Geographical features of Korea
Source: Environmental News Services, http://www.ens-newswire.com/ens/aug2010/2010-08-16-01.html

1.2. Overview and objectives

The objective of this thesis are 1) to estimate the effects of economic growth on water pollution (COD and BOD) by EKC theory to each of the four rivers in South Korea, and 2) to determine whether this relationship is constant across pollutants and regions within South Korea. Results for industrial and organic water pollution will be compared, and the relationship between these results and regional developments priorities will be assessed.

The thesis is organized into five chapters, including the introduction in Chapter 1. Chapter 2 reviews literature regarding Environmental Kuznets Curve (EKC). Chapter 3 presents the empirical model and describes the data sources and methodology. Chapter 4 reports the regression results which reveal the relationship between water pollution and economic growth in South Korea. Chapter 5 discusses the results of statistical analysis conducted by Chapter 4, policy implications, and recommendations for future study.

CHAPTER 2. LITERATURE REVIEW OF THE EKC THEORY

This chapter shows representative works from each continuing process, explaining other authors' achievements for our further understanding of EKC phenomena, as well as going through lacking aspects indicated by critics and supporters.

2.1. Empirical EKC reviews on country data

There has been much research about EKC, and there has been much discussion about the validity of the EKC hypothesis. For example, using 21 European countries, Ansuategi (2003) points out that there is an inverted U-shaped relationship for SO_2 emissions. Jha and Murthy (2003) estimate global environmental degradation with an environmental degradation index (EDI) incorporating six environmental indicators and find N-shaped relationship between economic indicators and environmental indicators. Maddison (2006) examines the EKC hypothesis for SO_2, NO_x, and CO_2 and presents evidence of inverted U-shaped EKC relationships. However, Harbaugh et al. (2002) find that the correlation between pollution and GDP is strongly linked to sample selection and empirical specification, and that there is little empirical support for the EKC theory. Table 2.1 summarizes the literature reviews on country data including authors, economic indicators (explanatory variables), environmental indicators, results, regions/periods and econometric estimation techniques.

Table 2.1. The literature reviews on country data

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Grossman and Krueger (1991)	GDP per capita, characteristics of the site and city, and a time trend	Sulphur dioxide and Dark matter suspended: Inverted U-shape	A cross-section of urban areas in 42 countries (Each indicator has different time periods.)	Level[1], Cubic, Fixed-and Random-effects
Shafik and Bandyopadhya y (1992)	GDP per capita, a time trend	Deforestation and Air (carbon emission): Inverted U-shape, Water (DO and fecal coliforms): Insignificant	149 countries 1961-1986	Log[2], Quadratic and Cubic, Fixed-effects
Hettige, Lucas, and Wheeler (1992)	GDP per capita, interaction between per capita and time	Toxic intensity of manufacturing, Inverted U-shape	80 countries 1960-1988	Log, Quadratic, OLS
Panayoton (1993)	GDP per capita, population density, interaction between per capita and population density	SO_2, NO_x, Deforestation: Inverted-U shape	Developing and developed countries, cross section in the late 1980	Translog[3], Quadratic, OLS
Shafik (1994)	GDP per capita, a time trend, and the fixed effect for site-specific factors	Deforestation and SPM : Inverted U-shape	149 countries 1960-1990	Log, Quadratic, Cubic, OLS
Selden and Song (1994)	GDP per capita and population density	SO_2, NO_x, SPM, CO: Inverted U- shape	A cross-national panel of data 1952-1985	Level, Quadratic and Cubic, OLS, Fixed-and Random-effects
Cropper and Griffiths (1994)	Per capita income, population density, Percentage change in income and population, price of Def.	Def.: \$4,760(Africa) \$5420(Latin America), Inverted U-shape	Latin America , Asia and Africa 1961-1988	Level, Quadratic, Fixed effects with Paris-Winsten technique

[1] The quadratic levels function has been widely applied as a methodology. Quadratic levels function of the relationship between income and environment is problematic (Jayanthakumaran and Liu, 2012).
[2] The quadratic log function is more appropriate as its rate of decrease is gradual once it passes the turning point (Jayanthakumaran and Liu, 2012).
[3] The translog formulation has the advantages of allowing for interaction efforts between variables and of permitting direct reading of elasticities (Panayoton, 1993).

Table 2.1. The literature reviews on country data (continued)

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Grossman and Krueger (1995)	GDP per capita, a three-year average of lagged per capita GDP and a vector of other covariates as a dummy variables	Air, Water(DO), and Nitrate: Inverted U-shape Bacteria: N-shape	A cross-section of urban areas in 42 countries (Each indicator has different time periods.)	Reduced form[4], Quadratic, Cubic, Generalized Least Squares (GLS)
De Bruyn (1997)	GDP per capita	Find SO_2 deduction in west Germany and Netherlands is a result of technology innovation.	27 countries cross section	Reduced form, Decomposition analysis
Panayotou (1997)	GDP per capita, population density, annual growth rate, policy variable and interaction variables	The quality of policies and institutions reduce environmental degradation at low income and speed up improvement at high income.	30 developing countries 1982-1994	Level, Quadratic, and Cubic, GLS with Fixed-and Random-effects, and Decomposition analysis with Reduced form
Bruyn, Bergh, and Opschoor (1998)	GDP per capita and price of input related factors	Strong positive relationship between economic growth and emissions(SO_2, NO_x, CO_2), except for SO_2 in Netherlands	Netherlands, Western Germany, UK and USA 1960-1993	Reduced form and Intensity of use
Kaufmann, Davidsdottir, Garnham and Pauly (1998)	GDP per capita, population density, economic activity and Iron and steel exports	SO_2: $12500, New equation about how changes in the level and spatial intensity of economic activity affects the concentration of SO_2.	23 countries 1974-1989	Level, Quadratic, and Cubic, Fixed- and Random-effects
Galeotti and Lanza (1999)	GDP per capita	CO_2: Inverted U-shape (All countries, Non-OECD, and OECD)	110 countries 1971-1996	Log, Gamma and Weibull functions
Harbaugh et al. (2003)	GDP per capita, a three-year average of lagged per capita GDP and a vector of other covariates	Find no evidence between air pollutants and income	Similar case of Grossman and Krueger, but data was added from AIRS[5]	Reduced form, Quadratic, Cubic, GLS with Fixed-and Random-effects

4 The reduced form gives the net effect of a nation's income on pollution and spares validity about data we easily can't correct. (Grossman and Krueger, 1995; De Bruyn, 1997) .

5 Environmental Protection Agency in USA maintains ambient pollution data in its Aerometric Information Retrieval System (AIRS). (Harbaugh et al, 2003).

Table 2.1. The literature reviews on country data (continued)

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Canas, Ferrao, and Conceicao (2003)	GDP per capita	Dependent variable (Direct material input[6]) and independent variable (GDP per capita) have an inverted U-shaped relationship.	16 industrialized countries 1960-1998	Level, Quadratic, and Cubic, Fixed- and Random-effects
Perman, and Stern (2003)	GDP per capita, population, a time trend, country-specific effect and time-specific effects	EKC pattern is a problematic concept for relationship between SO_2 and GDP.	74 countries 1960-1990	Cointegration test[7]
Jha and Murthy (2003)	Human Development Index (HDI)[8]	N-shaped relationship between Environmental Degradation Index (EDI)[9] and Human Development Index (HDI)	174 countries 1990-1996	Level, Quadratic, and Cubic, OLS
Chimeli and Braden (2005)	Stock of capital	A U-shaped response of environmental quality to variation in total factor productivity depends on the curvature of utility function.	Parameters were derived from inspected literatures	Maximizing social welfare at an optimal provision of environmental quality from Samuelson condition
Dinda and Coondoo (2006)	GDP per capita and a time trend	Bi-directional relationship between CO2 and income in classified areas as a whole	88 countries 1960-1990	Cointegration test, Error Correction Test (ECM)
Yoshiaki (2009)	GDP per capita	Biological Oxygen Demand (BOD): $5050 Total Phosphorus (TP): $11200, Both inverted U-shape	7 developing-countries 1998-2002	Using first and second order equations with linear-linear and log-log scales

6 To investigate the intensity of material consumption when industrialized economies grow (Canas, Ferrao, and Conceicao, 2003).

7 To deal with the issue of endogeneity problem and causal mechanisms (Baek, Cho, and Koo, 2009).

8 Human Development Index (HDI) is from United Nations.

9 $EDI_i = \sum_j w_j x_{ji}$ where w_j is the j th component score and x_{ji} is value of the j th variable for the I th country given j equal to 1, 3, 4, and 5 (Jha and Murthy, 2003).

Table 2.1. The literature reviews on country data (continued)

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Jill, Dustin, and James (2009)	GDP per capita, population, country-specific effect and time-specific effects	Ecological Footprint (EF)[10]: No inverted U-shape with economic development	146 countries 1961-2000, 5-year time periods	Log, Quadratic, Fixed-and Random-effects
Baek, Cho, and Koo (2009)	GDP per capita and trade openness	An increase in the level of income results in an improvement (deterioration) of environmental quality for developed countries (developing countries).	50 countries 1960-2000	Cointegration test
Lee, Chiu, and Sun (2010)	GDP per capita, trade openness and population	Inverted U-shaped EKC in America and Europe, but not in Africa, Asia and Oceania	97 countries 1980-2001	Generalized Method of Moments (GMM)

2.2. Empirical EKC reviews on in-country and time-series data

One final result of section 2.1 is that the empirical evidence on the EKC is incomplete and significantly limited according to geographical conditions, economic activities, culture and history in different countries. Most research has been investigated with panel data from a variety of countries, even though some research in section 2.1used country data to provide arguments favorable to the EKC theory. Coondo and Dinda (2002) derive that the relationship of pollution and income differs from groups of countries. Some researchers have begun to investigate the relationship between income and environment within one country. For example, Roca et al. (2001) explained that relation between SO_2 and GDP per capita in Spain is inverted-U shaped curve. Shen (2006) also derived that EKC exists for Chemical Oxygen Demand (COD), Arsenic, and Cadmium in China

[10] The EF "measures the human demand on nature by assessing how much biologically productive land and sea area is necessary to maintain a given consumption pattern" (Wiedmann et al., 2006).

during the period between 1993 and 2002. However, Hossein Farzin and Grogan (2011) revealed that most water quality indicators do not have EKC pattern, and are significantly correlated with education, ethnic composition, age, land use, and population density.

Table 2.2. summarizes the literature reviews on in-country and time-series data, including authors, economic indicators (explanatory variables), environmental indicators, results, regions/periods and econometric estimation techniques.

Table 2.2. The literature reviews on in-country and time-series data

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Roca, Padilla, Farre, and Galletto (2001)	GDP per capita, per capita elasticity generalized in conventional consumption thermal power stations in a case of SO_2	Only SO_2 has EKC pattern of other atmospheric pollutants.	Spain 1973-1996	Log, linear, OLS
Friedl and Getzner (2002)	GDP per capita, temperature, imports as a ratio to GDP, value of service sector, dummy variable	Find N-shape between CO_2 and GDP.	Austria 1960-1990	Level, Quadratic, and Cubic, Stationarity and Cointergration analysis
Shen (2006)	GDP per capita, per capita government pollution abatement expense, secondary industry share, population density, per capita physical capital, and labor	Inverted U-shape between each of Chemical Oxygen Demand (COD), Arsenic, and Cadmium in water and income	31 provinces in China 1993-2002	Log, Square, Two stages least squares (2SLS)

Table 2.2. The literature reviews on in-country and time-series data (continued)

Authors	Economic indicators	Environmental indicators and results	Regions/periods	Econometric techniques
Yachun (2006)	GDP per capita and other socio economic variables	Some air quality variables exhibit an EKC pattern.	Taiwan 1976-2004	Level, Quadratic, and Cubic, OLS
Chen (2007)	GDP per capita, population, share of import and export in GDP, FDI inflow, proxy of environmental regulation, country specific effects and time specific effects	EKC theory is not clear in China with all types of pollutants and regions.	29 provinces in China 1992-2005	Log, Reduced form, Cubic, Fixed-effects
Liu, Heilig, Chen, and Heino. (2007)	GDP per capita	Production-induced pollutants support EKC while consumption-induced pollutants do not support it.	1 region: Shenzhen in China 1989-2003	Log, Quadratic, OLS
Diao, Zeng, Tam, and Vivian (2009)	GDP per capita	Find inverted U-shape between each of wastewater, waste gas, soot, and dust and income.	1 city: Jiaxing in China 1995-2005	Level, square, Cubic, OLS
Zhao,Mao, and Peng (2009)	GDP per capita	Industrial wastewater: Positive U-shape, Waste gas: right half of the U-curve, SO2: U-shape, and Solid waste: weak inverted U-shaped curve	Qinghai province 1986-2006	Level, Quadratic, OLS
Hossein Farzin and Grogan (2011)	GDP per capita, water body type, a time trend, socioeconomic variables, and special variables	Most of water quality indicators does not have EKC pattern, and are significantly correlated with education, ethnic composition, age, land use and population density.	California 1993-2006	Level, Quadratic, and Cubic, OLS
Jayanthakumaran and Liu (2012)	Industrial income, trade openness[11] and terms of trade[12]	COD and SO_2: Inverted U-shape	30 provinces in China 1990-2007	Log, First differencing, Quadratic, Random-effects

[11] Exports plus imports to GDP in percentage (Jayanthakumaran and Liu, 2012).
[12] The ratio of the price index of export goods to the price index of imported goods (Koo and Lynn Kennedy, 2005).

2.3. Implication of water pollution

Several water pollution indicators closely related to EKC theory were found in the literature (Shafik and Bandyopadhyay, 1992; Shafik, 1994; Grossman and Krueger 1995; Shen, 2006; Diao et al., 2009; Yoshiaki, 2009; Zhao et al., 2009; Lee et al., 2010; Jayanthakumaran and Liu, 2012). For example, Shafik and Bandyopadhyay (1992) and Grossman and Krueger (1995) used Dissolved Oxygen (DO) for EKC theory and explained U-shaped relationship between DO and income. In addition, Yoshiaki (2009) and Lee at al., (2010) revealed an inverted U-shape relationship between Biological Oxygen Demand (BOD) and income. Shen (2006) revealed an inverted U-shape between each of COD, arsenic and cadmium in water and income. Diao et al., (2009) and Zhao et al., (2009) derived positive U-shape between wastewater discharges and income, and Jayanthakumaran and Liu (2012 recently revealed on an inverted U-shape between COD and income.

CHAPTER 3. METHODOLOGY

Chapter 3 starts with the order of the following sections: ⅰ) conceptual model ⅱ) hypotheses and tests, ⅲ) area of study ⅳ) data explanation, and ⅴ) estimation procedures.

3.1. Conceptual model

According to Grossman and Krueger, 1991; Shafik and Bandyopadhyay, 1992; Selden and Song, 1994; Panayotou, 1997; Baek, Cho, and Koo, 2009; Lee, Chiu, and Sun, 2010, population, trade, and GDP can be explanatory variables for explaining EKC theory. Hence, the conceptual model relates water pollution indicators to population, trade, and GDP:

$$\text{Water pollution indicators} = \text{F}\ (Population, Trade, \text{GDP}) \qquad (3.1.)$$

where water pollution indicators are BOD and COD, and the three explanatory variables are population, trade, and GDP (See 3.4 data for detailed descriptions).

First, to reveal the pollution effect with respect to each explanatory variable, the partial derivative of every explanatory variable in equation 3.1 is needed. Each of effects is indicated as ⅰ) population effect ($\frac{\partial Water\ pollution}{\partial Population}$), ⅱ) trade effect ($\frac{\partial Water\ pollution}{\partial Trade}$), and ⅲ) GDP effect ($\frac{\partial Water\ pollution}{\partial GDP}$) . The positive, negative, or constant sign about water pollution with respect to population, trade, and GDP will be determined through empirical models in the chapter 4.

Second, finding the turning point in EKC model is required to do the first derivative of equation (3.2) with respect to GDP: the general empirical EKC model are required to specifically explain the turning point and the EKC relationship (see below paragraph), and then it is set to be zero and solved for the value of GDP:

$$Y = \beta_0 + \beta_1 Population + \beta_2 Trade + \beta_3 \mathrm{GDP} + \beta_4 \mathrm{GDP}^2 \quad (3.2.)$$

$$\left(\frac{\partial Y}{\partial GDP}\right) = \beta_3 + 2\beta_4 \mathrm{GDP} = 0 \quad (3.3.)$$

$$2\beta_4 \mathrm{GDP} = -\beta_3 \quad (3.4.)$$

$$\mathrm{GDP} = -\frac{\beta_3}{2\beta_4} \quad (3.5.)$$

The increasing to decreasing point of water pollution is determined by β_3 and β_4 coefficients of GDP explanatory variable, hence, GDP is the most necessary factor in EKC model to reveal a turning point.

Third, a shape of EKC model is decided by the sign of coefficients in the estimated equation. There are several kinds of relations in the equation 3.2 between water pollution and economic growth as follows:

i) $\beta_3 = \beta_4 = 0$. A flat shape or no relationship between GDP and water pollution.

ii) $\beta_3 > 0$ and $\beta_4 = 0$. A monotonic increasing relationship between GDP and water pollution.

iii) $\beta_3 < 0$ and $\beta_4 = 0$. A monotonic decreasing relationship between GDP and water pollution.

iv) $\beta_3 > 0$ and $\beta_4 < 0$. An inverted-U-shaped relationship between GDP and water pollution, that means, EKC.

v) $\beta_3 < 0$ and $\beta_4 > 0$. A U-shaped relationship.

3.2. Hypotheses and tests

To look at whether each of the 4 major rivers and the pooled data shows evidence for EKC theory, two hypotheses and empirical models are needed. Two hypotheses are as follows:

Hypothesis 1. H_0: There is no relationship between water pollution and population, trade and GDP.

H_1: There is a positive relationship between water pollution and population, a negative relationship between water pollution and trade, and an inverted U-shaped relationship between water pollution and GDP.

Hypothesis 2. H_0: There is no relationship between water pollution and GDP.

H_1: There is an inverted U-shaped relationship between water pollution and GDP.

If a p-value of explanatory variables in the hypotheses is less than 0.10, then the explanatory variable indicated with p-value < 0.10 will be statistically significant and used to establish correct empirical model as an independent variable, and vice versa. Also, whether or not the null hypothesis (H_0) of hypothesis 1 and 2 are rejected, it will be decided to the each p-value in the explanatory variables of the hypotheses.

Two empirical models (See equations 3.6 and 3.7) depending on a type of hypothesis can be assumed as follows:

Empirical model 1

$$Y_{it} = \alpha_i + r_t + \beta_0 + \beta_1 Population_{it} + \beta_2 Trade_{it} + \beta_3 GDP_{it} + \beta_4 \mathrm{GDP}^2{}_{it} + \varepsilon_{it} \quad (3.6.)$$

Empirical model 2

$$Y_{it} = \alpha_i + r_t + \beta_0 + \beta_1 GDP_{it} + \beta_2 \mathrm{GDP}^2{}_{it} + \varepsilon_{it} \quad (3.7.)$$

where i is river,

t is time,

α_i is the regional specific effects and,

r_t is the time specific effects.

The assumed sign of population coefficient is positive if the countries where more people live in consume more products. On the other hand, the assumed relationship between trade and environmental indicators is negative if trade-induced income growth inspires people to strengthen their demand for cleaner quality of the environment (given that environmental quality is a normal good). Likewise, the assumed signs of GDP and GDP^2 coefficients are positive and negative, respectively, according to the EKC theory.

These empirical models use panel data analysis (fixed-effects and random-effects). The fixed-effects model regards the parameters the α_i and r_t as regression parameters. The random-effects model treats the α_i and r_t as components of the random disturbance. The other dimension of difference between the possible specifications is the characteristic of the cross-sectional or time-series effect. The empirical models can be referred to as fixed-effects models if the effects are nonrandom and as random-effects models otherwise (Stock et al, 2010; SAS 9.2 and 9.3).

3.3. Area of Study

To understand this empirical study, important background of the study is required (agriculture & livestock changes, production of household waste, forest area, water usage and water law system, industrial development process during the last 30 years in South Korea).

3.3.1. Basic Background of Study Area

3.3.1.1. Agriculture & livestock change

The arable hectare in South Korea has been continuously decreased for the last 30 years (see Figure 3.1.), and this decreased proportion mainly converted for industrial complex and enlarged demand for living place and environmental quality. Also, agricultural chemical consumption from 1980 to 2009 and agriculture fertilizer usage from 1990 to 2009 have been gone down in the Figure 3.2. and Figure 3.3., respectively.

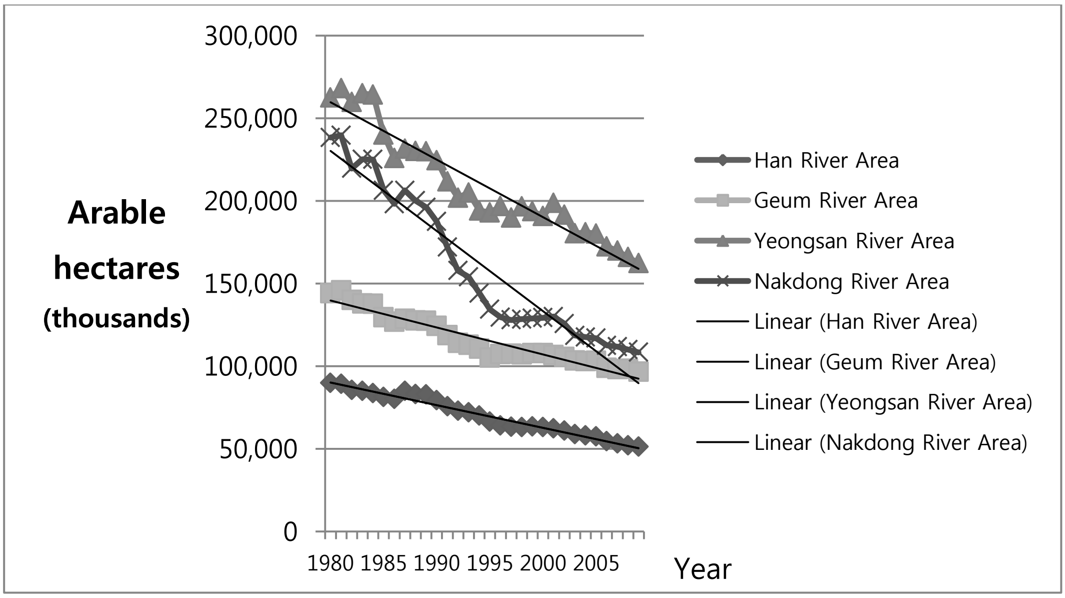


Figure 3.1. Arable hectares in the four river basins from 1980 to 2009
Source: Statistics Korea from 1980 to 2009

where Han River area implies Seoul, Incheon and the province of Gyenggi, and Geum River area is Daejeon and both the provinces of South Chungcheong and North Chungcheong. Yeongsan River area implies Gwangju and both the provinces of North Jeolla and South Jeolla, and Nakdong River area includes Daegu, Busan, Ulsan, and both the provinces of North Gyeongsang and South Gyeongsan. The Y axis is measured by units of hectare.

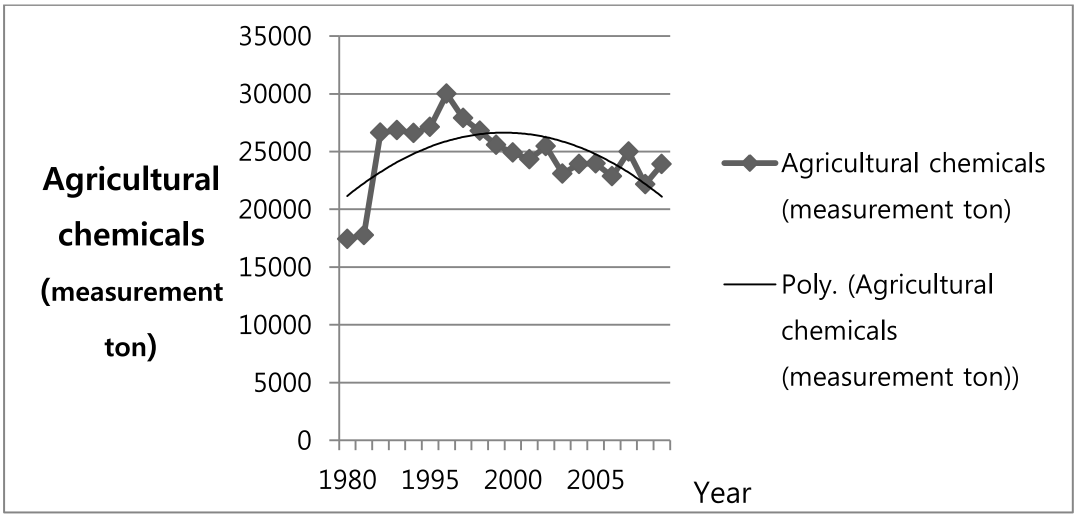


Figure 3.2. Agricultural chemical consumption from 1980 to 2009
Source: Statistics Korea from 1980 to 2009
Note: This data is a country data, not data separated by the 4 rivers.

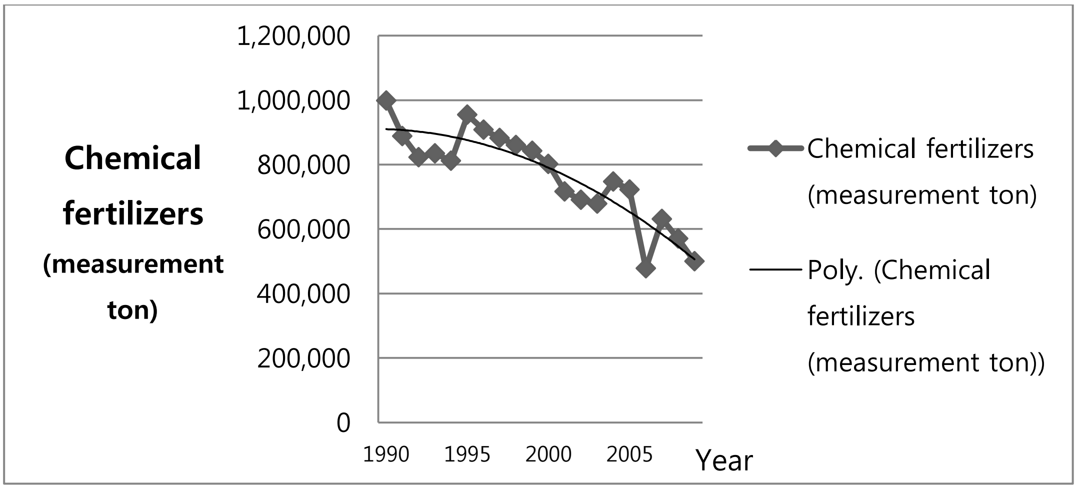


Figure 3.3. Chemical fertilizer usages from 1990 to 2009
Source: Statistics Korea from 1990 to 2009
Note: This data is a country data, not data separated by the 4 rivers.

The livestock production has been increased in the Figure 3.4., but there may be a big bias. This is because livestock-related disease (e.g., foot-and-mouth disease and bird flu) might be prevalent through the country in particular years.

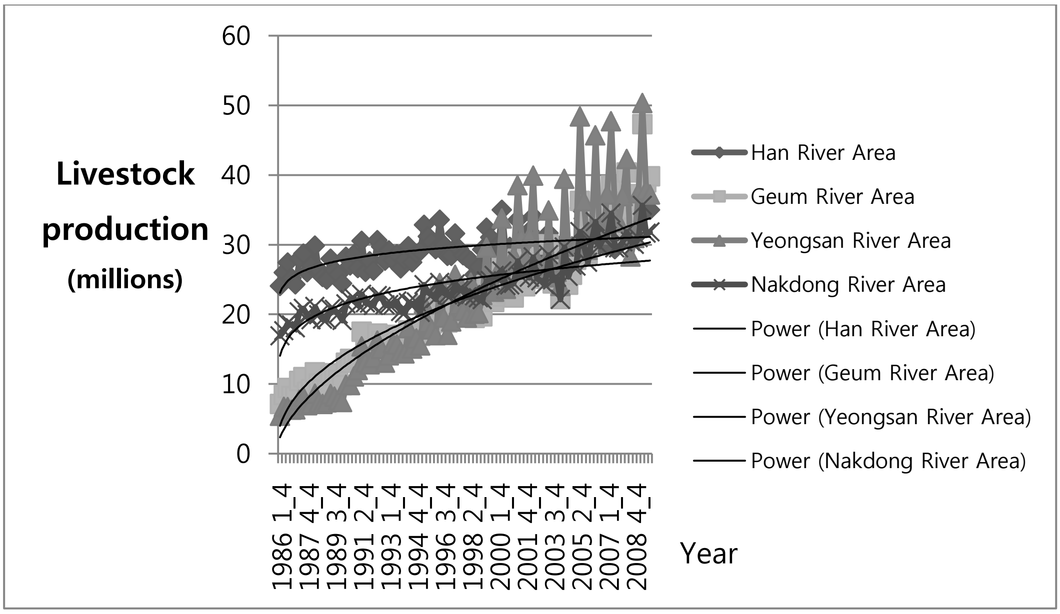


Figure 3.4. Livestock production in the four river basins from 1986 1st quarter to 2009 4st quarter
Source: Statistics K orea from 1986 1st quarter to 2009 4st quarter

The Y axis in Figure 3.4. is the sum of the number of Korean cow, pig, and chicken, and represents the number of total livestock. Unlike the Figure 3.1, time series here is quarter data.

Figure 3.5. shows the change of the livestock production and the production in livestock excretion at the extent of country from 1992 to 2009. With increase of livestock, the production of livestock excretion goes up.

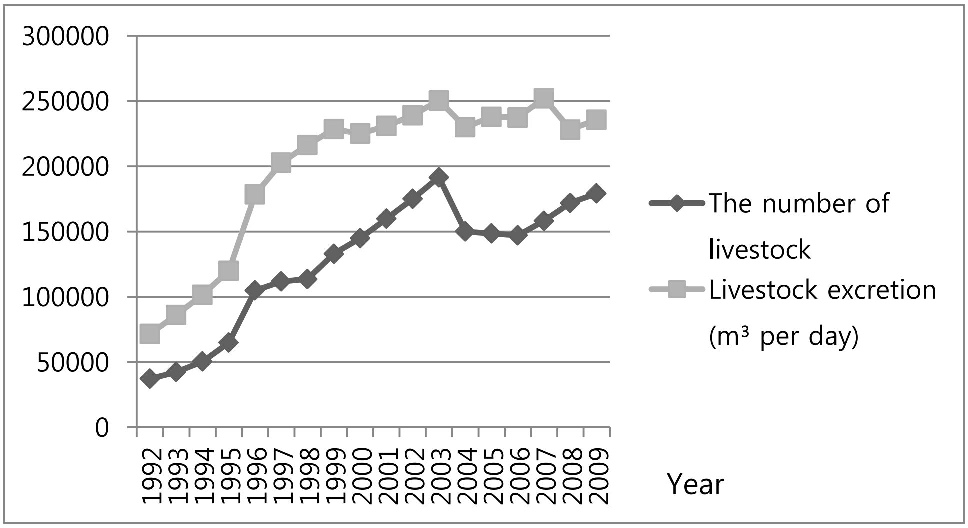


Figure 3.5. The number of livestock and the production of livestock excretion
Source: Statistics Korea from 1992 to 2009

The Figure 3.6. shows that transformation of livestock excretion into eco-friendly resources has increased over time.

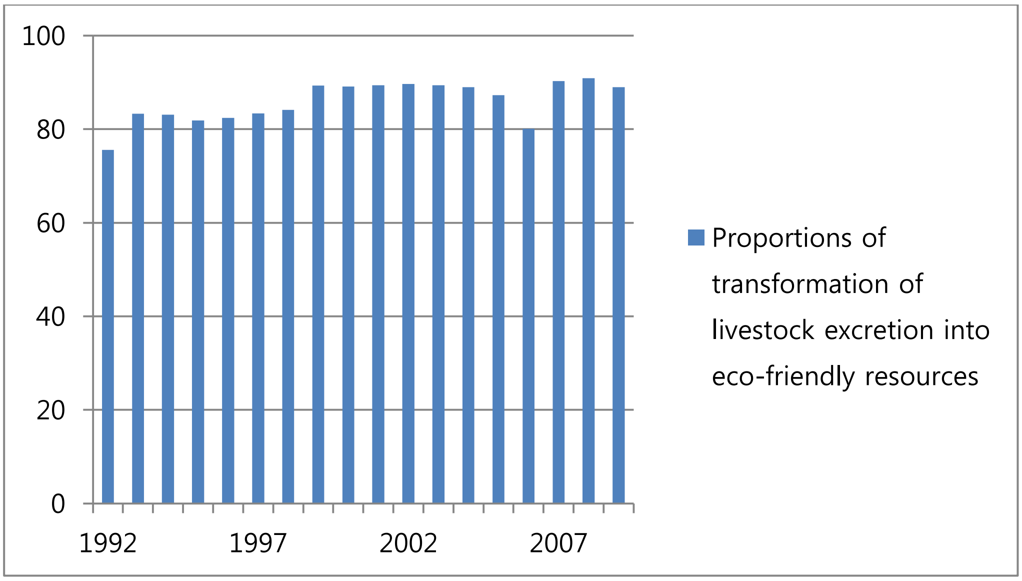


Figure 3.6. Proportions in transformation of livestock excretion into eco-friendly resources
Source: Statistics Korea from 1992 to 2009

3.3.1.2. The change of household waste

Figure 3.7. indicates the decline in household wastewater entering the four major rivers in South Korea from 1990 to 2009. Likewise, Figure 3.8. provides

evidence of improved sewage treatment performance from 1994 to 2009.

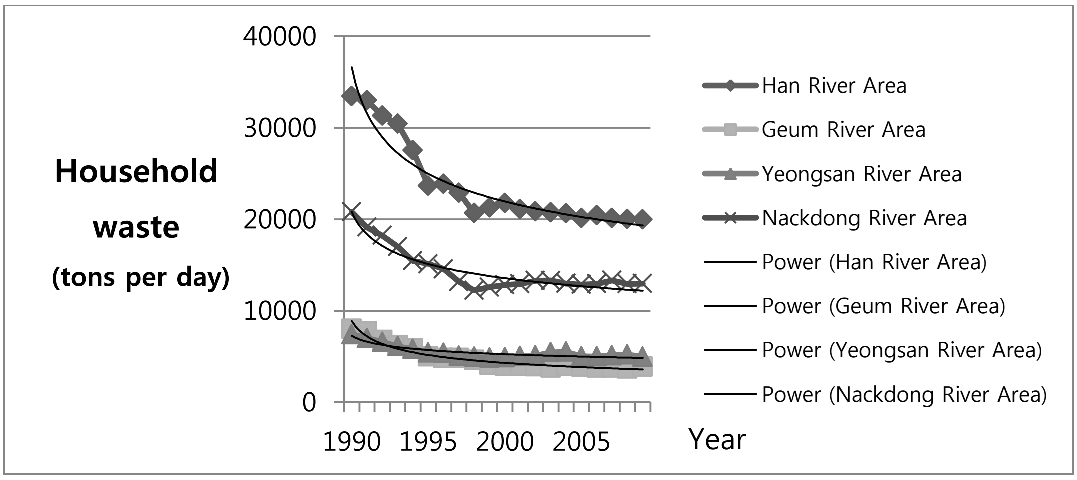


Figure 3.7. The change of household waste
Source: Statistics Korea from 1990 to 2009
Note: This data could be available from 1990 to 2009, not from 1985.

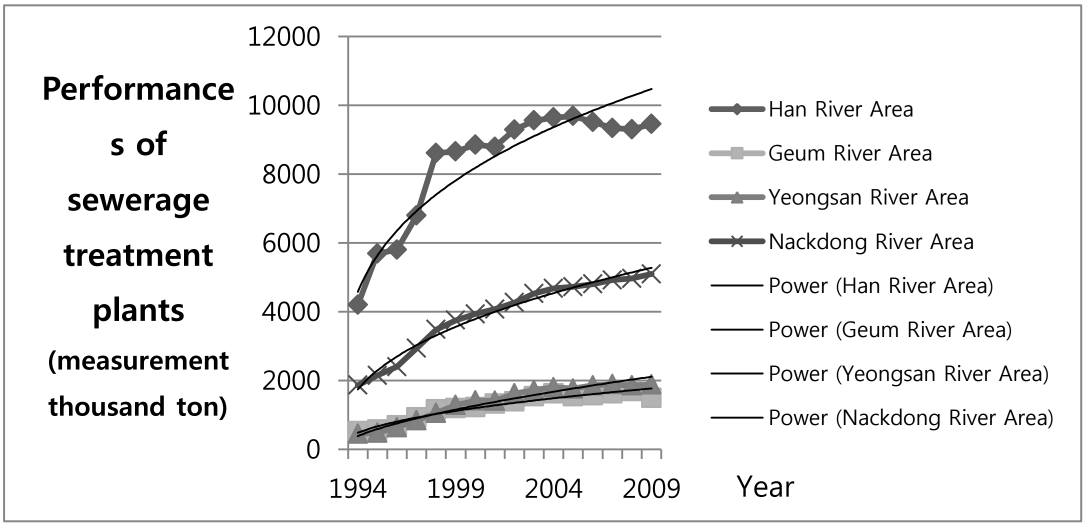


Figure 3.8. Performances of sewerage treatment plants
Source: Statistics Korea from 1994 to 2009
Note: This data could be available from 1994 to 2009, not from 1985.

3.3.1.3. Water usage and water law system

South Korea has tried to sustainably use its water resources for the last few decades. The difficulty of implementing this policy is mainly caused by seasonal and regional rainfall difference, abrupt water emission attributed by steep slides in waterways, and demographic increase in heavily populated metropolitan areas.

This section provides information about how water has been utilized over time and whose entity is charged with providing classified water acts and what kinds of water acts currently exist in South Korea.

According to Kwon (2009, pp.4-6), the water usage over time has been changed by the four assorted categories (See Table 3.1). In Table 3.1., the water usage in 2011 for agricultural purposes indicated the highest proportion (45%) was 15.8 billion m^3, and the water usage in 2011 for residential purposes (23% of total water usage) was 8.1 billion m^3. For instream use, the water usage in 2011 (24%) was 8.3 billion m^3, and the water usage in 2011 for industrial purpose was 3.1 billion m^3 showing the lowest proportion (8%).

The water usage for residential purposes increased from 12% in 1980 to 23% in 2011. This is attributed to the process of urbanization, increasing population, higher income level compared to the past, and the pursuit of cleaner sanitation and healthier bodies. For industrial purposes, the water usage just increased from 5% in 1980 to 8% in 2011, but its actual volume enormously increased as a result of the total usage doubling from 1980 to 2011. In the case of agriculture, the real volume of water usage increased 1.5 times compared to 1980, but its percentage change decreased from 67% in 1980 to 47% in 2011. Instream usage increased from 16% in 1980 to 24% in 2011, implying a continuous increase in interests about clean water environments from the people and the government (Kwon, 2009, pp. 4-6).

Table 3.1. Water usage over time by four classified fields (a unit of billion m^3/year)

	1980	1990	1998	2003	2011
Total usage	15.3	24.9	33.1	33.7	35.5
Residential purposes	1.9 (12%)	4.2 (17%)	7.3 (22%)	7.6 (23%)	8.1 (23%)
Industrial purposes	0.7 (5%)	2.4 (10%)	2.9 (9%)	3 (8%)	3.2 (8%)
Agricultural purposes	10.2 (67%)	14.7 (59%)	15.8 (48%)	16 (47%)	15.8 (45%)
Instream usage	2.5 (16%)	3.6 (14%)	7.1 (21%)	7.5 (22%)	8.3 (24%)

Source: Kwon, 2009, p.6

The Environmental Pollution Prevention Act in 1963was started to deal with air pollution and water pollution caused by light industry as a result of the first Five-Year economic development plan. Since the Heavy and Chemical Industry Policy of the 1970s and 1980s, the economy of South Korea entered into a stage of rapid industrialization and urbanization. However, this resulted in a few serious environmental problems: ⅰ) more fossil fuels were used for industrial and household purposes, causing a dense concentration of nitrogen and sulfur oxides in the air and ⅱ) increases of household and industrial wastes, which increased degradation of both water quality in rivers and lakes and land quality. Against continuous pollution in water, land, and air, there emerged the Environmental Protection Act in 1983, the Framework Act on Environmental Policy in 1990, and the Water Quality Conservation Act in 1991. The Water Quality Conservation Act contains future water management plans: management policy and regulation of industrial waste, water quality conservation in rivers and lakes, and management policy of non-point pollutant sources. This act was revised two times in 2002 and 2006 to establish legal bases for non-point pollutant source management and water quality remote control systems (National Archives & Records Service, 2012).

The water acts in South Korea are assorted by both field and managing entity. Current water acts count up to 85 laws. The field in Table 3.2 is a classifier, and there are three categorized groups (water quantity, water quality, and Disaster). However, water is generally maintained by three managing entities (the federal government, local governments, and public enterprises). The federal government generally establishes a long-range plan, and then local governments and public enterprises are charged with performing the plan. Table 3.2 shows the system in the current water acts classified by field, act, main topic, and administration office (Kwon, 2009, p. 3).

Table 3.2. Water acts by classified fields

Field	Act	Main topic	Administration office
Water quantity	River Act (1961)	Water resource long-range plan	Ministry of Land, Transport and Maritime Affairs
	Dam Act (1970)	Multipurpose dam construction and management	
	Ground water Act (1993)	Groundwater investigation, development and usage	
	Water Supply and Waterworks Installation Act (1961)	Water supply, management and construction	Ministry of Environment
	Management of Drinking Water Act (1995)	Drinking water development	
	Small River Maintenance act (1995)	Small river maintenance	Ministry of Public Administration and Security
	Rearrangement of Agricultural and Fishing Villages Act (1994)	Agricultural and fishing village development	Ministry for Food, Agriculture, Forestry and Fisheries
Water quality	Framework Act on Environmental Policy (1990)	Composite environment plan and environmental standards	Ministry of Environment
	Water Quality Conservation Act (1991)	Water quality measurement standards	
	Water Supply and Waterworks Installation Act (1961)	Water reserve designation and management	
	Sewerage Act (1966)	Termanal disposal plant of sewage installation and maintenance	
	Wastewater Act (1991)	Wastewater maintenance	
	Four River Basins Act (1999)	Water quality improving measurement and standards	
	Management of Drinking Water Act (1995)	Drinking water standards	
Disaster	Countermeasures against Natural Disasters Act (1995)	Disaster restoration and disaster basic plan	Ministry of Public Administration and Security
	Act on the Prevention of and Countermeasures against Agricultural and Fisheries Disasters (1967)	Agricultural or fishery disaster precaution	Ministry for Food, Agriculture, Forestry and Fisheries

Source: Kwon, 2009, p. 3

3.3.2. The major four rivers

The major four rivers in South Korea are respectively chosen as the area of study in this thesis. They are called Han River, Geum River, Yeongsan River, and Nackdong River. As we see in the basic backgrounds, the four-river areas are closely connected with each regional background. They have different trends with respect to population, but show similar growth patterns in trade and GDP (See the Figure 3.9. to 3.11.).

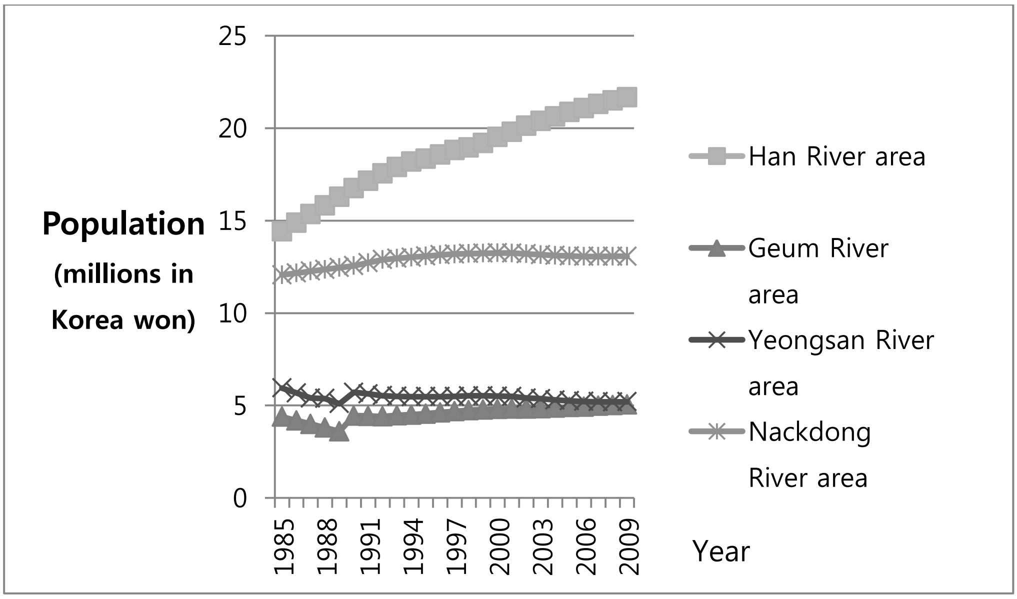


Figure 3.9. Population change over time from 1985 to 2009
Source: Ministry of Environment (1985-2009)

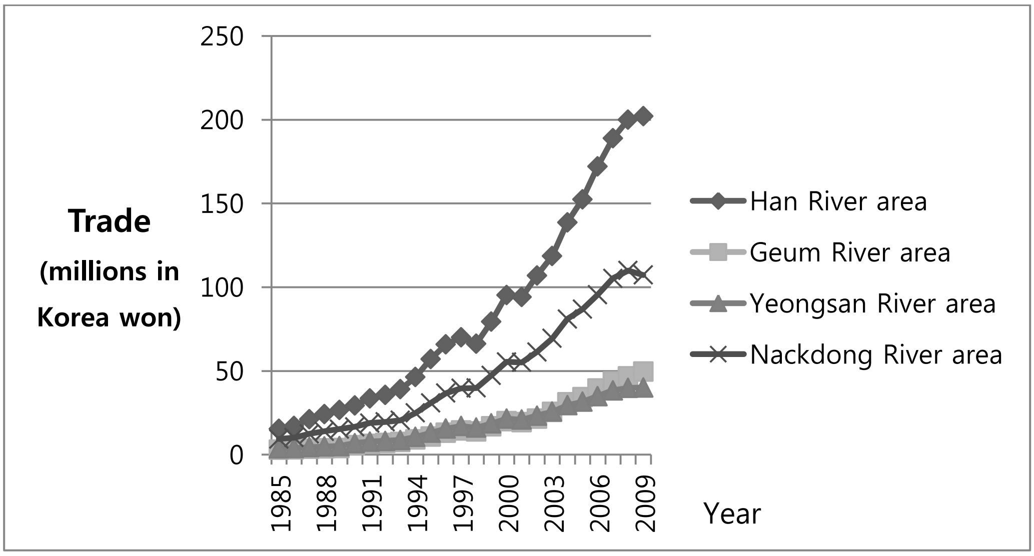


Figure 3.10. Trade change over time from 1985 to 2009
Source: Ministry of Environment (1985-2009)

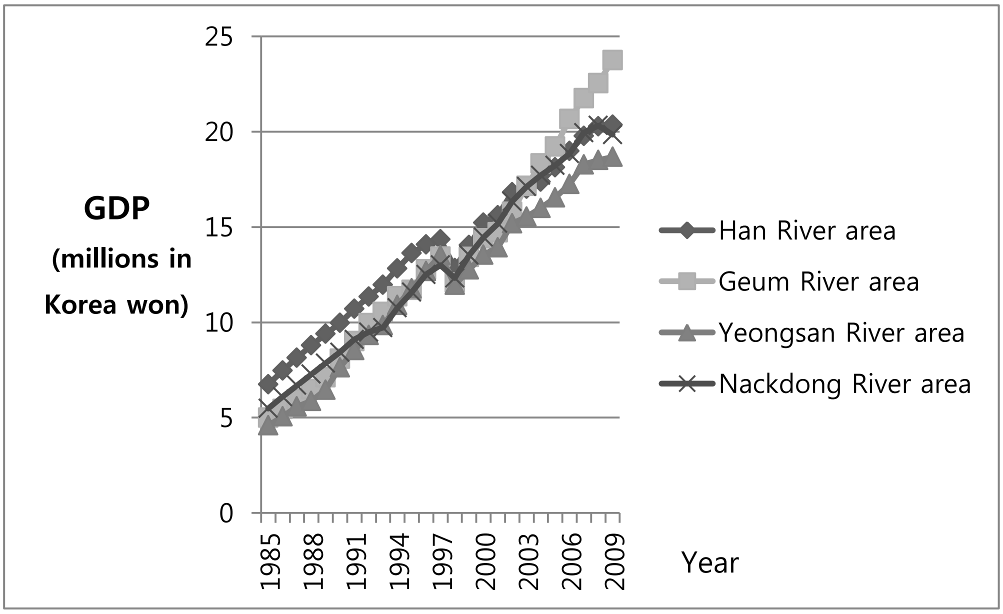


Figure 3.11. GDP change over time from 1985 to 2009
Source: Ministry of Environment (1985-2009)

This section shows the basic information about dams in the four-river areas (see table 3.3. to 3.6.), which places are used for water quality observatories, and try to explain the four rivers with industrialization information. The exact graphical figure (see Figure 3.12.) between the 4 rivers and related cities and provinces is as follows:

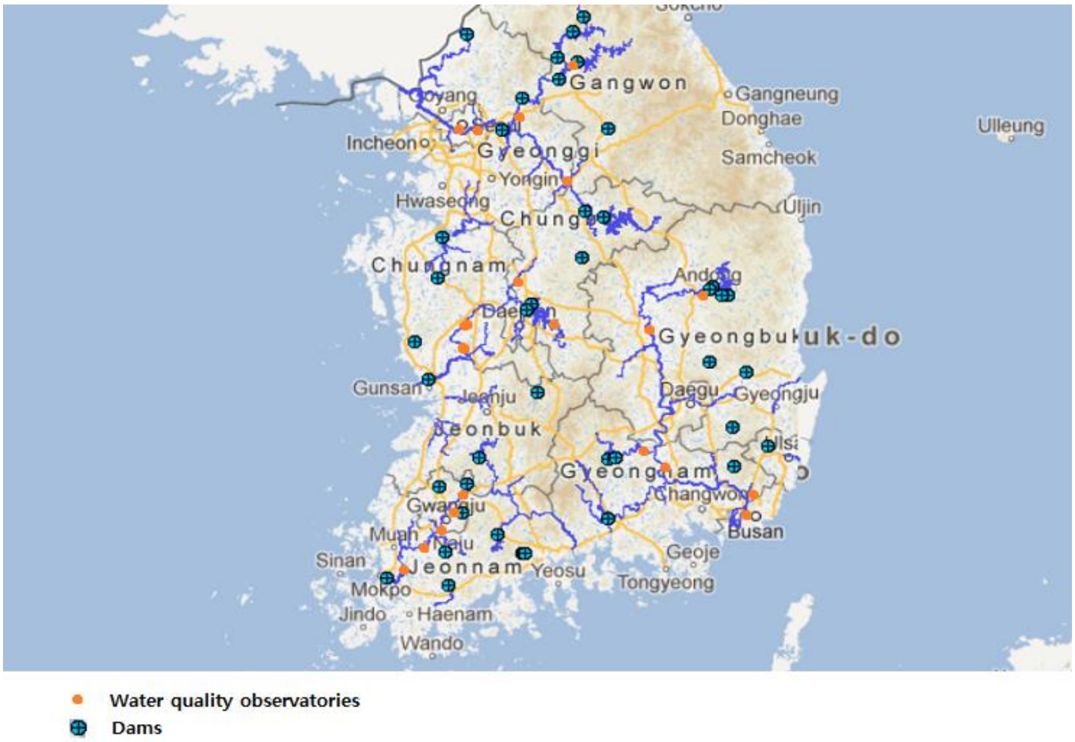


Figure 3.12. The four rivers in South Korea
Source: Ministry of Environment:http://211.114.21.28/weisnew/default.aspx?stationType=WATER&title=WATER

3.3.3. Han River

The Han River is approximately 319 miles long, and passes through the provinces of Gangwon and Gyeonggi, and the capital city, Seoul (see Figure 3.13.). The agriculture activity in this river has decreased during the last 30 years as showing in Figure 3.1. But, the use of water in the river for industrial purpose has changed considerably in the process of industrial development. During the 1970s and 1980s, the city of Seoul’s industries evolved from rubber and textile to the more strategic metal and electronics. But from the middle of 1980s, these industries moved to Incheon, and Gyeonggi province. Government policy has been to regulate industrial growth in Seoul with the Capital Region Rearrangement Plan Law (1984, 1994) and the Small and Medium Sized Industry Promotion Law

(1991). The existing industrial complex in the Seoul since 2000s was replaced with high-tech products related to information technology (IT) (Kim and Gallent, 1997, 1998; Yu and Ji, 1998; Suck, 2008, Water Information System, the Ministry of Environment, 2012).

Figure 3.13. The Han River
Source: Department of Environment, South Korea:
http://211.114.21.28/weisnew/default.aspx?stationType=WATER&title=WATER

Table 3.3. Basic information about dams[13] in Han River

Dam name	Purpose	Height (unit: m)	Length (unit: m)	Altitude (unit: m)	Total reservoir capacity (unit: million m^3)	Annual electricity capacity (unit: millions KWh)
Chunchon Dam	Hydroelectricity	40	453	107	150	145
Soyanggang Dam	Multipurpose	123	530	203	2,900	353
Uiam Dam	Hydroelectricity	23	273	77	80	161
Cheongpyeong Dam	Hydroelectricity	31	407	53	185.5	271
Paldang Dam	Hydroelectricity	29	575	32	244	378
Hoengseong Dam	Multipurpose	48.5	205	184	86.9	5.6

Source: Water Management Information System:
http://www.wamis.go.kr/eng/main.aspx

3.3.4. Geum River

The Geum River passes through the provinces of North Chungcheng and South Chungcheng, and the city of Daejeon (see Figure 3.14). The length of this river is approximately 248 miles long. The South Chungcheong and North Chungcheong provinces have traditionally developed with primary industries like agriculture and livestock since government-led industrial planning policy in 1960s. The city of Daejeon (the nation's fifth largest metropolis) has developed a large industrial complex with metal, chemical, petroleum, and electronics industries and the Daedeok Science Town. Since the 1990s, Cheonan and Asan in the province of South Chungcheong have semiconductors and precision parts industries (Kim and Gallent, 1997, 1998; Yu and Ji, 1998; Suck, 2008, Water Information System, the Ministry of Environment, 2012).

[13] International Commission on Large Dams (ICOLD) defines large dams as higher than 15 meters and major dams as over 150 meters in height.

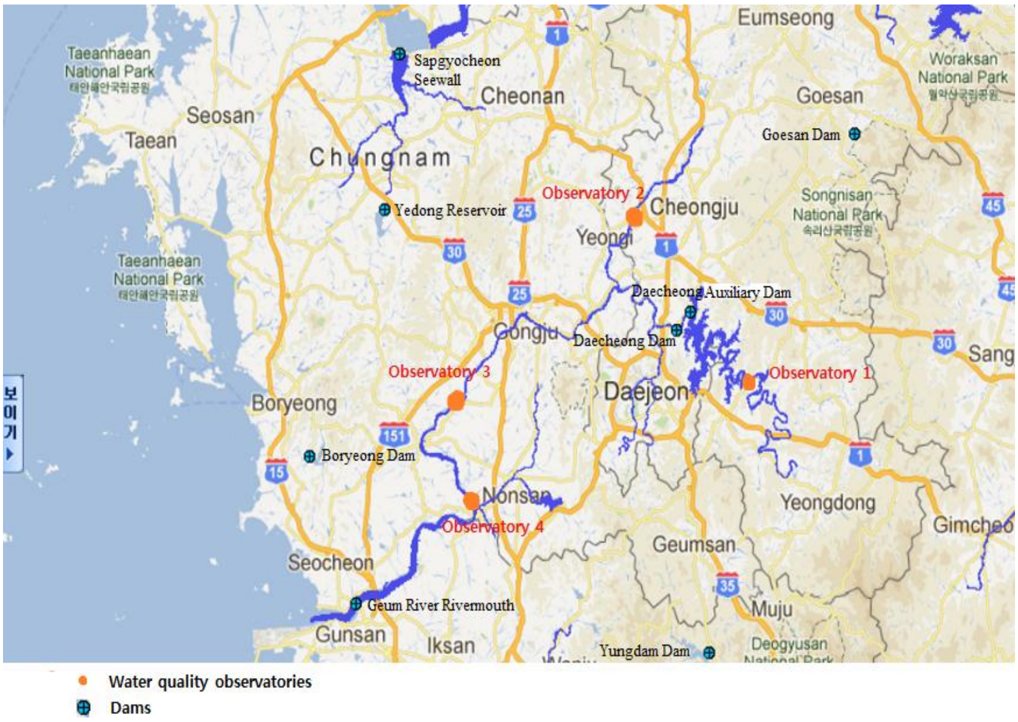


Figure 3.14. The Geum River
Source: Department of Environment, South Korea:
http://211.114.21.28/weisnew/default.aspx?stationType=WATER&title=WATER

Table 3.4. Basic information about dams in Geum River

Dam name	Purpose	Height (unit: m)	Length (unit: m)	Altitude (unit: m)	Total reservoir capacity (unit: million m^3)	Annual electricity capacity (unit: millions KWh)
Goesan Dam	Hydroelectricity	28	171	137.7	15.3	10.8
Daecheong Dam	Multipurpose	72	495	83	1,490	240
Yungdam Dam	Multipurpose	70	498	268.5	815	198.5
Boryeong Dam	Multipurpose	50	291	79	116.9	5.7

Source: Water Management Information System:
http://www.wamis.go.kr/eng/main.aspx

3.3.5. Yeongsan River

The Yeongsan River is about 72 miles long, and passes through the provinces of North Jeolla and South Jeolla, and the city of Gwangju (see Figure 3.15.). The North Jeolla and South Jeolla provinces have had traditional industries (agriculture and livestock) since the initial economic development plan in 1962. However, the

Second Five-Year Economic Development Plan (1967-1971) provided a good chance for the city of Yosu in the province of South Jeolla to be the center of a petrochemical industry. Through the 1970s, the government developed a steel industry at Kwangyong in the South Jeolla province. The city of Gwangju (the sixth largest metropolis in South Korea) has metal, chemical, semiconductors, precision parts, and heavy industries. Gwangyong became a center of making value-added ships, and Jeonju in North Jeolla province has progressed with automobile manufacturing with the successful of the Hyundai carmaker (Kim and Gallent, 1997, 1998; Yu and Ji, 1998; Suck, 2008, Water Information System, the Ministry of Environment, 2012).

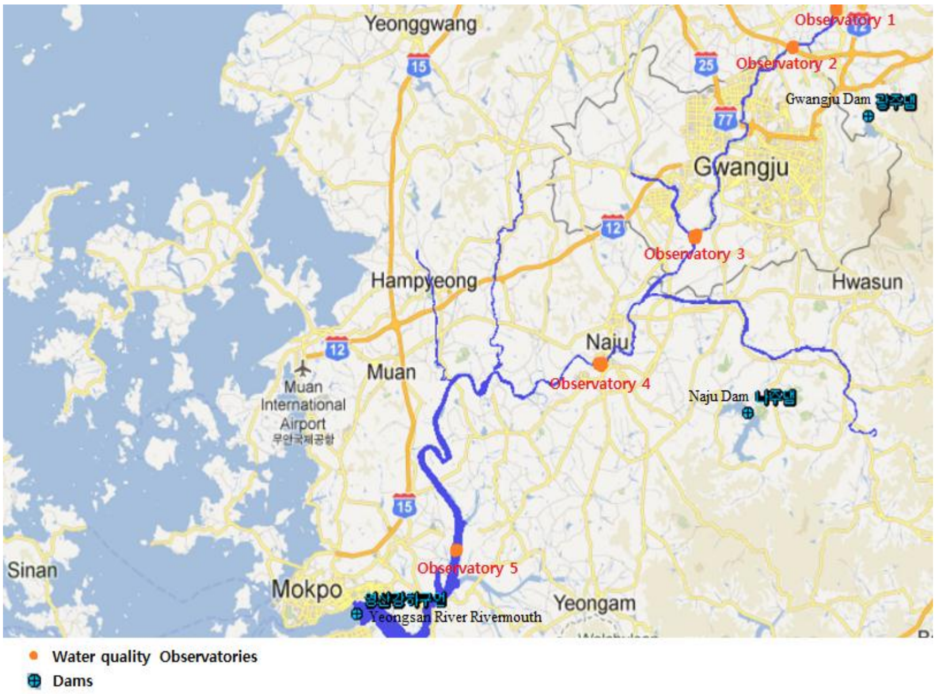


Figure 3.15. The Yeongsan River
Source: Department of Environment, South Korea: http://211.114.21.28/weisnew/default.aspx?stationType=WATER&title=WATER

Table 3.5. Basic information about dams in Yeongsan River

Dam name	Purpose	Height (unit: m)	Length (unit: m)	Altitude (unit: m)	Total reservoir capacity (unit: million m^3)	Annual electricity capacity (unit: millions KWh)
Gwangju Dam	Only agriculture	N/A	N/A	N/A	N/A	N/A
Naju Dam	Only agriculture	N/A	N/A	N/A	N/A	N/A

Source: Water Management Information System:
http://www.wamis.go.kr/eng/main.aspx
Note: N/A means ‘not available’ in the information system.

3.3.6. Nackdong River

The Nakdong River (see Figure 3.16.) passes through the provinces of North Gyeongsang and South Gyeongsang, and the city of Daegu. It is approximately 314 miles long. Like the Han River, the agriculture activity in this river has decreased, but the industrial activity has noticeably increased during the last 30 years. The first and second Five-Year Economic Development Plan from 1962 to 1971 provided important opportunities of regional economic growth at Ulsan as the center of a petrochemical industry; at Daegu and Kumi as hubs of textile and dye industries;, and at Busan as an important port city and export , import, and transportation center. Through the 1970s to 1980s, the government expanded the existing industrial parks in Ulsan and Daegu as well as new industrial parks in the provinces of North Gyeongsang and South Gyeongsang: at Ulsan for automobile, shipbuilding, and petrochemical industries, at Pohang for steel industry; in Kumi for electronics; and at Changwon for machinery. These industrial trends started to change in the mid-1990s: at Daegu for medical equipment and precision machinery industries; at Pohang for value-added ship industry; at Kumi for semiconductors and cell phones;, and at Changwon for precision machinery industry (Kim and

Gallent, 1997, 1998; Yu and Ji, 1998; Suck, 2008, Water Information System, the Ministry of Environment, 2012).

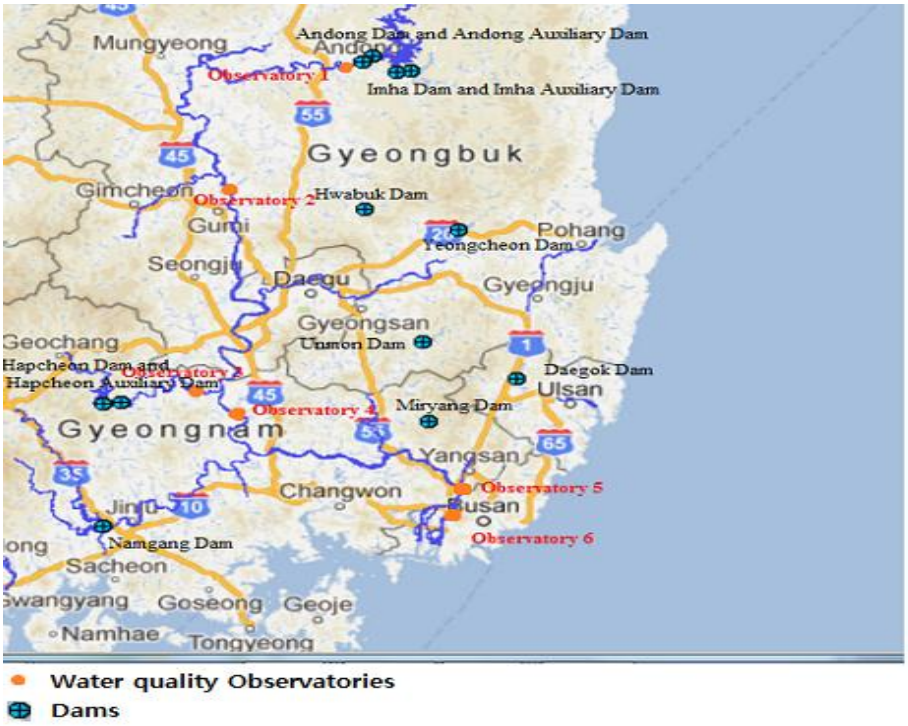


Figure 3.16. The Nackdong River
Source: Department of Environment, South Korea: http://211.114.21.28/weisnew/default.aspx?stationType=WATER&title=WATER

Table 3.6. Basic information about dams in Nackdong River

Dam name	Purpose	Height (unit: m)	Length (unit: m)	Altitude (unit: m)	Total reservoir capacity (unit: million m^3)	Annual electricity capacity (unit: millions KWh)
Andong Dam	Multipurpose	83	612	166	1,248	89
Imha Dam	Multipurpose	73	515	168	595	96.7
Yeongcheon Dam	Water supply for residence	42	960	162	162.2	N/A
Unmon Dam	Water supply for residence	55	407	155	160	N/A
Daegok Dam	Water supply for residence	52	190	126	36.2	N/A
Miryang Dam	Multipurpose	89	535	212.5	73.6	70
Hapcheon Dam	Multipurpose	96	472	181	790	232.4
Namgang Dam	Multipurpose	34	1,126	51	309.2	41.3

Source: Water Management Information System:

http://www.wamis.go.kr/eng/main.aspx

3.4. Data

3.4.1. Water quality indicators

Water quality indicators (BOD and COD) are monitored through the measuring network installation program in the Water Quality Conservation Act; also, measurements of BOD and COD are taken along rivers at specific points that are least affected by the deviation of water flow, water quantity, temperature, and pH.

3.4.1.1. Biological Oxygen Demand (BOD)

BOD measured by a unit of mg/L generally investigates organic pollution in water through the amount of oxygen consumed by microorganisms while consuming organic compounds for food. Higher amount of BOD shows worse water quality (Borglin et al., 1951; Boyles, 1997; Butkus and Manous, 2005).

3.4.1.2. Chemical Oxygen Demand (COD)

COD measured by a unit of mg/L tests the content of all chemicals present in the water that are be able to be oxidized by the strong oxidizing agent, a combination of potassium dichromate with sulfuric. This indicator is not affected by toxic substances, thereby mainly is applied to measure industrial wastewater. Higher amount of COD means worse water quality (Boyles, 1997; Pisarevsky, 2003).

3.4.2. Economic indicators

3.4.2.1. Population

Population is measured in millions of persons around the regions (provinces and major cities) along each of the 4 rivers.

3.4.2.2. Trade

The national trade volume indices of export and import collected from the United Nations Conference on Trade and Development (UNCTAD) is used with industrial index which is a proportion of regional GDP to national GDP. Each regional trade volume indices with industrial index represents regional trade volume indices for the 4 rivers.

3.4.2.3. GDP

The regional GDP per capita is measured in millions of constant 2005 Korea won and starts with units of million.

3.4.3. Data specification

The data of two water pollutants (COD and BOD) and three economic indicators (GDP, trade and population) are used from 1985 to 2009 from South Korea's four rivers (Han River, Geum River, Yeongsan River, and Nakdong River). To reveal whether the hypothesis 1 and 2 (see section 3.2) are statistically significant, basic statistics of the four rivers were described in Table 3.8 to 3.11, respectively and pooled data in the four rivers is also depicted in Table 3.7: the tables summarize variables, observations, mean, standard deviation, minimum and maximum. All the original data are from the database of Statistics Korea and Ministry of Environment (excluding trade data which comes from UNCTAD). COD and BOD are measured by a unit of mg/L, and population, trade and GDP start with units of million. (Appendix A describes the changes of each variable.)

Table 3.7. Statistic description of variables about pooled data in the four rivers

Variable	Observation	Mean	Std. Dev.	Min.	Max.
COD	500	4.79360	2.19413	0.90000	15.70000
BOD	500	3.11160	2.18599	0.60000	21.10000
Population	500	10.79911	5.71924	3.60003	21.66891
Trade	500	43.36473	44.67213	3.12632	202.18738
GDP	500	12.96523	4.66406	4.59303	23.74561

Source: Ministry of Environment (1985-2009)

Table 3.8. Statistic description of variables in Han River

Variable	Observation	Mean	Std. Dev.	Min.	Max.
COD	125	3.75760	1.96655	0.90000	11.60000
BOD	125	2.50240	2.12540	0.60000	14.60000
Population	125	18.60283	2.11664	14.41837	21.66891
Trade	125	83.93109	59.80113	15.46653	202.18738
GDP	125	13.83320	4.04723	6.73681	20.36190

Source: Ministry of Environment (1985-2009)

Table 3.9. Statistic description of variables in Geum River

Variable	Observation	Mean	Std. Dev.	Min.	Max.
COD	100	4.29400	1.70802	1.30000	8.30000
BOD	100	2.62500	1.11386	0.90000	6.90000
Population	100	4.58640	0.37016	3.60003	5.04924
Trade	100	18.22554	14.52072	3.12632	49.60462
GDP	100	13.22630	5.49097	4.99960	23.74561

Source: Ministry of Environment (1985-2009)

Table 3.10. Statistic description of variables in Yeongsan River

Variable	Observation	Mean	Std. Dev.	Min.	Max.
COD	125	5.05520	1.98061	1.10000	9.80000
BOD	125	3.19520	1.74452	0.80000	9.10000
Population	125	5.43863	0.18685	5.09892	5.94877
Trade	125	18.08576	11.90042	3.89175	40.19329
GDP	125	11.99979	4.39554	4.59303	18.67846

Source: Ministry of Environment (1985-2009)

Table 3.11. Statistic description of variables in Nakdong River

Variable	Observation	Mean	Std. Dev.	Min.	Max.
COD	150	5.48933	2.28686	1.20000	15.70000
BOD	150	3.33933	2.67188	0.70000	21.10000
Population	150	12.90487	0.36357	12.06498	13.25258
Trade	150	47.38471	33.04656	9.42026	110.05040
GDP	150	12.87240	4.65188	5.48174	20.32094

Source: Ministry of Environment (1985-2009)

Table 3.7. describes summary statistics for pooled data. The mean COD and BOD of the 4 river areas during 1985-2009 was 4.79 and 3.11, respectively. The mean COD and BOD in the Table 3.10. (Yeongsan River) and 3.11. (Nakodng River) are relatively higher than the mean value in the table 3.7., implying that Yeongsan River and Nakdong River might be more seriously contaminated. The Han River area in table 3.8. has the highest mean in population, trade, and GDP, but it has less polluted values of COD and BOD rather than other areas. It suggests that eco-friendly actions from residents, local firms, and municipality might have been performed in this river over time. Standard deviations in the tables are overall low in all variables excluding trade, indicating the homogeneous nature about the 4 rivers.

3.5. Estimation procedures

An econometric technique, the Generalized Method of Moment (GMM), was initially used to consider the region-specific effects and the dynamic adjustment of pollution emissions. This method, however, generally requires exact or over identification between instruments and explanatory variables: e.g., if the number of instruments (m) and the number of endogenous regressors (k) are equal, exactly identified. If m is greater or less than k, overidentified or underidentified, respectively. The problem of choosing inappropriate instruments could eventually cause poor prediction in these empirical models, and then found alternative way, time-series analysis (Hansen, 1982; Hansen and Singleton, 1982; Arellano and Bond, 1991; Lee et al., 2010).

The second alternative was ordinary regression analysis with time series data. This method had critical reviews when this thesis was reported to committee because the ordinary regression residuals with time series data are usually correlated over time. Specifically speaking, this implies three problems: ⅰ) significance of parameters for predicted values are not correct, ⅱ) less efficiency due to correlated residuals, and ⅲ) no accuracy to predict future estimated values (Pindyck and Rubinfeld, 1997; Wooldridge, 2003; Stock and Watson, 2010).

Finally, one- and two-way Fixed-effects and Random-effects models with a robust standard error were respectively investigated with the two hypotheses Also, two additional research were performed: ⅰ) as distinguishing upstream sections and downstream sections along each river, revealing the more exact effects of pollution on economic growth, and ⅱ) investigating not regional, but national relationship between water pollution and economic activity, regarding the four rivers as one river. The Breush-Pagan test (to check homoscedasticity), Durbin-Watson test (for confirming serial correlation), and F-statistic (for deciding proper econometric technique among Random-effects and Fixed-effects techniques) as well as all of the results of panal analysis were described in chapter 4.

CHAPTER 4. RESULTS

Chapter Ⅳ shows the three results concerning: ⅰ) the national relationships between water pollution and economic activity, using hypothesis 1 and 2, ⅱ) the regional relationships of water pollution and economic activity along each of the four rivers in the case of hypothesis 1 and 2, and ⅲ) distinguishing the upstream sections and downstream sections along each river as well as the pooled data.

4.1. The national relationships between water pollution and economic activity, using hypothesis 1 and 2

Finding the country's level of relations between water pollution and economic growth begins with estimating the pooled data of Han River area, Geum River area, Yeongsan River area, and Nackdong River area with the Fixed-effects model (tested with F Statistic to reject no Fixed-effects). Given that the small sample covers 4 rivers and the period of 1985-2009, there might have been econometric problems like heteroskedasticity and serial correlation. The Breusch-Pagan tests for heteroskedasticity reject the null hypothesis of homoscedasticity in Table 4.1 and 4.3. The Durbin-Watson tests for serial correlation in Table 4.1. and 4.3. are under 2, suggesting positive serial correlation. To correct these econometric problems, the Fixed-effects model with a robust standard error was used (the robust standard error obtained from the asymptotic covariance matrix is considered to be more robust and can deal with problems about failure to meet classical assumptions, such as normality, homoscedasticity, and no serial correlation) (Jayanthakumaran and Liu, 2012).

The empirical results for hypothesis 1 are summarized in Table 4.1. The table shows that the relationship between BOD or COD and trade, population, and GDP is mixed. From the result, the three explanatory variables (trade, population, and GDP) do not show statistically significant at even the level of 10% when combined in empirical models. This leads to a question about the probability of multicollinearity among the three explanatory variables.

To check correlation of all variables, multicollinearity diagnosis on the pooled data was performed. According to Table 4.2., regressors for trade, GDP, and population might have high multicollinearity: Correlation coefficient (CC) between 0.9 and 1.00 – Very high correlation, CC between 0.7 and 0.89 – High correlation, CC between 0.4 and 0.69 – Moderate correlation, CC between 0.00 and 0.39 – Low, quite small correlation, (Wooldridge, 2003). The correlation coefficients between GDP or population and trade are 0.6898 or 0.6996, respectively which are significant with p-values less than 0.001. These indicate some strong positive linear relationships between these variables.

Table 4.1. Estimation results of the Fixed-effects regression about the national relationships in hypothesis 1

Regressors	BOD	COD
Population	-0.05196 (0.7306)	0.10212 (0.3748)
Trade	-0.00788 (0.0814)*	-0.01553 (0.000)***
GDP	0.02378 (0.7461)	0.18896 (0.0090)***
GDP^2	-0.0018 (0.5025)	-0.00044725 (0.8725)
Constant	2.99826 (0.2420)	-0.68967 (0.7153)
R^2	0.5937	0.6786
F Statistic	32.87 (0.000)***	47.20 (0.000)***
No. of Obs.	500	500
B-P Test	16.60 (0.0023) ***	27.48 (0.0001)***
D-W Test	1.097	1.245
Turning point	N/A	N/A
Shape of curve	N/A	N/A

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

Table 4.2. Correlation of regressors on the pooled data

Pearson Correlation Coefficients					
The pooled data with the four rivers					
	BOD	COD	GDP	Trade	Population
BOD					
COD	0.74332 (0.000)				
GDP	-0.19858 (0.000)	0.15786 (0.0004)			
Trade	-0.23952 (0.000)	-0.0490 (0.2738)	0.68987 (0.000)		
Population	-0.14343 (0.0013)	-0.13227 (0.0030)	0.19947 (0.000)	0.69967 (0.000)	

Any time a given change in one variable occurs, the corresponding observations on its highly correlated partners are to change in predictably similar fashions. Thus the presence of multicollinearity implies that there will be very little data to confidently make the regressing results accurate.

Instrumental variable estimation is one method to correct multicollinearity, but it generally has two potential problems: when instruments are correlated with error term, instrumental variable estimates are inconsistent, and another problem is that weak instruments (when the number of instruments is less than the number of endogenous variables) are not likely to have much success in predicting the ultimate outcome. However, confirming EKC is necessary to have GDP variable in empirical models, and finding appropriate instrumental variables instead of trade and population variables is not easy in the case of hypothesis 1.

Therefore, these two endogenous variables (population and trade), which are showing high correlation relationship with GDP, were removed from empirical model 1 (hypothesis 1), and empirical model 2 (hypothesis 2) shows relations between GDP and COD or BOD in Table 4.3. Researchers (De Bruyn, 1997; Galeotti and Lanza, 1999; Canas et al., 2003; Liu et al., 2007; Diao et al., 2009; Yoshiaki, 2009; Zhao et al., 2009) use just GDP and GDP squared model for proving EKC in their research. Table 4.3. shows coefficients of regressors, R^2, F statistics, numbers of observation, Breush-Pagan tests, Durbin-Watson tests, turning points, and shapes of curve.

Table 4.3. Estimation results of the Fixed-effects regression about the national relationships in hypothesis 2

Regressors	BOD	COD
GDP	0.05149 (0.5080)	0.26221 (0.0006)***
GDP^2	-0.00496 (0.0659)**	-0.00634 (0.0222)**
Constant	1.63709 (0.0027)***	0.11681 (0.8167)
R^2	0.5852	0.6654
F Statistic	32.92 (0.000)***	47.91 (0.000)***
No. of Obs.	500	500
B-P Test	11.89 (0.0026) ***	18.30 (0.0001)***
D-W Test	1.109	1.2409
Turning point	5.19 (estimated)	20.679 (estimated)
Shape of curve	Decreasing right-half of inverted U	Increasing left-half of inverted U

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

The empirical results about the national relationship between water pollution and economic activity are summarized in Table 4.3. The table shows the relationship between BOD or COD and GDP. The coefficient of the explanatory variable (GDP) in the BOD is not statistically significant at even 10%, but the coefficients of the other explanatory variables all are statistically significant at 10%. Models in the pooled data are fit in terms of R^2 values (0.5852 and 0.6654).

From the pooled data in Figure 4.1., it is possible to conclude that the EKC might exist in the relations between BOD or COD and GDP. The BOD model shows a decreasing right-half of an inverted U-shape and the COD depicts increasing a left-half of an inverted U-shape. The estimates of inverted U-curve turning points of BOD and COD in each river cannot be used for comparison of the turning points in the pooled data (see Table 4.6). Figure A.9. in Appendix A shows the GDP per capita from 1970 to 2009, and showes logical bases for the turning points of the BOD and COD in Figure 4.1. According to Figure A.9., South Korea reached the level of about 5 million won in GDP in the early 1990s. BOD changes in Figure 4.1 matches the patterns of each river regarding water pollution regulations in 1990, national decrease in agriculture land, and decreasing household waste in Figure 3.1. to 3.8. The COD values in Figure 4.1. seem to be constant between the interval of about 17.5 to 21 million GDP, and are consistent to the trend of industrial restructuring in South Korea toward higher value-added industries during the mid-1990s and the early 2000s.

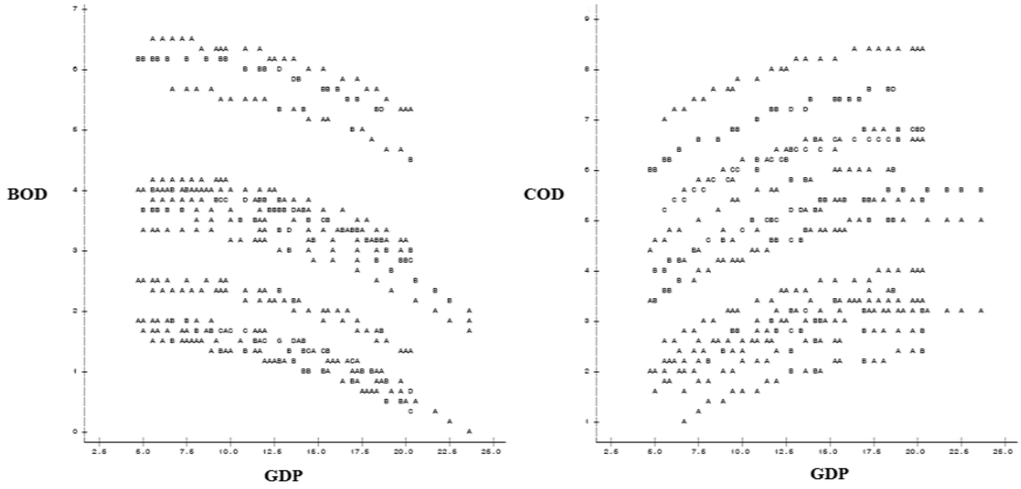


Figure 4.1. Estimation figures in the pooled data about BOD and COD

4.2. The regional relationships of water pollution and economic activity along each river in the case of hypothesis 1 and 2

Estimating hypothesis 1 and 2 in terms of each river starts with the Fixed-effects model with a robust standard error, because the Breusch-Pagan tests for heteroskedasticity in the Han River and Nackdong River reject the null hypothesis of homoscedasticity, and the Durbin-Watson tests show serial correlation in Table 4.4. and 4.6.

The empirical results for hypothesis 1 are summarized in Table 4.4. The table shows the three explanatory variables (trade, population, and GDP) do not show statistically significant at even the level of 10% when combined in empirical models. This again leads to the problem of multicollinearity among the three explanatory variables.

According to Table 4.5., regressors for trade, GDP, and population might have severe multicollinearity. The correlation coefficients between trade and GDP along the four rivers have high or very high correlation, and the correlation coefficients between trade or GDP and population indicate moderate or high correlation along the four rivers.

Table 4.4. Estimation results of the Fixed-effects regression about the regional relationships in hypothesis 1

	BOD				COD			
Regressors	Han River	Geum River	Yeongsan River	Nackdong River	Han River	Geum River	Yeongsan River	Nackdong River
Population	-1.36505 (0.01030)**	0.06894 (0.2106)	-0.53469 (0.1328)	-0.85078 (0.7597)	-0.32268 (0.5054)	0.49427 (0.000)***	-0.69928 (0.3848)	1.52472 (0.5099)
Trade	0.01254 (0.5435)	-0.26515 (0.1294)	-0.06621 (0.3171)	0.00528 (0.9156)	0.00497 (0.7503)	-0.05518 (0.8352)	0.11537 (0.2881)	0.00770 (0.8646)
GDP	0.89861 (0.3217)	0.04492 (0.000)***	0.16352 (0.1240)	0.28007 (0.7912)	0.03587 (0.9605)	0.32003 (0.000)***	0.89102 (0.000)***	-0.12348 (0.8915)
GDP^2	-0.01829 (0.5870)	0.0220 (0.000)***	-0.0000767 (0.9943)	-0.01695 (0.6948)	0.00261 (0.9174)	0.00077 (0.000)***	-0.04677 (0.0114)**	0.000076 (0.9983)
Constant	17.02805 (0.000) ****	0.65089 (0.2867)	3.63582 (0.0960)*	12.63307 (0.6636)	6.97529 (0.0564)*	-3.00142 (0.0006)***	1.65533 (0.7284)	-13.88414 (0.5628)
R^2	0.6890	0.6220	0.7844	0.3679	0.7912	0.8812	0.5715	0.4332
F Statistic	55.84 (0.000)***	42.88 (0.000)***	103.58 (0.000)***	17.10 (0.000) ***	108.28 (0.000)***	84.71 (0.000)***	30.18 (0.000)***	40.36 (0.000)***
No. of Obs.	125	100	125	150	125	100	125	150
B-P Test	20.81 (0.0003)***	5.30 (0.2579)	4.56 (0.3352)	8.80 (0.0664) *	15.59 (0.0036)***	10.01 (0.0403)**	6.14 (0.1887)	14.48 (0.0059) ****
D-W Test	1.0874	1.8286	1.2692	0.9758	1.1454	1.2585	1.5460	1.0697
Turning point	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shape of curve	Decreasing W	N/A	N/A	N/A	N/A	Increasing linear	N/A	N/A

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

Table 4.5. Correlation of regressors in Han River, Geum River, Yeongsan River, or Nackdong River

Pearson Correlation Coefficients								
	Han River				Geum River			
	BOD	COD	GDP	Trade	BOD	COD	GDP	Trade
BOD								
COD	0.8777 (0.000)				0.4275 (0.000)			
GDP	-0.255 (0.004)	0.0229 (0.799)			-0.072 (0.472)	0.733 (0.000)		
Trade	-0.218 (0.014)	0.0492 (0.585)	0.9568 (0.000)		-0.121 (0.229)	0.690 (0.000)	0.974 (0.000)	
Population	-0.275 (0.001)	0.0089 (0.920)	0.9890 (0.000)	0.921 (0.000)	-0.051 (0.611)	0.6718 (0.000)	0.856 (0.000)	0.7969 (0.000)
	Yeongsan River				Nackdong River			
	BOD	COD	GDP	Trade	BOD	COD	GDP	Trade
BOD								
COD	0.6756 (0.000)				0.7100 (0.000)			
GDP	0.0078(0 .930)	0.2673 (0.002)			-0.310 (0.000)	0.0459 (0.576)		
Trade	-0.023 (0.797)	0.2061 (0.021)	0.961 (0.000)		-0.308 (0.000)	0.0190 (0.817)	0.9752 (0.000)	
Population	-0.013 (0.879)	-0.151 (0.090)	-0.606 (0.000)	-0.643 (0.000)	-0.219 (0.006)	0.1221 (0.136)	0.7611 (0.000)	0.6129 (0.000)

For both pollutants (BOD and COD) in Table 4.6, all coefficients of GDP and GDP^2 are statistically significant at10%, but not the coefficient of GDP in the Han River. Models in the four rivers are fit in terms of R^2 values (0.4384 to 0.8782). There are the estimates of an inverted-U curve turning point of BOD at 11.796 through 12.696 (million won) and that of COD at 13.805 through 14.076(million won), and all four rivers already passed at the pollution peak points between 1994 and 1998.

Table 4.6. Estimation results of the Fixed-effects regression about the regional relationships in hypothesis 2

	BOD				COD			
Regressors	Han River	Geum River	Yeongsan River	Nackdong River	Han River	Geum River	Yeongsan River	Nackdong River
GDP	-0.13420 (0.0010)***	0.13966 (0.0366)**	0.24678 (0.0121)**	-0.17809 (0.000)***	-0.33808 (0.1155)	0.40347 (0.000)***	0.69620 (0.000)***	0.43930 (0.0101)**
GDP^2	N/A	-0.00550 (0.0258)**	-0.01046 (0.0150)**	N/A	0.01267 (0.0757)*	-0.00624 (0.0077)***	-0.02473 (0.0005)***	-0.01591 (0.0081)***
Constant	3.1764(0.000)***	0.52693 (0.1692)	0.22613 (0.6448)	3.39241 (0.000)***	4.47336 (0.0034)***	-1.40625 (0.0009)***	-1.31987 (0.0846)*	0.29848 (0.7842)
R^2	0.6641	0.5552	0.7810	0.4384	0.7906	0.8782	0.5650	0.5970
F Statistic	53.03 (0.000)***	37.23 (0.000)***	103.70 (0.000)***	17.43 (0.000)***	109.82 (0.000)***	84.39 (0.000)***	30.24 (0.000)***	40.76 (0.000)***
No. of Obs.	125	100	125	150	125	100	125	150
B-P Test (p-values)	10.09 (0.000)***	2.60 (0.2720)	4.10 (0.1290)	7.66 (0.0217)**	14.30 (0.0008)***	7.09 (0.0289)**	1.81 (0.4038)	13.31 (0.0013)***
D-W Test	1.0461	1.4863	1.263	1.114	1.1459	1.5398	1.540	1.114
Turning point	N/A	12.696	11.796	N/A	13.341	N/A	14.07602	13.805
Shape of curve	Decreasing line	Inverted U	Inverted U	Decreasing line	Weak U	Increasing left-half of inverted U	Inverted U	Inverted U

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

An inverted-U shape does not exist in the relationship between BOD or COD and GDP in the Han River. The industrial growth regulations of the 1980's in Seoul and of the 1990's in the Gyeonggi province (1990s) with the Capital Region Rearrangement Plan Law and the Small and Medium Sized Industry Promotion Law have dispersed pollution generating companies to be out of the Han River.

Decentralization, factory relocating regulations, increasing environmental awareness from the residents over time, and enlarging wealth increased the desire for clean and agreeable water in the environment, thereby COD (indicator of industrial water pollution) had been decreased in Figure 4.2. However, the increasing COD trends have existed since 2000, which might be attributed to deregulation of the limited development district in 2002 through relaxation of the Greenbelt Law[14] in the Han River area.

The BOD is a result of organic pollution, and it is attributed to the extent of use of agriculture chemicals & fertilizers, livestock excretion, as well as household waste. The BOD in Figure 4.2 has decreased over time; this is because the Han River area consists of a low proportion of arable hectares with decreasing trend over time, meaning a low level of agricultural chemicals is emitted and less fertilizer is used (see Figures 3.1 to 3.3). The livestock excretion in the Han River area was high in 1985 and increased little by 1992. Since 1992, the trend of livestock production has been constant. The government has been transforming livestock excretion into eco-friendly resources since the 1990s, and its rate of success ranges from 80% in1990 to 90% in 2009 (see Figures 3.4 to 3.6). The livestock excretion was just discarded less than 7% to seas and less than 10% to rivers or lakes through the sewage treatment plants (Ministry for Food, Agriculture, Forestry and Fisheries, 2009). There exist another reasonable base of decrease of the BOD in Figure 4.2; decrease of the household waste over time in the Han River

[14]The Greenbelt Law is a policy and land use regulation to maintain the city of Seoul and the Gyeonggi province as limited development districts, (Kim and Gallent, 1998, 2010).

in Figure 3.7 similarly matches decrease of the BOD in Figure 4.2.

In the Han River, the COD shows a negative and significant relationship with the growth of the GDP before the lowest point but a positive and significant relationship with the growth of GDP after the turning point. The BOD remains decreasing line with increase of GDP. Mathematically, the exact GDP effect ($\frac{\partial Water\ pollution}{\partial GDP}$) is 2*a*X + b (a: the coefficient of the GDP^2, X: a value of GDP, and b: the coefficient of the GDP). The exact amount of GDP effect varies depending on a value of GDP, and its effect cannot be calculated in the case of BOD in the Han River.

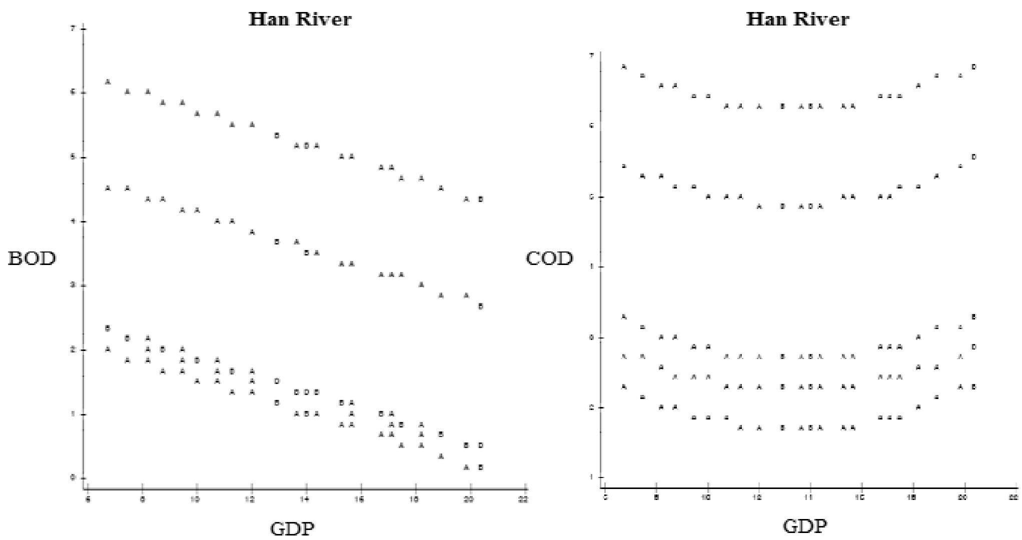


Figure 4.2. Estimation figures in the Han River about BOD and COD

For the Geum River in Figure 4.3, EKC exists in the relations between BOD and GDP, and it might exist in the relations between COD and GDP. The BOD shows a positive or negative and significant relationship with the growth of GDP before or after the turning point, but the COD depicts a positive and significant relationship with the increase of GDP all the time.

Decentralization and factory establishment regulations in the city of Seoul and the Gyeonggi province in the 1980s to the 1990s provided an opportunity to the city of Daejeon and the Chungcheong province as industrial development hubs since the 1990s. Such a trend is shown in Figure 4.3 of the COD. Industrial water pollution has increased over time in the Geum River, and it is possible to guess when this river will be able to get a turning point (a starting point of increase of income, but decrease of industrial water pollution) according to EKC theory. To maintain successful EKC, these districts might need stricter pollution regulation and higher interests about industrial water pollution from the local residents as well as the local governments.

The Geum River area has had large hectares of agriculture land with a gentle slope in decreasing arable hectares and increasing livestock production over time. The organic water pollution might have been increased until the early 1990s, which is when this thesis considers the slow decreasing rate of agriculture hectares with high increasing rate of agriculture chemicals (fertilizers are unclear) (see Figures 3.1 to 3.3); however, increasing stricter water pollution regulations about chemical complexity since the Water Quality Conservation Act in 1991 and policy of transforming livestock excretion into eco-friendly resources in 1992 as well as decreasing household waste might have had a positive impact on the decrease of organic pollution.

Like the Han River case, the GDP effect ($\frac{\partial Water\ pollution}{\partial GDP}$) in the BOD indicates 2*a*X + b, and it changes according to a value of GDP; on the other hand, there exists an estimated value of COD through the calculated equation, not an actual future value.

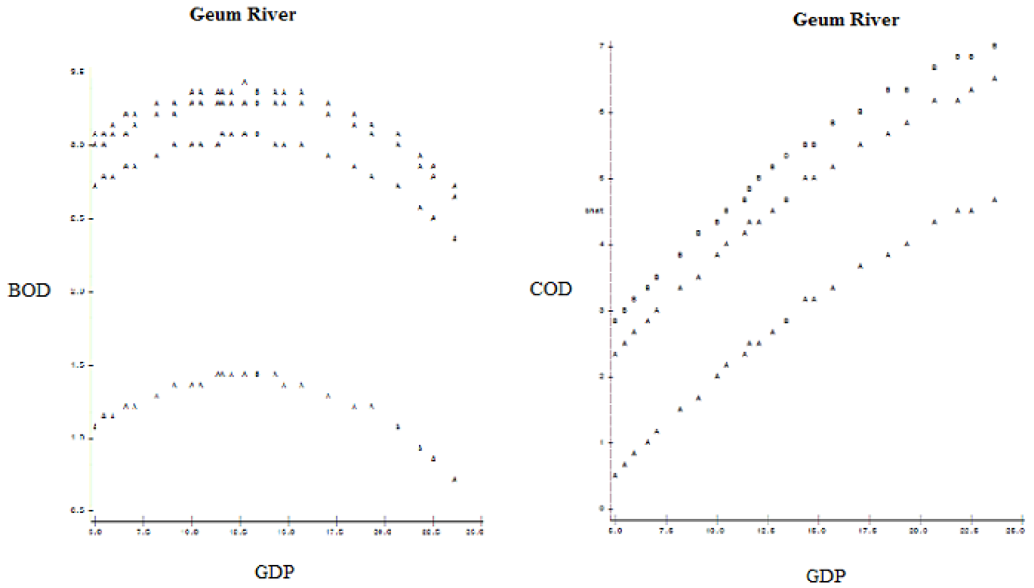


Figure 4.3 Estimation figures in the Geum River about BOD and COD

An inverted-U shape exists in the relationship between BOD or COD and GDP in the Yeongsan River through Figure 4.4. The BOD and COD show a positive or negative and significant relationship with the growth of GDP before or after the turning points.

Industrial development progress based on the chemical and heavy industries through the 1980s and the 1990s increased incomes of the Jeolla province and the city of Gwangju, but this also increased industrial water pollution. The Yeongsan River area, after the mid-1990s, entered in a new growth stage (passed the turning point in Figure 4.4) because of industry structure reorganization toward high value-added businesses using newer, lower-polluting technology.

The Yeongsan River area occupies the highest agriculture land with a gentle slope in decreasing arable hectares over time; therefore, the usage of agriculture chemicals (fertilizers are unclear) continued to be detrimental to water quality until the early 1990s (see Figures 3.1 to 3.3). The organic water pollution of this river area might have been affected with fast increasing livestock production until the early 1990s as well. Like the Geum River, regulations against increasing water pollution (the Water Quality Conservation Act in 1990) played an important role in decreasing organic pollution in the Yeongsan River. Decrease in household waste through increase of the performance of sewerage treatment plants had a positive impact on the decrease of organic pollution as well (see Figure 3.8).

The calculation and interpretation of the GDP Effect on BOD and COD in the Yeongsan River are same with the BOD case of the Geum River.

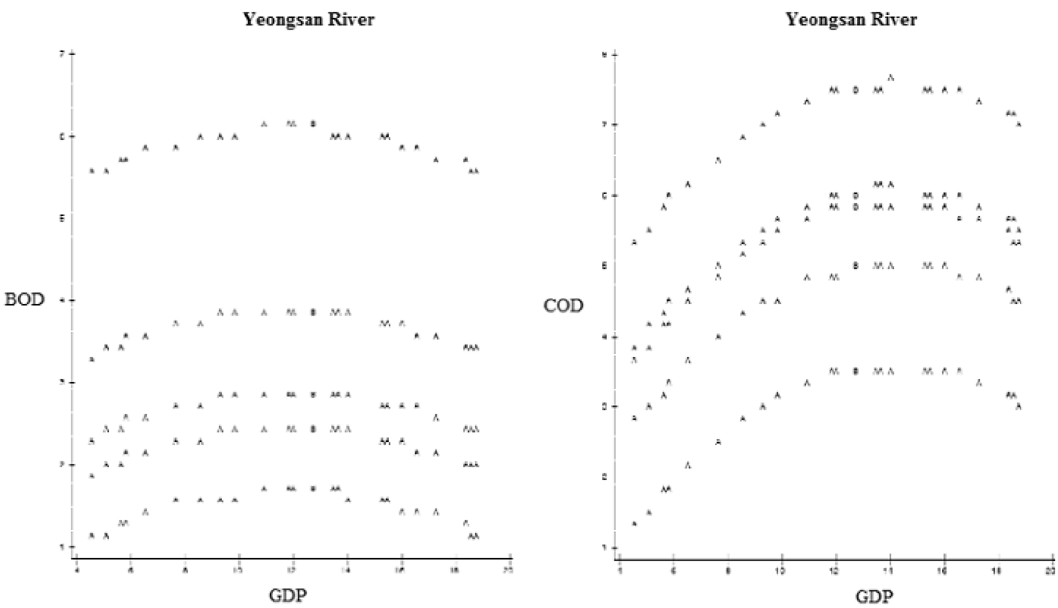
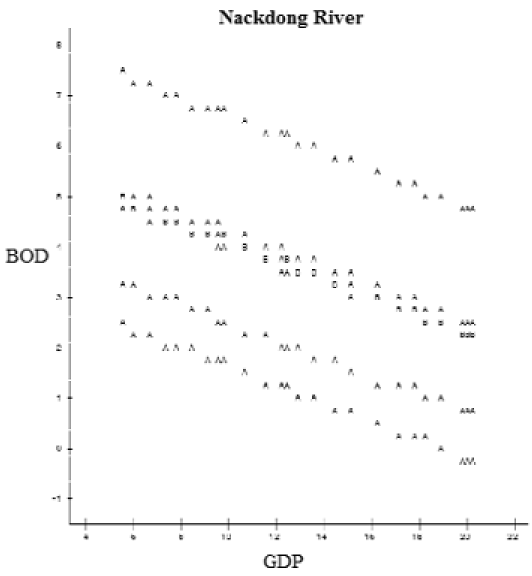


Figure 4.4. Estimation figures in the Yeongsan River about BOD and COD

For the Nackdong River in Figure 4.5, EKC does not exist in the relations between BOD and GDP, but the relationship between COD and GDP finds an inverted-U shape. The BOD shows a decreasing line with the growth of GDP over time, but the COD shows a positive or negative and significant relationship with the growth of GDP before or after the turning point.

The Nackdong River area had developed early with many industrial parks like petrochemical industry, chemical industry, dye industry, and steel industry through the 1970s and 1980s, but new industrial trends started to replace existing pollution-generating industries in the mid-1990s (e.g., medical equipment, precision machinery, semiconductor, and cell phone industries). This shows an increase of industrial water pollution with the growth of income until the early 1990s, but decrease of industrial water pollution with the growth of income occurred after the mid-1990s. The reasons for this decrease were industrial restructure and the introduction of newer, lower-polluting technologies and stricter regulations of industrial water pollution in the Nackdong River area.

The linear decreasing BOD is shown in Figure 4.5. It seems to have a few logical reasons: ⅰ) though this area had large amounts of agriculture land in 1980, its decreasing proportion was exponential; ⅱ) the low increase rate of the production of livestock was not a big problem given that proportions in transformation of livestock excretion into eco-friendly resources are increasing over time; and ⅲ) the household waste in Figure 3.7 continuously is decreasing over time.



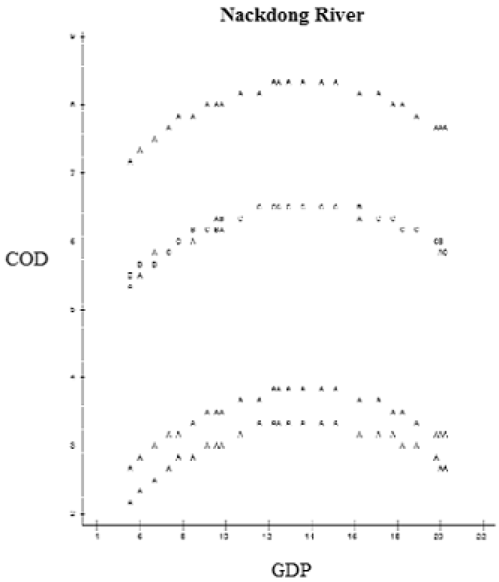


Figure 4.5. Estimation figures in the Nackdong River about BOD and COD

4.3. Distinguishing the upstream sections and downstream sections along each river as well as pooled data

To find the detailed effects of water pollution with respect to GDP in each river and the pooled data, it is required to further break down the rivers into upstream sections and downstream sections. This estimation first begins with separating water quality observatories from each section of the streams. In the case of the Han River, there are 5 observatories. Observatories 1 to 3 were chosen to be representative of upstream sections because the Yansu-ri is the confluence of the Namhan River and the Bukhan River, and they are the best points before the rivers reach Seoul and the most industrialized areas. The rest of them (observatories 4 and 5) were selected to represent the downstream sections (see Figure 3.15.). The observatories 1 and 2 of the Geum River are representative of the upstream sections, and observatories 3 and 4 are representative of the downstream sections. These locations were chosen because they are before the city of Daejeon (see

Figure 3.16.). The observatories 1 and 2 are located before the city of Gwangju, and represent the upstream sections. Observatories 3 to 5 were selected to represent downstream sections for the same reasons (see Figure 3.17.). Observatories 1 and 2 of the Nackdong River are representative of the upstream sections. Observatories 3 to 6 were selected to represent downstream sections for the same reasons as well (see Figure 3.18.).

The empirical results in Table 4.7., Figure 4.6., and Figure 4.7. support the results of the national relationships between water pollution and economic activity. Upstream sections and downstream sections are not perfectly the same, but their pollution trends are quite similar (see Figure 4.1.). The absolute pollution levels in downstream sections are much higher than those of upstream sections in the COD and BOD; hence, downstream sections might earlier enter into a decreasing trend than upstream sections as a result of increase in demand of clean water quality around downstream sections-area and a faster response to the changes of economic activity including agriculture land, household waste, water pollution policy, etc.

Table 4.7. Estimation results of the Fixed-effects regression about BOD and COD as distinguishing upstream sections and downstream on the pooled data

	BOD		COD	
Regressors	Upstream sections	Downstream sections	Upstream sections	Downstream sections
GDP	0.16526 (0.000)***	-0.14141 (0.000)***	0.28427 (0,000)***	0.27783 (0.0318)**
GDP2	-0.00662 (0.000)***	N/A	-0.00522 (0.0137)**	-0.00819 (0.0893)*
Constant	0.40882 (0.1130)	5.55614 (0.000)***	-0.42016 (0.2739)	2.95770 (0.000)***
R^2	0.5794	0.3340	0.6899	0.2764
F Statistic	35.5 (0.000)***	9.76 (0.000)***	40.70 (0.000)***	8.58 (0.000)***
No. of Obs.	225	275	225	275
B-P Test	2.73 (0.2551)	9.67 (0.0019)***	9.87 (0.0072)***	20.64 (0.000)***
D-W Test	1.303	1.126	1.334	1.325
Turning point	12.48187 (estimated)	N/A	27.22893 (estimated)	16.96154 (estimated)
Shape of curve	Inverted U	Decreasing line	Increasing left-half of inverted U	Inverted U

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

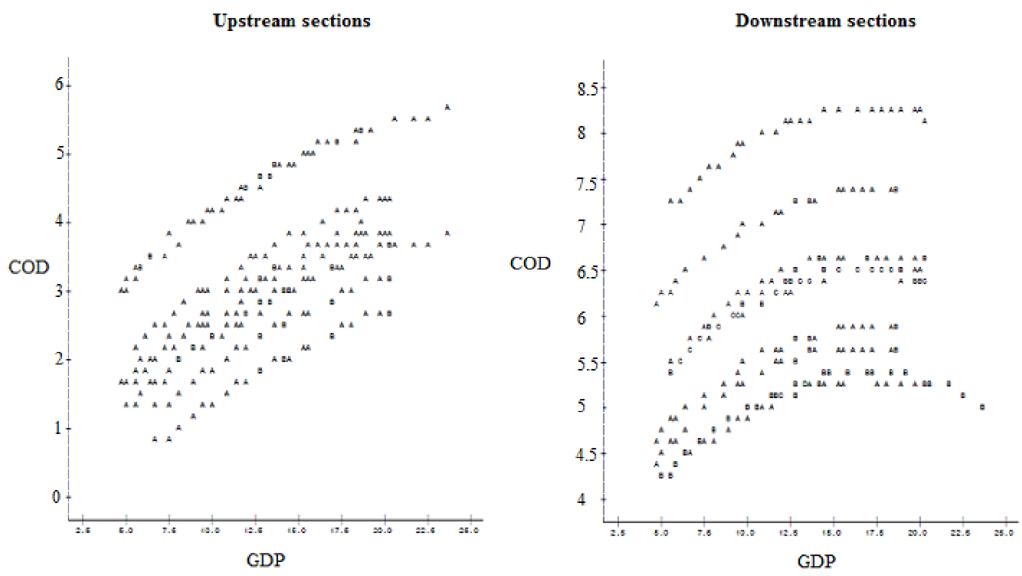


Figure 4.6. Estimation figures in upstream and downstream sections about COD

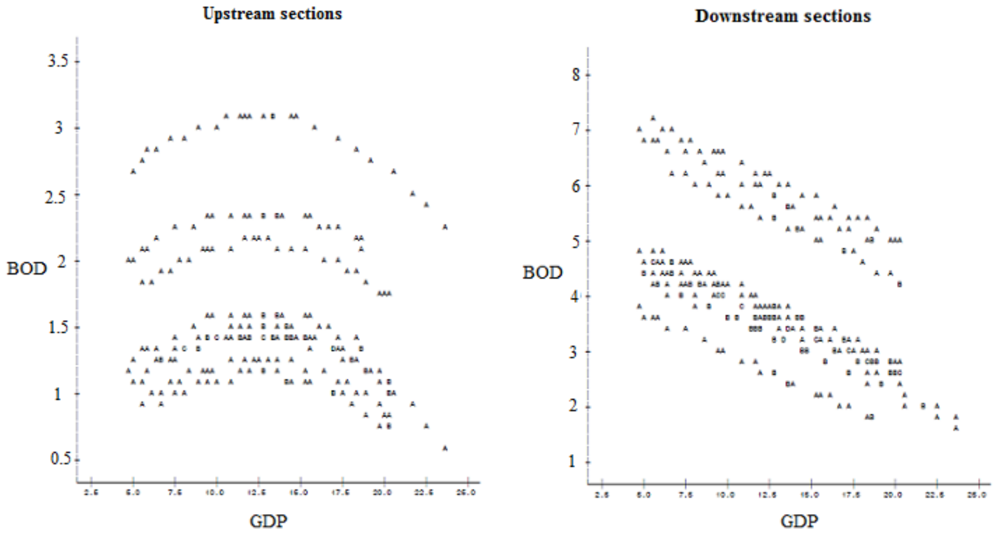


Figure 4.7. Estimation figures in upstream and downstream sections about BOD

The empirical results about the upstream sections and downstream sections along each river are in Table 4.8. and 4.9. The tables show the relationships between BOD or COD and GDP. The coefficients of GDP (upstream sections in the Han River) and GDP and GDP^2 (downstream sections in the Geum River and upstream sections in the Yeongsan River) about BOD are not statistically significant at even 10%. The coefficient of GDP of upstream sections and that of GDP^2 of downstream section in the Han River about COD are not statistically significant at the same level as well. Overall, estimation models do not show good fits in terms of R^2 values: e.g., R^2 values about BOD from upstream sections in the Han River and Nackdong River and downstream sections in the Nackdong River remain about 0.3 and 0.003 from the downstream sections in the Geum River, meaning very low R^2 values when compared with the results of Table 4.4. and Table 4.6. The R^2 values of COD are below 0.4 in downstream sections in Han River, Yeongsan River, and Nackdong River as well.

Tables 4.8. and 4.9. reveal that the relationships between BOD or COD and GDP are a mess. A few upstream and downstream sections showed an inverted U shape, but all of them seemed to yield illogical results when these sections are tried to interpret them in a relationship between upstream and downstream sections. If upstream sections showed an inverted U shape, the downstream sections affected by the upstream sections should have a similar result, but it was not found in the results in Table 4.8. and Table 4.9. It might be attributed to the decrease in observatories in the process of distinguishing between upstream sections and downstream sections. Along each of the rivers, only 4 to 6 observatories exist, and they might not be enough to test this experiment.

Table 4.8. Estimation results of the Fixed- or Random-effects regression about the BOD as distinguishing upstream sections and downstream sections along each river

	BOD							
Regressors	Han River upstream	Han River downstream	Geum River upstream	Geum River downstream	Yeongsan River upstream	Yeongsan River downstream	Nackdong River upstream	Nackdong River downstream
GDP	0.08266 (0.1602)	-1.52434 (0.0196)***	0.1226(0.131)	0.156658 (0.1824)	0.02795 (0.7454)	0.39266 (0.0091)***	0.30652 (0.0232)**	-0.2602 (0.000)***
GDP^2	-0.00381 (0.0727)*	0.04437 (0.0383)**	-0.005 (0.065)*	-0.00554 (0.1779)	0.00049949 (0.8920)	-0.01777 (0.0068)***	-0.01223 (0.0198)**	N/A
Constant	0.96857 (0.0072)***	15.47535 (0.0013)***	0.7440 (0.115)	2.249814 (0.0083) ***	1.06308 (0.0173)**	1.85616 (0.0171)**	-0.55651 (0.4362)	9.41336 (0.000)***
R^2	0.3159	0.5221	0.6388	0.0383	0.4707	0.6790	0.3016	0.3272
F Statistic	10.74 (0.000)***	12.42 (0.0010)***	75.22 (0.000)***	0.11 (0.7422)	33.91 (0.000)***	69.97 (0.000)***	19.88 (0.000)***	6.71 (0.0004)***
No. of Obs.	75	50	50	50	50	75	50	100
B-P Test	2.68 (0.2619)	24.11 (0.000)***	1.49 (0.4738)	1.87 (0.3921)	9.81 (0.0074)***	3.28 (0.1943)	0.03 (0.8553)	5.81 (0.0159)**
D-W Test	1.665	1.1146	1.431	1.511	0.924	1.373	1.3108	1.216
Turning point	10.847	17.177	11.232	N/A	N/A	11.048	12.531	N/A
Shape of curve	Inverted U	U	Inverted U	N/A	N/A	Inverted U	Inverted U	Decreasing linear

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

Table 4.9. Estimation results of the Fixed- or Random-effects regression about the COD as distinguishing upstream sections and downstream sections along each river

	COD							
Regressors	Han River upstream	Han River downstream	Geum River upstream	Geum River downstream	Yeongsan River upstream	Yeongsan River downstream	Nackdong River upstream	Nackdong River downstream
GDP	-0.05874 (0.4163)	-0.75708 (0.0920)*	0.34978 (0.000)***	0.457159 (0.000)***	0.56047 (0.0169)**	0.78668 (0.0004)***	0.35799 (0.0011)***	0.47996 (0.0530)*
GDP^2	0.00534 (0.0402)**	0.02368 (0.1118)	-0.00578 (0.0272)**	-0.0067 (0.0294)**	-0.01721 (0.0965)*	-0.02973 (0.0020)***	-0.00832 (0.0406)**	-0.01970 (0.0234)**
Constant	2.13259 (0.000)***	10.65652 (0.0013)***	-0.78998 (0.0820)*	0.347486 (0.5289)	-0.91709 (0.3758)	0.93162 (0.4013)	-0.07478 (0.8946)	5.47310 (0.0043)***
R^2	0.6993	0.3543	0.8889	0.8577	0.4506	0.3497	0.6515	0.2143
F Statistic	43.51 (0.000)***	14.91 (0.000)***	160.76 (0.000)***	0.00 (0.9822)	17.88 (0.000)***	10.63 (0.000)***	9.71 (0.0031)***	6.75 (0.0004)***
No. of Obs.	75	50	50	50	50	75	50	100
B-P Test	2.93 (0.2316)	18.68 (0.000)***	1.81 (0.4050)	3.58 (0.1667)	7.06 (0.0293)**	1.00 (0.6062)	2.00 (0.3683)	11.48 (0.0032)***
D-W Test	1.2894	1.1796	1.212	1.425	1.439	1.569	1.576	1.688
Turning point	N/A	15.985	N/A	N/A	N/A	13.230	N/A	12.181
Shape of curve	Increasing right-half of U	U	Increasing left-half of inverted U	Increasing left-half of inverted U	Increasing left-half of inverted U	Inverted U	Increasing left-half of inverted U	Inverted U

Notes: dependent variables are BOD and COD, and the p-values are in parenthesis; *, **, and *** indicate significance at 10%, 5%, and 1%, respectively; turning points are in Won in 2005 prices. The coefficients on all cross-sectional dummies have been omitted. Breush-Pagan test assumes the null hypothesis is the homoscedasticity, and F Statistic's null hypothesis is no Fixed-effects. 'N/A' means that the results are not available.

CHAPTER 5. CONCLUSIONS

The three experiments concerning the relationship between water pollution and economic growth have been investigated to compare the effects of pollution level of the four rivers with different geographical features and economic activities as well as to confirm national relationship between economic growth and water pollution. The empirical results demonstrate that the EKC theory explains water quality change in South Korea, depending on the types of water pollutants and their generated regional characteristics (economic activity, agriculture land, household waste, water pollution policy, etc.). The Han River does not show inverted-U shapes for BOD and COD, but the Geum River (BOD), the Yeongsan River (BOD and COD), and the Nackdong River (COD) show inverted-U shapes. At the national perspective, BOD and COD might show inverted-U shapes; therefore, the EKC relationship cannot be always generalized between economic growth and environmental pollution.

The major contributions of this thesis exist in the three aspects: ⅰ) the EKC relationship of organic water pollution or industrial water pollution and economic growth were confirmed through the four rivers in South Korea. The amounts of agriculture land with chemical fertilizers and pesticides, household waste, and livestock excretion were used to support relationship among organic water pollution and economic development. For explaining relationship between industrial water pollution and economic growth, industrial development processes in each of the four rivers were provided ⅱ) since a water pollutant has different pollution effect with increase of income in different rivers, even in one country, the prediction of a particular water pollutant in a country should not jump to conclusions; and iii) the Korean government needs to pay special attention to industrial water pollution in the Han River because COD pollution is increasing over time after relaxing deregulation of limited development district in 2002. Also, to make a decreasing trend of industrial water pollution in the Geum River might require meticulous attention to stricter industrial water pollution regulation.

The improved future study of upstream sections and down stream sections about the four rivers by getting more observatories along each river or better econometric modeling should be applied. The successful results of distinguishing upstream sections and downstream sections will be able to provide more exact information regarding pollution effect with respect to economic growth along the four rivers.

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APPENDIX. VARIABLE CHANGES

The Figure A.1. to A.8. shows the changes of the COD and BOD along each river from 1985 to 2009. Han River area implies Seoul, Incheon and the province of Gyenggi, and Geum River area is Daejeon and both the provinces of S. Chungcheong and N. Chungcheong. Yeongsan River area implies Gwangju and both the provinces of N. Jeolla and S. Jeolla, and Nakdong River area includes Daegu, Busan, Ulsan, and both the provinces of N. Gyeongsang and S. Gyeongsan. For the observatories 1 to 6, refer to Figure 3.15. to 3.18. in the Chapter 3. The Figure 3.9. shows the GDP per capita in South Korea from 1970 to 2009.

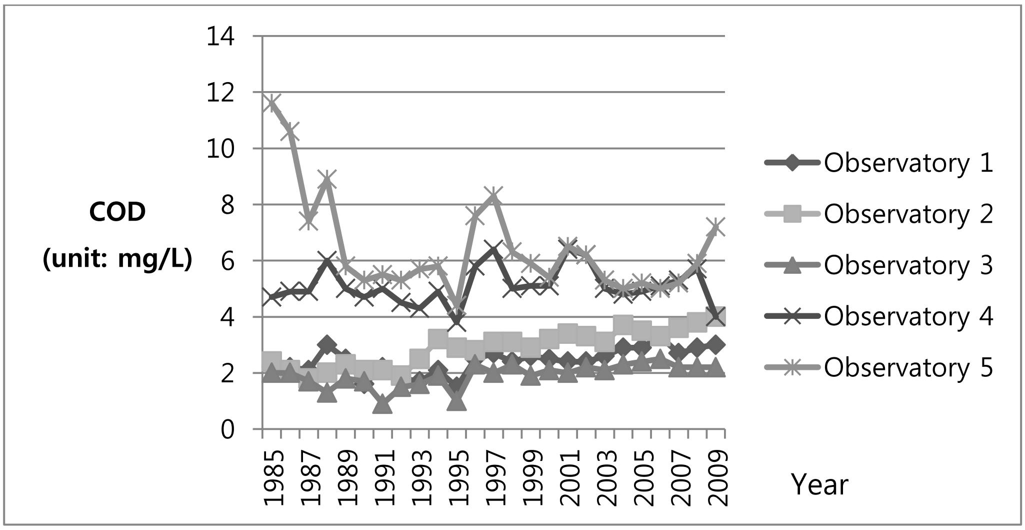

Figure A.1. COD in Han River area

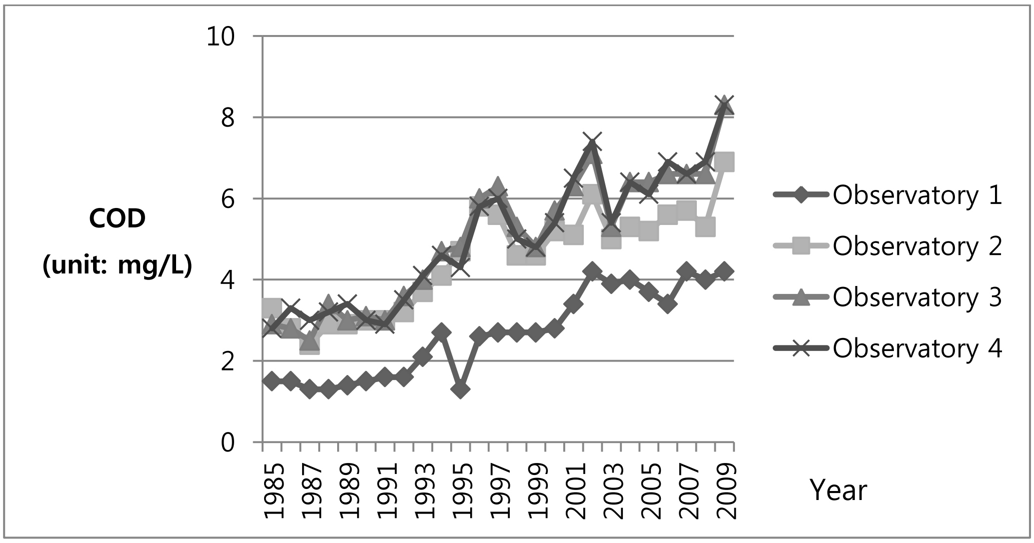

Figure A.2. COD in Geum River area

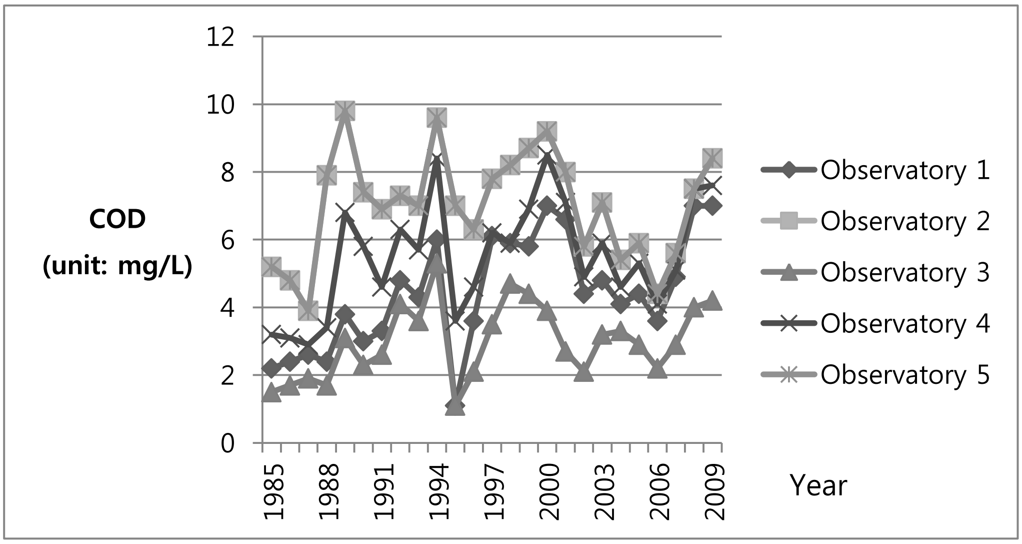

Figure A.3. COD in Yeongsan River area

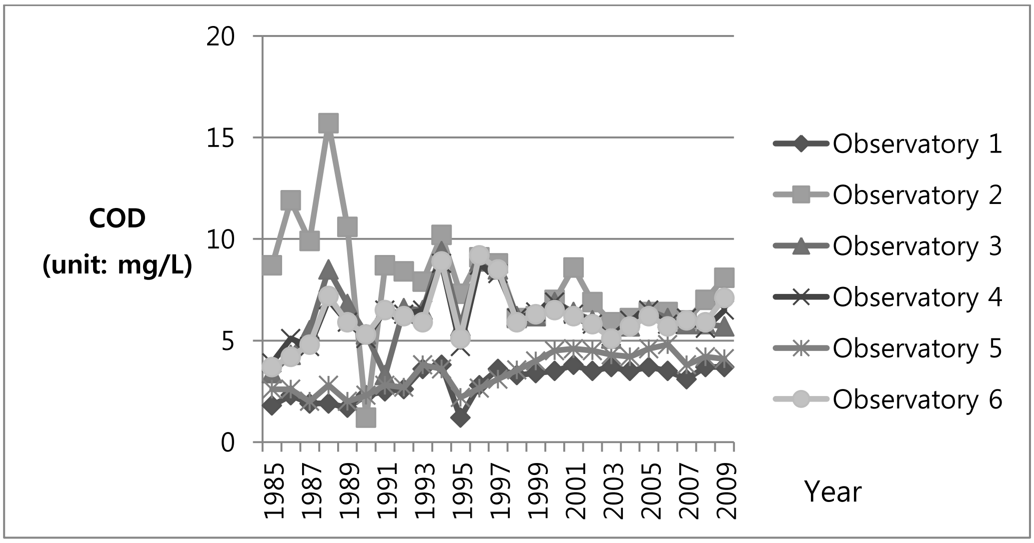

Figure A.4. COD in Nackdong River area

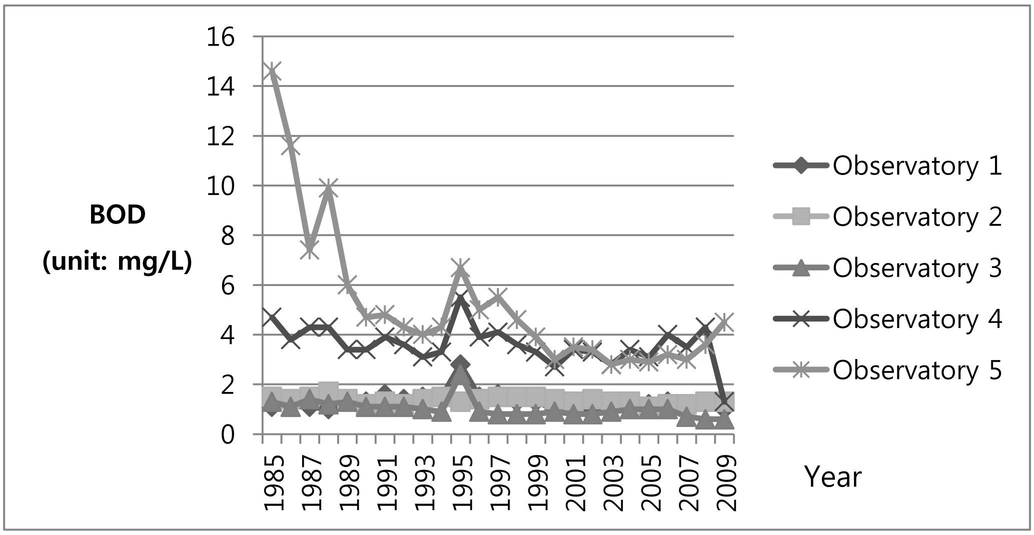

Figure A.5. BOD in Han River Area

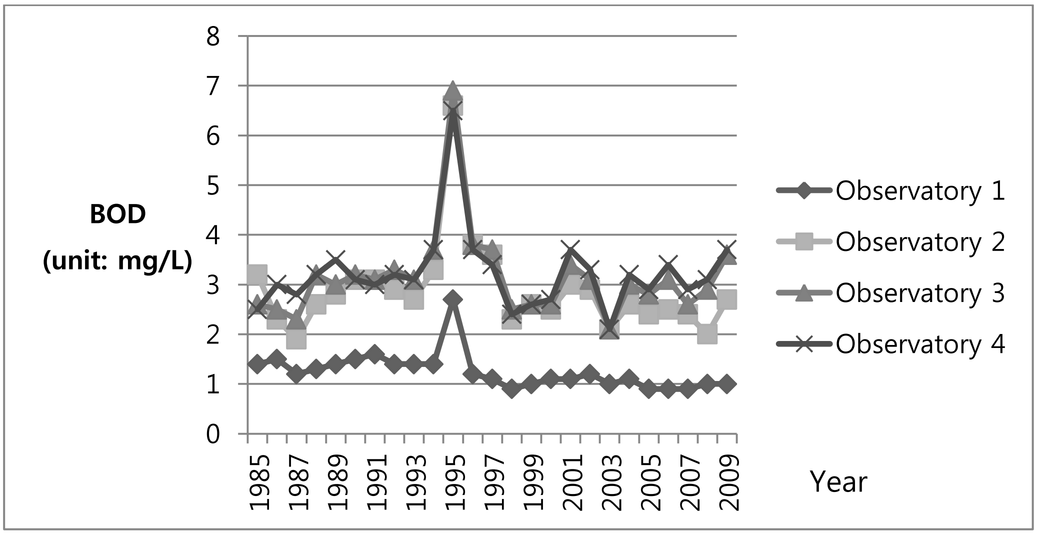

Figure A.6. BOD in Geum River Area

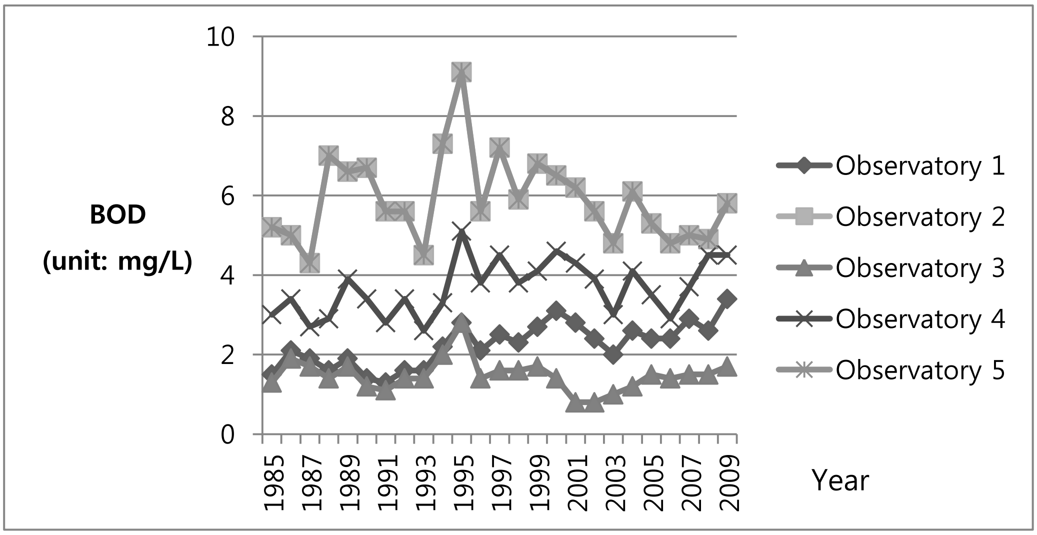

Figure A.7. BOD in Yeongsan River Area

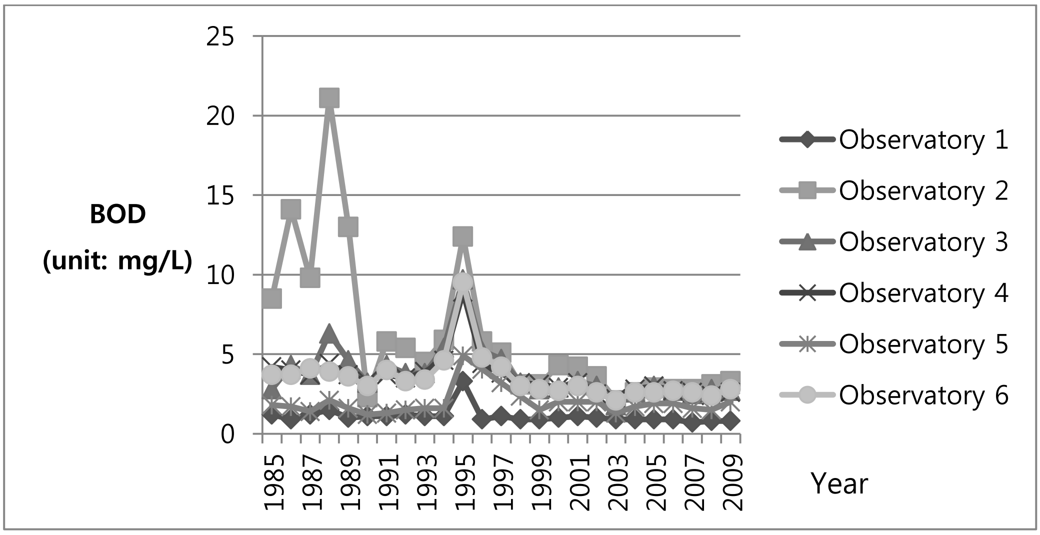

Figure A.8. BOD in Nackdong River Area

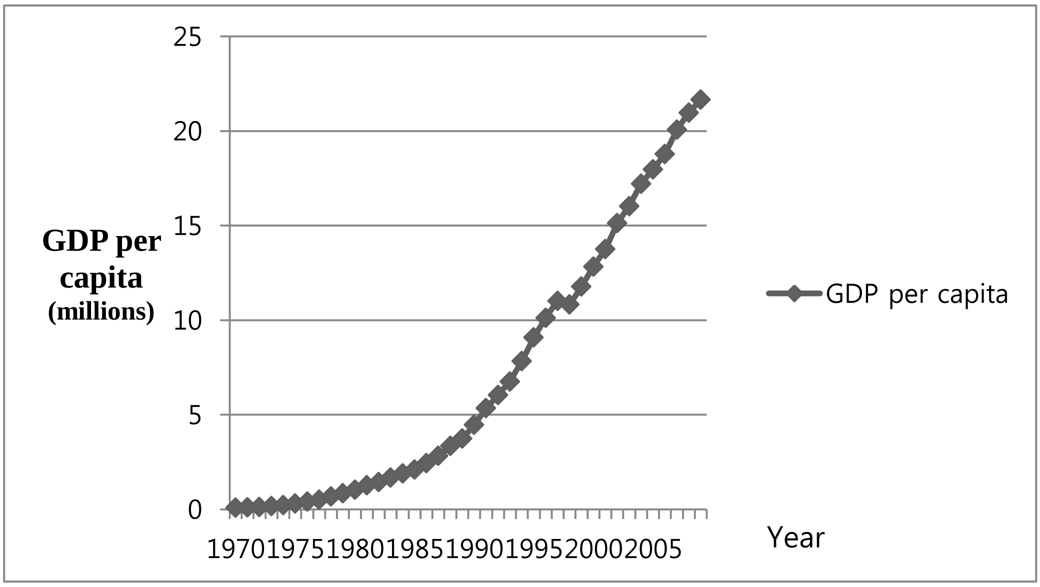

Figure A.9. GDP per capita in South Korea from 1970 to 2009