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# The Effect of the Total Maximum Daily Loads(TMDL) Management Implementation Plan on Total Phosphorus(TP)

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Graduate Capstone

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# Abstract

The Ministry of Environment of the Republic of Korea has been making efforts to improve water quality and the health of the aquatic ecosystems of the inland waters. Establishing water quality standards for point sources and permissible wastewater emission standards to achieve the target environmental standard were part of the efforts. Nevertheless, water quality indexes such as Biochemical Oxygen Demand(BOD) and Chemical Oxygen Demand(COD) has not improved significantly. Also, harmful cyanobacteria blooms have frequently been occurred, which, in particular, has brought people to lose faith in the environmental policy and has created anxiety about drinking water. As the solution, the government introduced the Total Maximum Daily Loads Management(TMDL) System for the major rivers in 2004. In the system, if water quality is worse than a target water quality, the local government should establish a TMDL implementation plan to limit pollution loads into the streams.

In this paper, I use a difference-in-difference approach to investigate whether the implementation plan for TMDL on total phosphorus (TP) was effective in reducing TP concentration. For that, I constructed a balanced panel data from three rivers in Korea from 2004 to 2015. Also, a fixed effects model was employed to handle the unobserved variables. The results show that the TMDL policy has a statistically significant effect on reducing TP concentration. It may be suggested that for the health of people and aquatic ecosystems, the government may need to expand the TMDL implementation plan to all regions where people rely on rivers for their drinking water. Even

though water quality of these regions satisfies the target water quality, the TMDL implementation plan might be helpful for preventing cyanobacteria blooms.

## 1. Introduction

In South Korea, according to a survey conducted in 2013, only 5.40% of people were drinking tap-water without any treatment, which is relatively lower than other countries[1]. People's high suspicion on the tap-water may be attributed to rusted pipes, frequent cyanobacteria(bluegreen algae) bloom[2] , and water pollution. Among these reasons, cyanobacterial blooms are a recently emerging as a substantial issue. According to the data of the Ministry of Environment of Korea(MOE), in the last 10 years, authorities have issued algae warnings[3] every year for the four major rivers which have been used as the drinking water supply resource.

Table 1. Days of algae warning events in the last 10 years in 4 major rivers

| Year (Spot) | 2007 (17) | 2008 (20) | 2009 (22) | 2010 (22) | 2011 (22) | 2012 (22) | 2013 (25) | 2014 (25) | 2015 (25) | 2016 (28) |
|---|---|---|---|---|---|---|---|---|---|---|
| Total | 198 | 99 | 152 | 177 | 93 | 161 | 267 | 372 | 673 | 404 |
| Hangang | 12 | 47 | 23 | 42 | 0 | 77 | 35 | 47 | 245 | 0 |
| Nakdonggang | 139 | 37 | 0 | 0 | 36 | 0 | 185 | 325 | 374 | 313 |
| Geumgang | 14 | 15 | 47 | 98 | 57 | 84 | 47 | 0 | 54 | 91 |
| Yeongsangang | 33 | 0 | 82 | 37 | 0 | 0 | 0 | 0 | 0 | 0 |

Source: Annual report on algae out-break and response in 2016

[1] Japan 22.0(2012), U.S. 56(2003), United Kingdom32(2002), MOE

[2] Cyanobacterial bloom is the phenomenon that phytoplankton diversity is broken, and mono-species (or nearly so) of cyanobacteria appears with very large populations over a short period and dense layer of cells at the surface of the water (Park, 2014; Falconer, 1999; Merel et al., 2013).

[3] Number of cell/ml in water over 10.000

Cyanobacterial blooms are a result of combined and aquatic conditions of eutrophication, retention time, water temperature, and lighting (Park, 2014; MOE, 2017). Some cyanobacteria are potentially poisonous[4]or bring off-odors and unpleasant taste in the water (HARRNESS, 2005; Falconer, 1999). Not only could they threaten health of the exposed humans and animals but they also have adverse effects on the economy, social activities, and ecosystems (Hudnell, 2010). Among the conditions of growth and persistence of cyanobacteria, eutrophication may be considered as a controllable factor for the administration, because eutrophication is due to overenrichment nutrients(nitrogen:N and phosphorus:P) from anthropogenic sources such as livestock manure, chemical fertilizer, and domestic sewage(Paerl, 2013; Park, 2014). Also, it is generally accepted that phosphorus control is the most valuable measure to prevent algal blooms (Levine et al., 1999; Shin et al., 1999; MOE, 2017). In order to control phosphorus, the government invested considerable budget in the construction of new sewage and wastewater treatment plants, and the addition of chemical phosphorus removal process modules to existing plants.

Table 2: Water environment management investment amount

(Billion Korea Won)

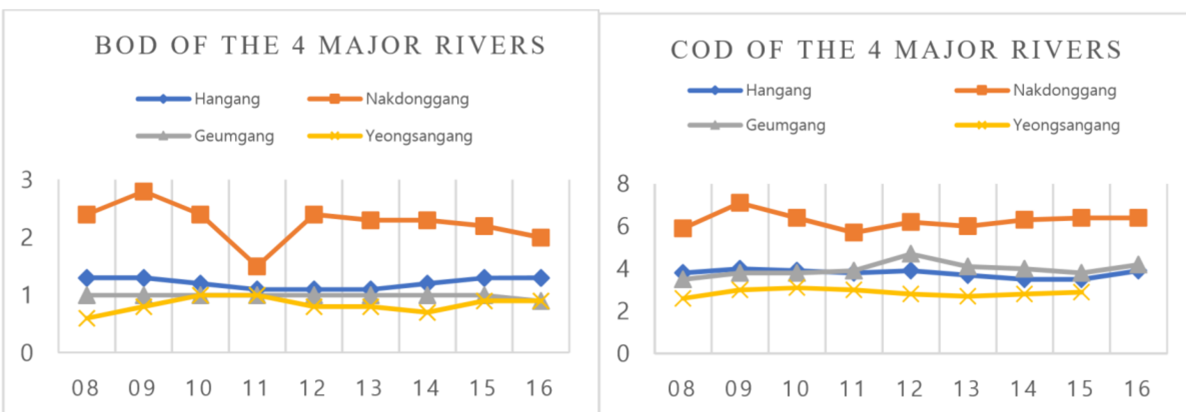
| Total | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|---|
| 377,911 | 35,831 | 35,435 | 40,438 | 49,607 | 45,764 | 45,167 | 49,400 | 52,920 | 53,760 | 57,115 |

[4] Examples: Microcystis, Anabaena, Aphanizomenon, and Oscillatoria

Source: The 2nd Water Environment Master Plan (MOE, 2017)

Moreover, the government has implemented various management policies including the land use control program for the drinking water resources protection area, the permission system for wastewater discharge facility, and the policy of emission concentration and violation fee (MOE 2017). However, despite these efforts, the total load of pollution increased so that some areas failed to meet the water quality standards as a result of the increase of pollution density due to fast economic growth and the expansion of cities (NIER, 2006).

Figure 1. The Condition of Water Quality in the main area of the four major rivers




Source: e-nara index http://www.index.go.kr/potal/main/EachDtlPageDetail.do?idx_cd=2788 Note: Hangang(Paldang Dam), Nakdonggang(Mulgeum), Geumgang(Daecheong Dam), Yeongsangang(Juam dam)

To overcome the limitation of these policies, the MOE introduced the Total Maximum Daily Loads Management System on the biological oxygen demand(BOD) on three rivers in 2004, and on TP in 2011. In this paper, I would like to empirically examine the effect of the Total Maximum Daily Loads Management Implementation Plan on total phosphorus in rivers.

## The operation of TMDL in South Korea

According to the MOE, the TMDL system sets target water quality for each watershed unit based on a scientific foundation and allocated an allowable discharge load, thereby keeping the total amount of discharged pollutants from a TMDL watershed unit below its allowable load. This system consists of planning, implementation, and assessment. Provincial governments can set target water quality at the outlets of 'unit watersheds' in their provinces, and then they can establish the TMDL basic plan which includes analyzing the environment of watersheds, calculation and allocation of pollution load for each unit watershed and each local government (NIER, 2006). If the annual average value of measured data at the outlets exceeds the target water quality twice in a row for any three years, a local government should establish a TMDL implementation plan including calculation of pollution loads and load allocations for individual pollution sources in the watershed and execute the plan (NIER, 2006). Last, local government should submit an implementation assessment report to the MOE. The MOE can restrict authorization for new development and construction projects if local government fails to fulfill their obligation (MOE, 2009). Even though it is an advanced management tool, there was public resistance in the initial state of its implementation because it was considered as another form of regulation to impede development. Also, there was some doubt about pollution load allocation due to possible uncertainties in measured data and modeling to allocate loads (MOE, 2009). However, the government put effort into persuading the stakeholders and at the same time, they introduced the system gradually. The first stage of the TMDL started in 2004 for the three rivers, Nakdonggang, Geumgang, and Yeongsangang and only BOD was target pollutant. The total phosphorus as the second target pollutant has been added in the second stage which began in 2010. The BOD TMDL for the Han River started in 2011.

## 2. Literature Review

This literature review focuses on academic studies on the causal relationship between cyanobacterium blooms and total phosphorus. Furthermore, to establish the hypothesis, I would like to review TMDL empirical research on other water quality indexes.

### 2.1 The threat of cyanobacteria bloom (Blue-green algal bloom)

When cyanobacterial blooms occur, it has negative impacts on the aquatic ecosystem, animal, and human. These impacts include toxins, off-odors and unpleasant taste in the water (HARRNESS, 2005; Falconer, 1999). The risks of harmful algal blooms(HAB) variously presented in commerce, recreation, and drinking-source (Hudnell, 2010).

Dodds and Bouska (2008) examined the potential economic damage of eutrophication, which is highly correlated with cyanobacterial blooms. They estimated the cost of annual value losses in waterfront real estate, recreational water usage, spending on the revival of threatened and endangered species, and tap water. Their results lead to the conclusion that the total costs were about $2.2 billion per year as a result of over-enrichment of nutrient in the U.S. They pointed out that the most significant economic losses were ascribed to property values and recreational use.

Pretty et al. (2003) studied the cost of freshwater eutrophication in England and Wales. They categorized the cost of environmental and social damage costs and policy response costs. Environmental and social damage costs included reduced value of waterside properties, drinking water treatment costs, health costs to humans and livestock. Responding to eutrophication incurs policy response costs such as sewage treatment costs and monitoring costs for water. Pretty pointed out that the damage costs of freshwater are $150-160 million per year and the policy response costs are $77 million per year. Their findings showed the severe effect of nutrient enrichment.

In South Korea, Cho et al.(2016) tried to measure the environmental and aesthetic costs caused by cyanobacterial blooms. They analyzed public willingness to pay to avoid blue-green algae bloom occurrence. They randomly surveyed 1,000 households. They estimated the household willingness to pay to be 4,129 KRW yearly. Considering the national population, it expands to approximately 80.8 billion KRW per year (1,100 KRW are about $1.00).

### 2.2 Preventing cyanobacteria bloom by Phosphorus control

Nitrogen(N) and phosphorus(P) are the primary sources of eutrophication of aquatic environments (Paerl, 2013). Levine and Schindler (1999) examined the impact of nitrogen to phosphorus supply ratios on cyanobacteria and phytoplankton species composition in the Lakes

Area in Canada. They pointed out that phosphorus load cutbacks remain the most valuable means of cyanobacterial control.

Shin et al. (1999) investigated monthly dynamics of water environmental factors and algal populations in Daechong Reservoir. They found that the dominance of blue-green algae such as anabaena and microcystics in the reservoir begins to form in early summer continuing to late fall. They explained that from March to June, low levels of chlorophyll-a could be due to a deficiency of phosphorus rather than other factors. In other words, phosphorus acted as a limiting nutrient for algae growth. From these previous studies, the dominant limiting factor of algal growth in aquatic environment may be phosphorus(P).

Liu et al. (2008) tried to quantify the phosphorus loads related to mining, farming, livestock density, household consumption, and land use. He found that a net loss of phosphorus from the world's farmland is estimated at 10.5 million metric tons.

Park et al. (2016) examined the effect of pollutants control measures in So-oak watershed on the control of algae growth in Daechong Reservoir. They classified the control measures into watershed and in-reservoir, and they simulated the effect using a model. They explained that in a wet year, the contribution of non-point sources to a total load of phosphorus increased and in a dry year, the chemical control of phosphorus in the sewage treatment plant was more effective. They pointed out that for the best practice to control algal bloom, all livestock manures need to be treated and chemical fertilizers should be limited to amounts suggested in a usage guide.

## 2.3 Effect of TMDL implementation

A TMDL is an allocation of the amount of a single pollutant from all contributing point and nonpoint sources. Its process is that states picked out waters that are in danger of becoming threatened and then for these water, states compute an allocation pollutant reduction amount necessary to meet approved water quality standards (U.S EPA, 2018; Bosch, 2003). Existing studies have focused on a technical approach for the anticipation of the amount of pollutant rather than the effect of TMDL implementation.

Hoornbeek et al. (2012) examined implementing water pollution policy in the USA. They gathered information from interviews and reviewing 63 reports on the approved TMDL in Ohio and West Virginia. They found that progress of TMDL toward execution has taken place in many cases. However, advance in water quality remained uncommon, as partial and full recovery of water bodies has occurred in only 19% and 3% of cases, respectively.

Park et al. (2008) published a research paper regarding the effectiveness of 3-year implementation of BOD TMDL on three major rivers. They analyzed data from 2002 to 2007(the first stage) and explained that the difference in water quality before and after the TMDL implementation was 4.5% for the Nakdong River Basin, -6.5% for the Guem River Basin, and 3.4% for the Youngsan River Basin. This poor improvement may be because facilities for pollutant reduction were planned to be built in the late part of the first stage.

# 3 Research design

## 3.1 Thesis

The South Korea Government initiated TMDL on phosphorus through a tough negotiation with municipal governments and stakeholders. Even after the initiation, the effort to persuade them continued afterward. Also, according to the empirical analysis for the effect of the TMDL on BOD, the effect does not appear immediately in the aquatic ecosystems (Park et al., 2008), and some researchers doubted the accuracy of the modeling (Cha, 2014). Therefore, in spite of the intention of the government, the hypothesis can be built as below:

(1) The introducing of the implementation plan for TMDL on total phosphor us does not have effects on reducing phosphors concentration.

When loads of phosphorus increase, the river and reservoir become a nutrient overenriched. It enhances harmful cyanobacteria growth (Paerl, 2013; Park, 2014) and may cause change of other water quality index such as dissolved oxygen. Thus, it can be assumed that if the implementation plan for the TMDL on TP does not have any effect on improving water quality, the other water quality index will not be influenced. Therefore, the second hypothesis can be established as below:

(2) The introducing of TMDL on total phosphorus does not make improvem ent in the other water quality index like BOD and COD.

## 3.2 Data description

### 3.2.1 Data collection

To reflect the character of the watershed, a set of panel data for water quality was employed. Data related to water quality index such as TP, BOD, and COD were obtained from the Water Information System operated by The National Institute of Environmental Research (NIER). This system provides water quality data measured three to five times per month. From this information system, annual average values of water quality and temperature data were taken and then natural log transformation was applied to the data. The information is annual for analysis to match other social variable data. The pollutant source data such as population and the number of livestock were obtained from the performance evaluation report of TMDL by the NIER (NIER, 2017). Referring to the report enhanced the accuracy and help to reduce the burden of transferring the administrative-district-based data to watershed-based data by population ratios or area ratios. This balanced panel data set consisted of 660 observations on the 55 watershed units, of which 30 are treated, from 2004 to 2015 for the three Major Rivers Nakdonggang, Geumgang, and Yeongsangang.

### 3.2.2 Dependent Variable

This study especially gives attention to the effects of the TMDL implementation on strengthening water quality policy for a river. Especially TP is the main interest which is not only the significant factor in controlling the cyanobacteria but also this policy's target material. Therefore, the concentration of TP in the river is the primary dependent variable. Also, for analysis of the impact on other water quality indexes, I examined the BOD and COD at the same monitoring stations, which are the other dependent variables.

### 3.2.3 Independent variables

The independent variables can be categorized into four different groups. The first one in the first group is 'treated' variable which indicates the treatment group exposed to the implementation plan. It is a dummy variable to identify treatment. The second variable is the 'period' variable which is also a dummy variable. It indicates whether the time is before ('period'=0) or after ('period'=1) the TP TMDL implementation, which began in 2011. The last variable, 'DID' (difference in difference) in the first group, another dummy variable indicates the effect of the introducing of the implementation plan of TMDL of total phosphorus. It is defined as the product of the 'period' and the 'treated'.

The second group indicates the variables related to characteristic of water ecosystems. It consists of water quantity and water temperature variables. The water surface temperature is another significant factor to influence on the number of algae cells (Paerl, 2013). It is generally accepted that if temperature increases, it exacerbates cyanobacteria blooms. The other variable is water quantity variable. Some researchers argued that the water quantity has a positive coefficient on TP because rainfall flows into rivers with sediment-bound phosphorus originating from anthropogenic sources (Park et al., 2016).

The third group indicates population factors. It consists of a resident population and livestock population. If the resident population increases, discharge with nutrient from sewage treatment plants increases. Livestock population increases pollutant discharge in the form of point and non-point sources and influences aquatic ecosystem. The point source of livestock is mostly livestock manure treatment facilities and the major non-point source is uncollected livestock manure. The number of poultry, cattle, and pig are aggregated and used in this study.

The fourth group indicates industrial activity variables, which consist of the amount of the industrial wastewater and the area of using farmland. The increase of cultivation causes an increase of fertilizer use and loads of total phosphorous (Liu et al., 2008). Thus, examining the impact of land use change is important to identify the factors influencing water quality.

Table 3: Summary of Variables

| Classification | Variable | Unit of Measurement | Expected Direction |
|---|---|---|---|
| Dependent variables | | | |
| Total-Phosphorus | | Log | |
| BOD | | Log | |
| COD | | Log | |
| Independent variables | | | |

| | | | |
|---|---|---|---|
| Policy Effect | Period (after 2011) | Dummy | |
| | Treatment | Dummy | |
| | Did (policy effect) | Dummy | Negative |
| Water characteristic | Temperature of water surface | Log | positive |
| | Quantity of water | Log | positive |
| Population | Population of human | Units | Positive |
| | Amount of livestock | Units | Positive |
| Industrial activity | Industry wastewater | $m^3$/d | Positive |
| | Agricultural land(vegetable) | $m^2$ | Positive |
| | Agricultural land(rice) | $m^2$ | Positive |
| | Forest | $m^2$ | Negative |

Source: Water Information System operated by National Institute of Environmental Research of South Korea: http://water.nier.go.kr/main/mainContent.do

Table 4: Summary Statistics

| Variable | Obs | Mean | Std. Dev | Min | Max |
|---|---|---|---|---|---|
| Total-Phosphorus | 660 | -2.936 | 0.785 | -4.741 | -0.405 |
| BOD | 660 | 0.364 | 0.488 | -0.587 | 1.765 |
| COD | 660 | 1.435 | 0.322 | 0.695 | 2.320 |
| Temperature of water surface | 660 | 2.761 | 0.088 | 2.454 | 2.975 |
| Quantity of water | 660 | 2.748 | 1.427 | -0.298 | 7.361 |
| Population of human | 660 | 91858.3 | 233970.9 | 3224 | 1766633 |

| | | | | | |
|---|---|---|---|---|---|
| Amount of livestock | 660 | 897842.1 | 1221288 | 0 | 1.12e+07 |
| Industry wastewater | 660 | 7173.094 | 23544.31 | 0 | 365504 |
| Agricultural land(vegetable) | 660 | 36.403 | 22.714 | 5.36 | 109 |
| Agricultural land(rice) | 660 | 55.472 | 35.737 | 0 | 204.67 |
| Forest | 660 | 360.878 | 189.049 | 0 | 880 |

### 3.3 Empirical Model

The difference in difference model(DID) has been widely used to estimate causal effects of policy and evaluate the policy intervention (Athey, 2006; Mora, 2012: Villa, 2012). This study aims at examining the impact of introducing the implementation plan for TMDL on TP at the Korean rivers and for this, the DID model is employed with panel data. To use DID model, the watershed units belonging to the implementation plan are the treatment group and otherwise they are considered as the control group. Additionally, the dummy variable, 'period' is added to separate the time periods before and after 2011 when this policy first implemented. The final fitted model is presented as below:

<Model>

Outcome_vari= $\beta + \beta\ Period + \beta\ Treated + \beta$ (Period $*$ Treated ) + $\beta\ Others$ + e $_{i,t}$

- Outcome_ variable is the mean of the outcome TP, BOD, and COD

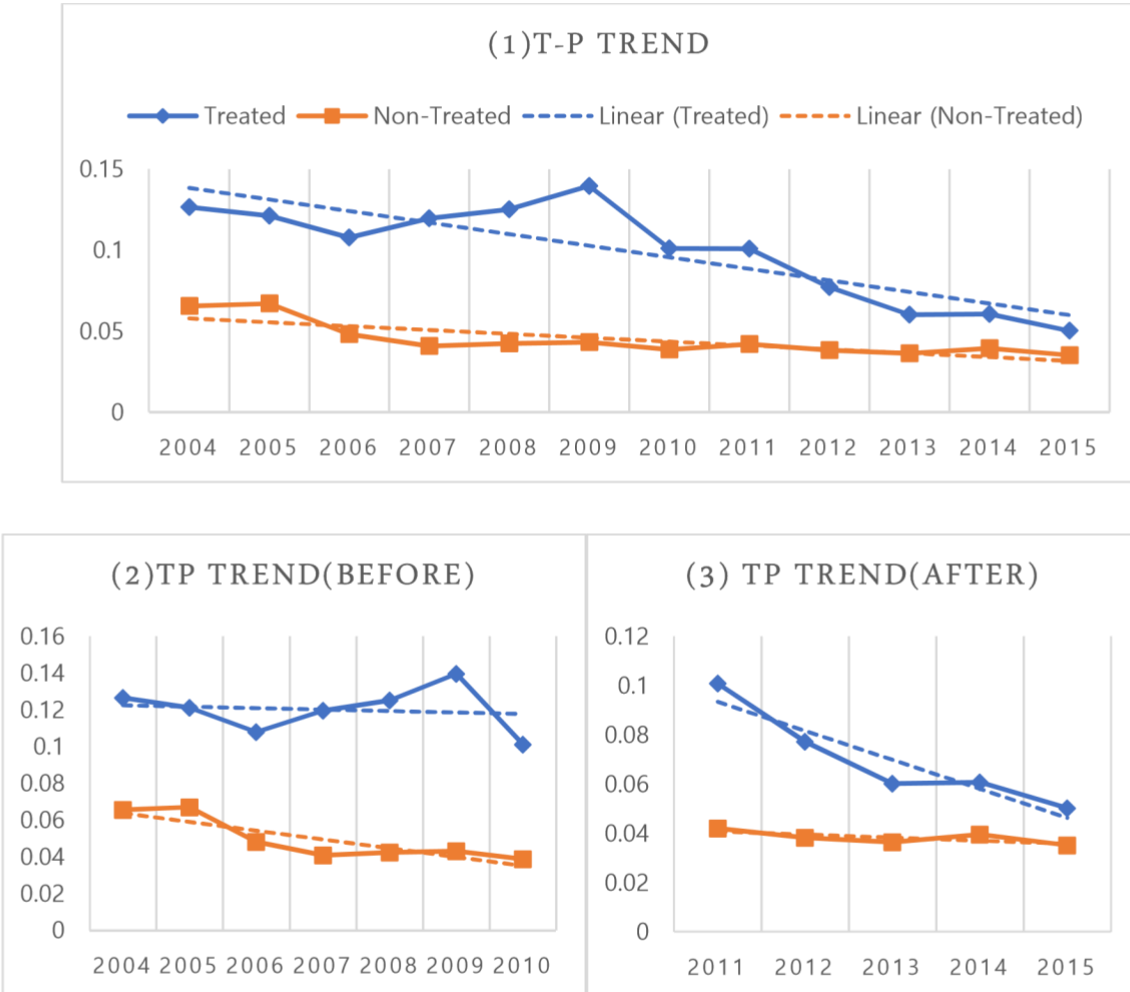
- Period is a dummy which is equal to 1 if the observation is from 2011(post)
- Treated is a dummy which is equal to 1 if the observation is from implement ation plan watershed unit.
- $\beta$ is the mean DID or impact
- Others are the other control variables impacting the outcome.

# 4. Result and Implication

## 4.1 TP trend

The TP concentration trends of the data used in this study are shown in Figure 2.

Figure 2; TP Trend of treated and non-treated group




As shown in Figure 2 (1), the T-P trend from 2004 to 2015 indicates that the treated and nontreated watershed has a slightly downward trend, although there are sudden changes in 2008 and 2009. For further analysis of the changes, the data is separated into two graphs indicating before and after TP TMDL implementation in 2011. Figure 2 (2) shows that the difference between treated and control group gradually increases but the difference dramatically decreases in Figure 2(3) which may explain TP concentration change due to introducing the implementation plan for TMDL on TP. Because the key assumption to identify the policy effect in the difference-in-difference model is the parallel paths assumption that the outcome in treated and non-treated groups would follow the same trend in the absence of treatment (Mora, 2012).

## 4.2 Finding of empirical data analysis

Table 5 presents the results of the analysis for the effect of the TP TMDL implementation.

Table 5: Estimation Results

| | T-P | BOD | COD |
|---|---|---|---|
| DID | -0.2742***<br>(0.04516) | -0.0278<br>(0.0282) | -0.0131<br>(0.0189) |
| Temperature | 0.7613***<br>(0.2576) | 0.5378***<br>(0.1609) | 0.0994<br>(0.1082) |
| Quantity | 0.1153***<br>(0.0211) | -0.0152<br>(0.0132) | 0.0038<br>(0.0088) |
| Human | 1.82*<br>(1.01) | -7.24<br>(6.33) | -1.69<br>(4.26) |
| Livestock | -4.18*<br>(2.26) | 3.05<br>(1.41) | 9.27<br>(9.50) |
| Industry | 1.55**<br>(7.61) | 4.74<br>(4.76) | 3.70<br>(3.20) |
| LAND-VEGITABLE | 0.0203***<br>(0.0058) | 0.0076**<br>(0.0036) | -0.0028<br>(0.0024) |
| LAND- Rice | 0.0225***<br>(0.0046) | -0.0003<br>(0.0029) | -0.0031<br>(0.0019) |

| | | | |
|---|---|---|---|
| Forest | -0.0018** | -0.0011** | 0.0011*** |
| | (0.0007) | (0.0005) | (0.0003) |
| Constant | -6.7124*** | -1.6862*** | 1.0113*** |
| | (0.7709) | (0.4817) | (0.3239) |
| R-squared | 0.3764 | 0.1317 | 0.2205 |
| observation | 660 | 660 | 660 |

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The coefficient estimates of the DID show a significantly negative value. This implies that the policy has a positive effect on reducing the TP concentration. Statistically, that means that there is strong evidence to reject hypothesis 1. In the result for the BOD and COD, the p-value of the coefficients exceeds the significant level meaning that the policy does not have a significant effect on the other water quality index. Therefore, it means that there is no strong evidence to reject hypothesis 2. The other variables, besides the DID, have a statistically significant relationship with the TP concentration as expected. Water characteristic variables, population variables, and industrial activity variables have positive relationships with the TP concentration. But contrary to the expectation the livestock variable has a negative relation with the TP concentration.

## 4.3. Implication

From the results, it can be said that the TP concentration is in a negative relation at the watersheds where the policy was implemented by the government. In other words, the policy was effective in reducing TP concentration. Specifically, these watersheds exceeded the target water quality. Therefore, the results are the reason for expanding policy to other upstream watersheds of drinking water resources. Meanwhile, the other water quality index (BOD, COD) does not show a statistically significant relationship with introduction of the implementation plan for TMDL on TP. Because this policy does not restrict BOD and COD sources directly. This indicates that each watershed needs to have own target substance that causes water quality problem in the area. For example, a watershed that has a problem with COD concentration should adopt the TMDL on COD assuming a TMDL on COD also has a negative effect on COD.

# 5. Limitation

As Table 8 showed above, the density of TP ratio has been influenced by water temperature and quantity. These variables show significant seasonal variation. Especially in Korea, the characteristics of monsoon climate such as the localized torrential downpours frequently occur, and water temperature is very high during the dry period in summer. Therefore, for sophisticated analysis, these seasonal characteristics should be reflected in the analysis. However, annual average data for analysis were used in this study. Because of the restriction on the control data, this study could not examine the effect of seasonal factors on cyanobacteria blooms.

## 6. Conclusion and Recommendation

This study aims to examine how the introduction of the implementation plan for TMDL on TP has impact on reducing TP concentration in the Republic of Korea. As shown in the above results, this policy has the statistically significant effect of reducing TP concentration in rivers. Meanwhile, there is no statistically significant effect on BOD and COD. It implies that the policy was well executed and meeting the policy objectives. The research results also suggest that the government should consider expanding its implementation to not only the region that failed to meet the targeted water quality but also the regions of drinking water resource.

Because of the restriction of the data, this study does not separate the effect of each river. If more data are accumulated through intensive monitoring, it is recommended that the analysis should be conducted again for each river because there is considerable difference in the factors controlling the water quality in each river.

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