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# Evaluation of long-term water quality management policy effect using nonparametric statistical methods

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**Abstract.** Long term water quality change was analyzed to evaluate the effect of the Total Maximum Daily Load (TMDL) policy. A trend analysis was performed for biochemical oxygen demand (BOD) and total phosphorus (TP) concentrations data monitored at the outlets of the total 41 TMDL unit watersheds of the Nakdong River in the Republic of Korea. Because water quality data do not usually follow a normal distribution, a nonparametric statistical trend analysis method was used. The monthly mean values of BOD and TP for the period between 2004 and 2015 were analyzed by the seasonal Mann-Kendall test and the locally weighted scatterplot smoother (LOWESS). The TMDL policy effect on the water quality change of each unit watershed was analyzed together with the results of the trend analysis. From the seasonal Mann-Kendall test results, it was found that for BOD, 7.8 % of the 41 points showed downward trends, 26.8 % and the rest 65.9% showed upward and no trends. For TP, 51.2% showed no trends and the rest 48.8% showed downward trends. From the LOWESS analysis results, TP began to decrease in most of the unit watersheds from mid-2010s when intensive chemical treatment processes were introduced to existing wastewater treatment plants. Overall, for BOD, relatively more points were improved in the main stream compared to the points of the tributaries although overall trends were mostly no trend or upward. For TP, about half of the points were improved and the rest showed no trends.

**Keywords:** TMDLs; LOWESS; Seasonal Mann-Kendall test; Nonparametric statistical methods

## 1. Introduction

It is not easy to decompose the causes of water quality change and sort out the effects of water quality policy because the change is forced by not only the policy implementation but also a combination of other factors, such as changes in external pollutants, weather, and internal river environment. However, the analysis of long-term water quality change trends may reveal the effects of the policy implementation that are obscured by these multiple factors (Hirsch and Slack 1984, Lettenmaier 1988). Long-term data covering sufficient time periods before and after the policy implementation and appropriate statistical methods are essential for achieving this purpose (Kim and Park 2004).

Because water quality data observed in natural water bodies are largely varied by seasons and do not usually follow a normal distribution, the seasonal Mann-Kendall test (Hirsch *et al*. 1982) can be used to analyze water quality trends (Kim *et al*. 2014). As the seasonal Mann-Kendall test is a non-parametric method, it can be applied without assuming the normal distribution of observations (Montomery and Reckhow 1984, Sokal and Rohlf 1995). The method accounts seasonality by computing the S statistic of the Mann-Kendall test on each of seasons separately and combining them. This method has an advantage of enabling quantitative evaluation of trend analysis and coping with missing values (Kim *et al*. 2014, Jung *et al*. 2016). However, its disadvantage is that because it is fundamentally based on linear trends, it cannot be applied if the trends change over the analysis period. To compensate for the disadvantage, the locally weighted scatterplot smoother (LOWESS) can be used to identify

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changing trends in a specific period by fitting regression models through the data points on moving straight lines without assuming specific regression models (Paul and Linfield 1997, Clow and Mast 1999). In this regard, for examples, Rodriguez-Murillo and Filella (2015) used the LOWESS method for analyzing the temporal variations of organic carbon concentration in a lake in Switzerland. Lu *et al*. (2015) applied the method to a long-term trend study of climate and hydrology in Pennsylvania, the United States. Imran Salim *et al.* (2019) used the Mann-Kendall test to analyze rainfall trend change by climate change and many other studies have been conducted.

Total Maximum Daily Loads (TMDLs) has been implemented in the major river watersheds since 2004 for BOD and 2011 for total phosphorus (TP), which is one of the most important water quality policies in Republic of Korea (Korea). For the policy implementation, flow and water quality data have been produced at every outlet of TMDL unit watersheds with an interval of eight days. However, no specific analysis has been made on the water quality trends to evaluate the policy effects so far. In this study, the effects of the TMDLs were assessed based on the long-term 8-days water quality data. Using the seasonal Mann-Kendall test method, the trends of BOD and TP concentrations were evaluated during the policy implementation period in the Nakdong River Basin (NRB). Also, specific characteristics of concentration changes over the period were analyzed by using the LOWESS analysis method. In addition, the characteristics were displayed through an XYZ triplet temporal-spatial long-term trend graph.

## 2. Materials and methods

### 2.1 TMDLs in Korea

In the '90s, despite of strict regulations on effluent concentrations of domestic wastewater treatment plants (WTPs) and industrial facilities, Korea still suffered increase of pollutants and limited improvement in water quality. The major reason of the failure was thought to be the weak point of the concentration based regulation method which could not inhibit increase of effluent amount, leading to increase of loads to rivers and lakes. To overcome the problem, the government enacted the Four River Basins Act in 2002 and launched the TMDL policy in which target water quality (TWQ) was established in each TMDL unit watershed (unit watershed) and pollutant loads cap to meet the TWQ was allocated to WTPs, industrial plants, and the local governments. Even though the local governments can pursue development of their districts by permitting, for instance, new apartment construction, industrial plants, and infrastructure but they do it only within the pollution allocation. However, if they reduce pollutant loads below the cap by implementing reduction measures, further development is allowed within the increased allocation. Therefore, the TMDL was designed to promote the environment friendly regional development and at the same time, to achieve environment conservation goals in harmony.

In the NRB, there are total 41 unit watersheds for which the TWQs were established for BOD and TP in 2004 and 2010 respectively. BOD was selected as the target substance of management for the first stage of the TMDL (2004~2010) and TP was added for the second stage (2011~2015). The TWQs for both BOD and TP are determined by considering the goals of the National Water Environment Management Plan (MOE, 2016), current pollution level, available reduction measures, and financial resources. By the law, evaluating if the TWQ is met is conducted by comparing it with the evaluated water quality (EWQ) which is calculated by the following equations based on the 8-days observed data.

$$EWQ = e^{\left(Transformed\ Average\ Concentration + \frac{Transformed\ Variance}{2}\right)} \quad (1)$$

$$Transformed\ Average\ Concentration = \frac{ln(C_n) + ln(C_{n+1}) + \cdots}{n} \quad (2)$$

$$Transformed\ Variance = \frac{\{ln(C_n) - Transformed\ Average\ Concentration\}^2 + \cdots}{n-1} \quad (3)$$

Eq. 1 is the mean of a log-normal distribution and thus the equation assumes that BOD and TP data follow log-normal distributions. As the log transformation tends to squeeze together the lager values and stretches out the smaller values, the mean value by Eq. 1 is usually lower compared to the arithmetic mean when there exist some large outliers. Thus, using Eq. 1 rather than the arithmetic mean is intended for the EWQ to be less affected by the outliers and for the stability of the policy implementation. The EWQ is calculated for three consecutive years for comparison with the TWQ and if the EWQ exceeds the TWQ, the local government should establish a reduction plan for the area of exceedance.

### 2.2. Statistical methods

#### 2.2.1 Seasonal Mann-Kendall Test

This method was first proposed by Mann (1945) and a covariance of Mann-Kendall statistics was later presented by Dietz and Kileen. It was then extended to be applicable to water quality data with seasonal variation characteristics (Hirsch and Slack, 1984). The Seasonal Mann-Kendall test excludes seasonality by performing a Kendall test independently for each season. The weighted sum of each result is calculated and the results of trend analysis are derived. The Mann-Kendall for each season is

$$S_g = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(X_{jg} - X_{ig}) \quad (4)$$

where $g(\text{season}) = 1,2\ldots,p$ (Hirsch and Slack, 1984). Then the S statistic is calculated as $S = \sum_{g=1}^{p} S_g$. The degree of trend can be determined by calculating the seasonal Kendall slope estimator. The data is based on monthly average time series data for each year. An increasing trend over time is indicated when the S is positive, and a decreasing trend is indicated when it is negative (Kim, 2008). Then, the z-value of Mann-Kendall statistics is calculated and the p-value is obtained to verify the significance of the trend. The null hypothesis ($H_O$) that there is no trend is accepted if the p-value ≥ 0.05 for the significance level (α = 0.05) in the 95% confidence level at both sides. If p-value ＜0.05, $H_O$ is rejected and the alternative hypothesis ($H_I$) that there is a trend is accepted (Kim, 2001). Therefore, the water quality trend is determined after the Z statistic and p-value are obtained and the significance is verified.

Although the seasonal Mann-Kendall test is known less subject to the effect of autocorrelation then the original Mann-Kendall test, we have evaluated autocorrelation of the monthly averaged data before the tread analysis. For that, seasonality was removed from the data by decomposition and then the autocorrelation function was applied. The results indicated that there was no significant autocorrelation once seasonality was removed and therefore, the seasonal Mann-Kendall test could be applied to the data.

### 2.2.2 LOWESS Trend Analysis

The nonparametric smoothing method compensates for the disadvantages of the linear trend, which only represents the monotonic change, by reflecting an appropriate data trend without limiting the shape of the regression line to the straight line when a trend variation exists during the research period.

After determining a constant vertical section (span or window) for a variable x rather than the entire section and adjusting the distance and influence, LOWESS obtains a moving line for each value, obtains a smoother y, and connects these smooth points with a straight line. This is a useful trend analysis method that adapts data to the regression model without making any assumptions about the primary or secondary regression models. As a method of calculating the moving line$(x_i, y_i)$, the width of a horizontal window is determined to include data for the integer closest to $n \times f$ around $x = x_i$(Kim, 2014). The weight function is symmetrical to $x = x_i$ and decreases to a smooth form as it gets farther from the center.

$$T(u) = (1 - |u|^3)^3, |u| < 1 = 0, |u| \geq 1 \tag{5}$$

Therefore, if the maximum distance from $x_i$ to the horizontal window is $d_i$, the weight $w_k$ of $(x_k, y_k)$ is calculated by the following equation:

$$w_k = T(x_k - x_i/d) \tag{6}$$

The function of R for LOWESS has the form lowess (y～x, f), where f is the ratio of the smoother span to the data size. Here, $x_i = x$, and the smoothing constant f ranges from 0 〈 f 〈 1 and the default value is 1/3~2/3. A larger f results in a larger section for x and more data affects the estimation of $\hat{y}_i$. Furthermore, the selection of an appropriate f can be subjective (Helsel and Hirsch, 2002). Therefore, the appropriate f value must be determined by observing the fitness of the observation data in detail. In general, the range of 1/3 〈f 〈 2/3 is recommended for the range of f, which is a smoothing constant, and the default value is 2/3. If the smoother span f is increased, the regression function becomes a flat curve that is close to a straight line (under-fitting), and if f is decreased, the regression function has a curve with a large degree of bending (over-fitting). In this study, 1/2 was used as the smoother span f value (Cleveland and Devlin, 1988; Rodriguez-Murillo and Filella, 2015).

## 2.3. Study area

The NRB drains the southern-east mountainous area of Korean Peninsula (Fig 1). The river originates in the Taebaek Mountain, which is 1,549 m above sea level, then flows about 509.7 km to reach the sea. Along its main path, there are a lot of hydraulic structures including one large multi-purpose dam (Andong Dam), eight large weirs recently constructed, and an estuary dam before flowing into the southern sea. The river bed is steep in the upstream mountainous area and relatively gentle in the lower plain (Kim and Park, 2004). The basin area is about 5,505 $km^2$, which consists of fields (6.9%), rice fields (10.4%), land (6.7%), forest area (68.6%), and others (7.4%). Large-scale industrial areas have been established in the middle and lower parts of the basin and the river supplies drinking water for about 13 million people (Jung, 2009). As part of the recent major river engineering project, eight large weirs within about 200 km river reach on the middle part of the river have been installed in 2012, which altered the flow regime and water quality. The sum of water storage capacity of the weirs is approximately 530 million tons, accounting for about 17% of the total capacity of the multipurpose dams in the basin (NIER, 2013).

The annual average precipitation of the meteorological stations in the NRB for 10 years from 2004 to 2013 was 1,180.7 mm and the precipitation from July to September accounted for 54.0% of the total precipitation. The geological structure is mainly composed of sedimentary rocks and partially metamorphosed rocks. The basin is divided into 41 TMDL unit watersheds where the watershed geography and TWQ are set as shown in Fig. 1.

## 2.4 Water quality data

BOD, TP, and flow rate data from 2004 to 2015 observed at the outlets of 41 unit watersheds of the Nakdong River basin were used for this study. The samples for water quality were taken at two depths: one third and two thirds of the total depth of the river. This was repeated at points on the right, left, and in the middle of the river. Subsequently, the samples were combined into one composite sample. They were transported in shielded and refrigerated (4℃) conditions to prevent head space and analyzed in the laboratory for BOD and TP according to the official water pollution test method (MOE, 2008). For the BOD analysis, an analytical method was used, which measures the amount of dissolved oxygen required for aerobic bacteria to oxidize organic matter in water and quantifies it as the amount of oxygen consumed by culturing them in a thermostat at 20 °C for five days. The UV/Visible Spectrometry-Ascorbic acid method was used for the TP analysis in which inorganic compounds and organic phosphorus compounds contained in a sample are oxidized and decomposed by the potassium persulfate decomposition method or the nitric acid-sulfuric acid

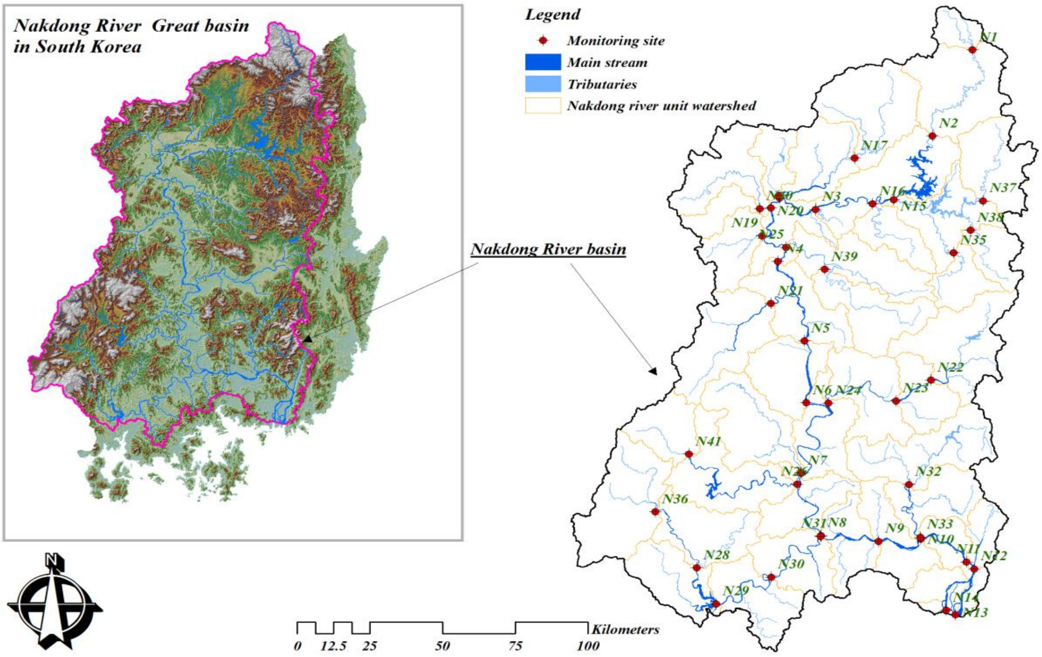



Fig. 1 41 TMDL unit watersheds of the Nakdong River Basin

Table 1 List of codes of 41 unit watersheds and associated streams

| Stream | Code | | |
|---|---|---|---|
| Main stream | N1, N2, N3, N4, N5, N6, N7, N8, N9, N10, N11, N12, N13, N14 | | |
| Namgang | N17, N28, N29, N30, N31 | | |
| Geumho | N22, N23, N24 | | |
| Stream | Code | Stream | Code |
| Banbyeon | N15, N37 | Byeongseong | N19 |
| Micheon | N16 | Yeonggang | N20 |
| Wicheon | N25, N39 | Hoecheon | N27 |
| Geumcheon | N34 | Yongjeon | N38 |
| Naeseong | N18, N36 | Gamcheon | N21 |
| Hwanggang | N26, N41 | Miryang | N32, N33 |
| Gilan | N35 | Ian | N40 |

decomposition method to convert all phosphorus compounds into phosphate ($PO_4$). TP is later determined quantitatively by acetic acid reduction spectrophotometry (Perkin Elmer UV/VIS lambda 35). Table 1 shows the codes of the 41 unit watersheds and the associated stream names.

## 3. Results and Discussion

### *3.1 Analysis of water quality characteristics*

In order to select an appropriate statistical technique for trend analysis, the characteristics of the data should be analyzed beforehand. To analyze the data in an exploratory manner, the distribution of data was expressed as five values: minimum (min), lower quartile (first quartile: $H_L$), median ($M$), upper quartile (third quartile: $H_U$), and maximum (max) (Fig. 2). The range between the first and third quartiles (*Spr(H)*) is a measure of the degree of data scattering (NRERC, 2009). Among the points, N14 and N24 showed average BOD concentrations of 3.8 mg/L and 3.7 mg/L, highest compared to other points. They also showed a large degree of scattering around the median. For TP, N7 and N21 showed highest concentrations, 0.159 mg/L and 0.184 mg/L among the points. The *Spr (H)* was found to be largest for N19, N21, and N24. For the given data, a point with a smaller *Spr(H)* tends to have a smaller number of pollution sources, and a point with a large range has a large number of pollution sources. The *Spr(H)* was large at N7 located in the middle part of the Nakdong River, which is influenced by small surrounding towns and industrial complexes, N14 downstream of the river, which is influenced by integrated sewage and wastewater, and N19 and N24 where the river flows through downtowns of cities. Overall, the water quality of upstream rivers with fewer artificial pollution sources was relatively good. The BOD and TP values were marginally influenced by the geographical location of the site, but is influenced more by anthropogenic activities, which affects the pollution levels of the surrounding water bodies. This result is consistent with previous studies in the tributaries of the Yeongsan River, Jicheon and Seomjin Rivers (Jung *et al*., 2013; Park *et al*., 2014; Kim, 2014).

### *3.2 Evaluation of target water quality*

Whether TWQs are achieved for BOD and TP is determined by using the log-transformed average method. The log-transformed averages for the BOD and TP data at the 41 unit-watershed points from 2013 to 2015 were

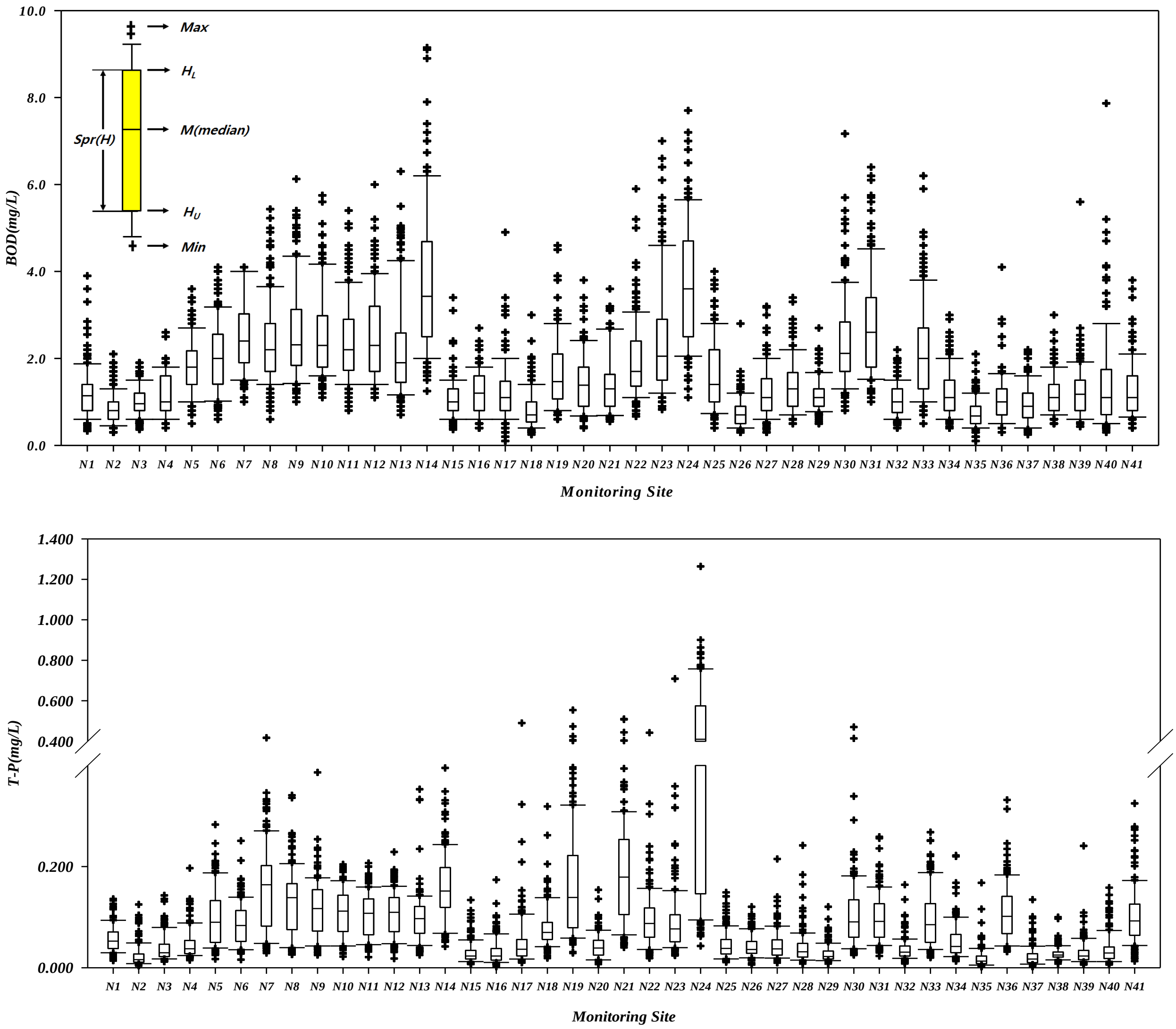



Fig. 2 Box plot of water duality at TMDL unit watersheds of the Nakdong River

calculated and shown together with TWQs in Tables 2 and 3. We evaluated whether the TWQs have been met within the latest 2nd phase of the TMDL (2011~2015). The EWQ was evaluated by using the Eqs. (1) ~ (3) for three consecutive years. This was done for the periods of 2011~2013, 2012~2014, and 2013~2015. In the current regulation, if the evaluated water quality exceeds the TWQ twice in succession, then the watershed fails to meet the TWQ and should establish new implementation plan for further reducing the pollution loads

The results for the three periods were different from one another, and the TP results showed a higher achievement rate of TWQ over time than those of BOD. In the BOD evaluation, the EWQ of N6 was 2.1 mg/L for 2011~2013, 2.4 mg/L for 2012~2014, and 2.3 mg/L for 2013~2015. Thus, the TWQ of 2.0 mg/L was exceeded three times in a row. N25 also exceeded the TWQ of 1.5 mg/L three times in a row.

The TP evaluation results in Table 3 show that the water quality of N18 evaluated by the current evaluation method was 0.087 mg/L for 2011~2013, 0.073 mg/L, for so 2012~2014, and 0.057 mg/L for 2013~2015, exceeding the TWQ of 0.053 mg/L three times in a row. N26 and N32 al exceeded the TWQs of 0.034 mg/L and 0.031 mg/L three times in a row. As shown in Table 3, 38 points excluding the three points achieved the TWQ for the period of 2013~2015 compared to 23 points for 2011~2013, 33 points for 2012~2014, indicating significant improvement of TP concentration after the enforcement of the TMDL policy.

### *3.3. Analysis of BOD concentration trends*

A long-term (12 years, from 2004 to 2015) trend analysis of BOD concentration in the NRB was carried out using the seasonal Mann-Kendall test and the LOWESS method, and the results are as follows (Tables 4, 5 and Figs. 3, 4). The trend analysis results of the seasonal Mann-Kendall test are divided into upward, downward, and no trend categories, and the slope is a measure of the seasonal Kendall slope statistic, which signifies the magnitude of the change (Kim *et al*., 2014; Jung *et al*., 2016). The seasonal Mann-Kendall test applied to the main stream

Table 2 Results of assessment of TWQ satisfaction for BOD

| Site Code | Unit watershed | TWQ (mg/L) | EWQ | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ‘11 ˜ ’13 | Evaluation | ‘12 ˜ ’14 | Evaluation | ‘13 ˜ ’15 | Evaluation |
| N1 | Nakbon A | 1.5 | 1.2 | ○ | 1.2 | ○ | 1.2 | ○ |
| N2 | Nakbon B | 1.4 | 0.9 | ○ | 1.0 | ○ | 1.1 | ○ |
| N3 | Nakbon C | 1.5 | 1.1 | ○ | 1.1 | ○ | 1.0 | ○ |
| N4 | Nakbon D | 1.5 | 1.4 | ○ | 1.5 | ○ | 1.6 | × |
| N5 | Nakbon E | 1.8 | 1.7 | ○ | 2.1 | × | 2.2 | × |
| N6 | Nakbon F | 2.0 | 2.1 | × | 2.4 | × | 2.3 | × |
| N7 | Nakbon G | 2.9 | 2.3 | ○ | 2.5 | ○ | 2.6 | ○ |
| N8 | Nakbon H | 2.7 | 2.1 | ○ | 2.5 | ○ | 2.4 | ○ |
| N9 | Nakbon I | 3.1 | 2.1 | ○ | 2.3 | ○ | 2.2 | ○ |
| N10 | Nakbon J | 2.9 | 2.2 | ○ | 2.4 | ○ | 2.4 | ○ |
| N11 | Nakbon K | 3.0 | 2.0 | ○ | 2.3 | ○ | 2.2 | ○ |
| N12 | Nakbon L | 3.1 | 2.3 | ○ | 2.5 | ○ | 2.3 | ○ |
| N13 | Nakbon M | 2.5 | 1.9 | ○ | 2.0 | ○ | 2.1 | ○ |
| N14 | Nakbon N | 4.3 | 3.9 | ○ | 4.1 | ○ | 4.0 | ○ |
| N15 | Banbyeon B | 1.4 | 1.1 | ○ | 1.3 | ○ | 1.4 | ○ |
| N16 | Micheon A | 1.5 | 1.2 | ○ | 1.3 | ○ | 1.3 | ○ |
| N17 | Namgang A | 1.5 | 1.2 | ○ | 1.4 | ○ | 1.4 | ○ |
| N18 | Naeseong B | 1.5 | 0.9 | ○ | 0.9 | ○ | 0.9 | ○ |
| N19 | Byeongseong A | 2.0 | 1.6 | ○ | 1.7 | ○ | 1.8 | ○ |
| N20 | Yeonggang A | 1.5 | 1.4 | ○ | 1.4 | ○ | 1.5 | ○ |
| N21 | Gamcheon A | 1.8 | 1.5 | ○ | 1.5 | ○ | 1.3 | ○ |
| N22 | Geumho A | 1.9 | 1.8 | ○ | 1.7 | ○ | 1.7 | ○ |
| N23 | Geumho B | 3.8 | 3.1 | ○ | 3.0 | ○ | 3.7 | ○ |
| N24 | Geumho C | 4.0 | 3.5 | ○ | 3.6 | ○ | 4.0 | ○ |
| N25 | Wicheon B | 1.5 | 1.8 | × | 2.1 | × | 2.4 | × |
| N26 | Hwanggang B | 1.0 | 0.7 | ○ | 0.8 | ○ | 0.9 | ○ |
| N27 | Hoecheon A | 1.5 | 1.3 | ○ | 1.6 | × | 1.6 | × |
| N28 | Namgang B | 1.6 | 1.3 | ○ | 1.5 | ○ | 1.6 | ○ |
| N29 | Namgang C | 1.2 | 1.1 | ○ | 1.1 | ○ | 1.3 | × |
| N30 | Namgang D | 2.5 | 2.0 | ○ | 1.8 | ○ | 1.9 | ○ |
| N31 | Namgang E | 3.1 | 2.5 | ○ | 2.4 | ○ | 2.4 | ○ |
| N32 | Miryang A | 1.4 | 1.1 | ○ | 1.2 | ○ | 1.3 | ○ |
| N33 | Miryang B | 2.5 | 1.9 | ○ | 1.9 | ○ | 2.1 | ○ |
| N34 | Geumcheon A | 1.5 | 1.3 | ○ | 1.4 | ○ | 1.4 | ○ |
| N35 | Gilan A | 1.5 | 0.7 | ○ | 0.7 | ○ | 0.9 | ○ |
| N36 | Naeseong A | 1.5 | 0.9 | ○ | 1.1 | ○ | 1.1 | ○ |
| N37 | Banbyeon A | 1.4 | 0.9 | ○ | 0.9 | ○ | 1.1 | ○ |
| N38 | Yongjeon A | 1.4 | 1.2 | ○ | 1.4 | ○ | 1.3 | ○ |
| N39 | Wicheon A | 1.5 | 1.2 | ○ | 1.0 | ○ | 1.0 | ○ |
| N40 | Ian A | 2.0 | 1.0 | ○ | 1.3 | ○ | 1.8 | ○ |
| N41 | Hwanggang A | 1.5 | 1.3 | ○ | 1.4 | ○ | 1.6 | × |

Table 3 Results of assessment of TWQ satisfaction for TP

| Site | Unit | TWQ | EWQ(current) | | | | | |
|---|---|---|---|---|---|---|---|---|
| Code | watershed | (mg/L) | ‘11 ˜ ’13 (mg/L) | Evaluation | ‘12 ˜ ’14 (mg/L) | Evaluation | ‘13 ˜ ’15 (mg/L) | Evaluation |
| N1 | Nakbon A | 0.057 | 0.047 | ○ | 0.046 | ○ | 0.047 | ○ |
| N2 | Nakbon B | 0.022 | 0.025 | × | 0.025 | × | 0.022 | ○ |
| N3 | Nakbon C | 0.033 | 0.040 | × | 0.030 | ○ | 0.024 | ○ |
| N4 | Nakbon D | 0.045 | 0.051 | × | 0.040 | ○ | 0.035 | ○ |
| N5 | Nakbon E | 0.053 | 0.086 | × | 0.061 | × | 0.050 | ○ |
| N6 | Nakbon F | 0.060 | 0.083 | × | 0.064 | × | 0.052 | ○ |
| N7 | Nakbon G | 0.137 | 0.121 | ○ | 0.080 | ○ | 0.062 | ○ |
| N8 | Nakbon H | 0.094 | 0.101 | × | 0.072 | ○ | 0.056 | ○ |
| N9 | Nakbon I | 0.093 | 0.087 | ○ | 0.068 | ○ | 0.054 | ○ |
| N10 | Nakbon J | 0.078 | 0.084 | × | 0.066 | ○ | 0.055 | ○ |
| N11 | Nakbon K | 0.074 | 0.083 | × | 0.069 | ○ | 0.054 | ○ |
| N12 | Nakbon L | 0.074 | 0.093 | × | 0.072 | ○ | 0.057 | ○ |
| N13 | Nakbon M | 0.069 | 0.090 | × | 0.062 | ○ | 0.052 | ○ |
| N14 | Nakbon N | 0.115 | 0.136 | × | 0.126 | × | 0.115 | ○ |
| N15 | Banbyeon B | 0.034 | 0.026 | ○ | 0.025 | ○ | 0.023 | ○ |
| N16 | Micheon A | 0.032 | 0.036 | × | 0.034 | × | 0.029 | ○ |
| N17 | Namgang A | 0.052 | 0.046 | ○ | 0.051 | ○ | 0.048 | ○ |
| N18 | Naeseong B | 0.053 | 0.087 | × | 0.073 | × | 0.057 | × |
| N19 | Byeongseong A | 0.130 | 0.111 | ○ | 0.088 | ○ | 0.074 | ○ |
| N20 | Yeonggang A | 0.050 | 0.034 | ○ | 0.031 | ○ | 0.026 | ○ |
| N21 | Gamcheon A | 0.110 | 0.114 | × | 0.096 | ○ | 0.079 | ○ |
| N22 | Geumho A | 0.104 | 0.068 | ○ | 0.061 | ○ | 0.056 | ○ |
| N23 | Geumho B | 0.236 | 0.113 | ○ | 0.093 | ○ | 0.080 | ○ |
| N24 | Geumho C | 0.254 | 0.276 | × | 0.164 | ○ | 0.112 | ○ |
| N25 | Wicheon B | 0.045 | 0.050 | × | 0.044 | ○ | 0.040 | ○ |
| N26 | Hwanggang B | 0.034 | 0.043 | × | 0.043 | × | 0.036 | × |
| N27 | Hoecheon A | 0.060 | 0.047 | ○ | 0.040 | ○ | 0.035 | ○ |
| N28 | Namgang B | 0.043 | 0.037 | ○ | 0.041 | ○ | 0.037 | ○ |
| N29 | Namgang C | 0.034 | 0.026 | ○ | 0.027 | ○ | 0.026 | ○ |
| N30 | Namgang D | 0.112 | 0.071 | ○ | 0.057 | ○ | 0.050 | ○ |
| N31 | Namgang E | 0.109 | 0.076 | ○ | 0.064 | ○ | 0.056 | ○ |
| N32 | Miryang A | 0.031 | 0.036 | × | 0.039 | × | 0.037 | × |
| N33 | Miryang B | 0.074 | 0.063 | ○ | 0.046 | ○ | 0.045 | ○ |
| N34 | Geumcheon A | 0.067 | 0.054 | ○ | 0.059 | ○ | 0.054 | ○ |
| N35 | Gilan A | 0.023 | 0.015 | ○ | 0.018 | ○ | 0.018 | ○ |
| N36 | Naeseong A | 0.110 | 0.086 | ○ | 0.073 | ○ | 0.058 | ○ |
| N37 | Banbyeon A | 0.025 | 0.020 | ○ | 0.021 | ○ | 0.020 | ○ |
| N38 | Yongjeon A | 0.046 | 0.031 | ○ | 0.031 | ○ | 0.027 | ○ |
| N39 | Wicheon A | 0.045 | 0.029 | ○ | 0.028 | ○ | 0.026 | ○ |
| N40 | Ian A | 0.047 | 0.031 | ○ | 0.039 | ○ | 0.040 | ○ |
| N41 | Hwanggang A | 0.100 | 0.089 | ○ | 0.076 | ○ | 0.060 | ○ |

Table 4 Seasonal Mann-Kendall trend for BOD from 2004 to 2015 for 14 unit watersheds on the main stream

| Site code | Unit watershed | Statistic S | p-value | Slope (mg/L/y) | Trend | |
|---|---|---|---|---|---|---|
| N1 | Nakbon A | 27.0 | 0.2033 | 0.0167 | no trend | - |
| N2 | Nakbon B | 51.0 | 0.0142 | 0.0375 | upward | ▲ |
| N3 | Nakbon C | 46.0 | 0.0258 | 0.0250 | upward | ▲ |
| N4 | Nakbon D | 99.0 | 0.0000 | 0.1000 | upward | ▲ |
| N5 | Nakbon E | 27.0 | 0.1953 | 0.0300 | no trend | - |
| N6 | Nakbon F | 60.0 | 0.0039 | 0.0646 | upward | ▲ |
| N7 | Nakbon G | -36.0 | 0.0872 | -0.0414 | no trend | - |
| N8 | Nakbon H | -9.0 | 0.6971 | -0.0413 | no trend | - |
| N9 | Nakbon I | -58.0 | 0.0055 | -0.1067 | downward | ▼ |
| N10 | Nakbon J | -53.0 | 0.0114 | -0.0688 | downward | ▼ |
| N11 | Nakbon K | -28.0 | 0.1884 | -0.0333 | no trend | - |
| N12 | Nakbon L | -31.0 | 0.1443 | -0.0500 | no trend | - |
| N13 | Nakbon M | -20.0 | 0.3558 | -0.0349 | no trend | - |
| N14 | Nakbon N | 13.0 | 0.5583 | 0.0113 | no trend | - |

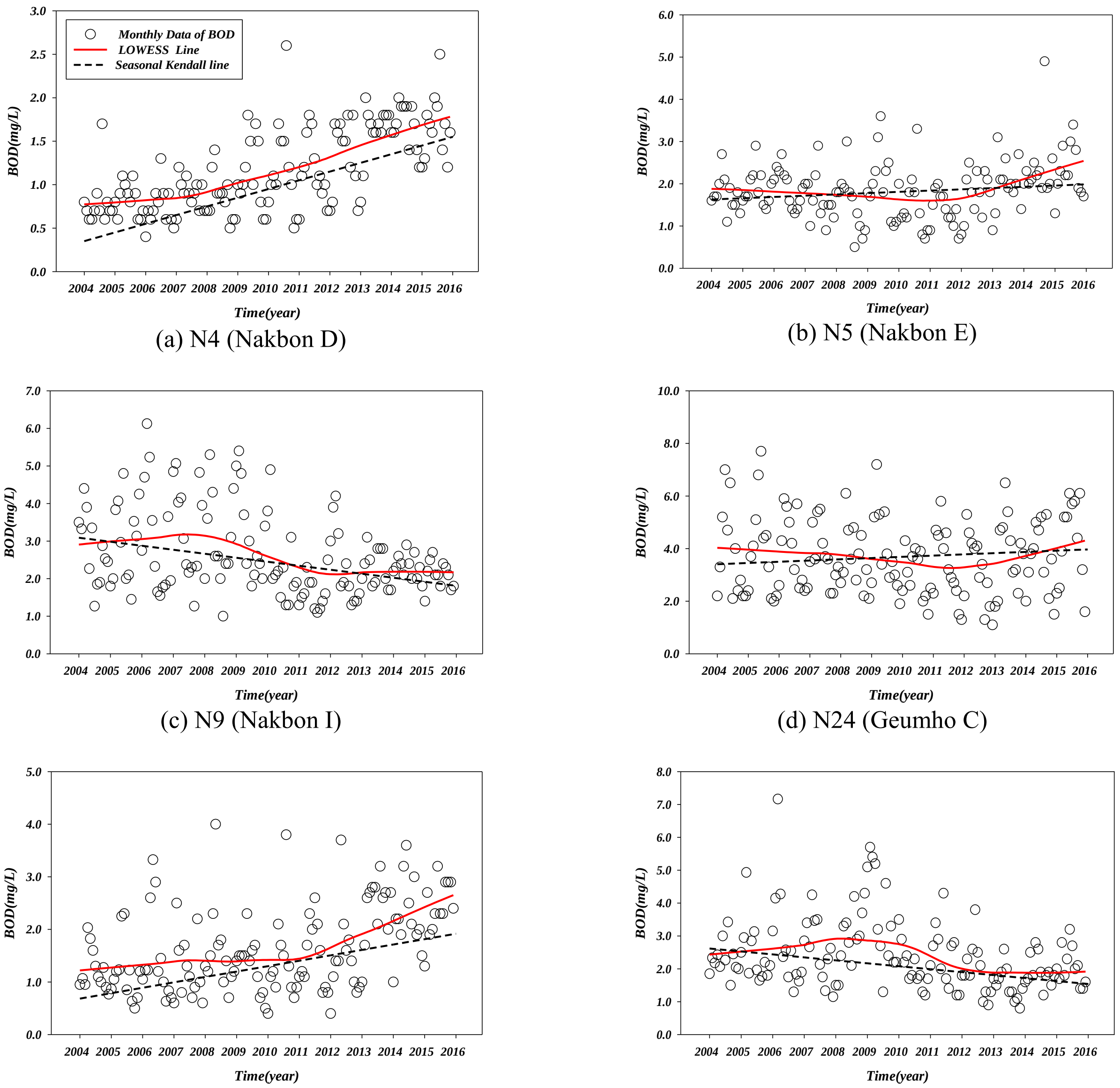
of the Nakdong River revealed that the BOD concentration of N2, N3, N4 and N6, which corresponds to the upstream watersheds among the 14 unit watersheds embracing the main stream, showed an upward trend at the significancelevel of 0.05 or lower with the 95% confidence level. On the other hand, the p-value showed a statistically significant downward trend for the two watersheds N9 and N10 located downstream. The N4 showed a trend of continuous increase during the research period and remained below the TWQ for a while, before exceeding the TWQ of 1.5 mg/L once during the 2013 ~ 2015 period. The N5 point showed no trend, but the LOWESS analysis results showed an increasing trend from 2013. This point also was maintained well below the TWQ during the TMDL period, but exceeded the TWQ 1.8 mg/L twice during the 2012~2014 and 2013~2015 periods. N15, N25, N27, N32, N34, and N41, which correspond to the tributaries, showed a statistically significant upward trend with the S statistics of 101, 79, 64, 49, 53, and 47, respectively. The N30 was the only point that showed a statistically significant downward trend with the S statistic of -59. Results of the LOWESS analysis showed that the overall concentration tended to decrease in this watershed, indicating water quality improvement by the enforcement of the TMDL policy. The other 20 points did not show any trend of change. N24 showed an increasing concentration trend since 2011, but as a result of trend analysis for the whole period, the concentration increased with the slope of 0.0.0469 $mgL^{-1}y^{-1}$. As a result of the seasonal Mann-Kendall test for the research period, 13 unit watershed points in the NRB showed concentrations change. The change rate of each point was illustrated and compared to each other (Fig. 4). The unit watersheds that showed the largest increase in concentration were N4 and N25, whereas N9 and N30 showed the largest decrease. N17, N19, N20, N26, N28, and N36 showed the smallest decrease.

Table 5 Seasonal Mann-Kendall trend for BOD from 2004 to 2015 for 27 unit watersheds for the tributaries

| Site code | Unit watershed | Statistic S | p-value | Slope (mg/L/y) | Trend | |
|---|---|---|---|---|---|---|
| N15 | Banbyeon B | 101.0 | 0.0000 | 0.0500 | upward | ▲ |
| N16 | Micheon A | 14.0 | 0.5252 | 0.0146 | no trend | - |
| N17 | Namgang A | -4.0 | 0.8832 | 0.0000 | no trend | - |
| N18 | Naeseong B | 43.0 | 0.0388 | 0.0167 | upward | ▲ |
| N19 | Byeongseong A | 5.0 | 0.8445 | 0.0000 | no trend | - |
| N20 | Yeonggang A | 1.0 | 1.0000 | 0.0000 | no trend | - |
| N21 | Gamcheon A | 15.0 | 0.4888 | 0.0061 | no trend | - |
| N22 | Geumho A | 6.0 | 0.8069 | 0.0023 | no trend | - |
| N23 | Geumho B | 39.0 | 0.0644 | 0.0500 | no trend | - |
| N24 | Geumho C | 21.0 | 0.3316 | 0.0469 | no trend | - |
| N25 | Wicheon B | 79.0 | 0.0001 | 0.1028 | upward | ▲ |
| N26 | Hwanggang B | -2.0 | 0.9609 | 0.0000 | no trend | - |
| N27 | Hoecheon A | 64.0 | 0.0021 | 0.0688 | upward | ▲ |
| N28 | Namgang B | 4.0 | 0.8832 | 0.0000 | no trend | - |
| N29 | Namgang C | 26.0 | 0.2196 | 0.0140 | no trend | - |
| N30 | Namgang D | -59.0 | 0.0048 | -0.0900 | downward | ▼ |
| N31 | Namgang E | -23.0 | 0.2829 | -0.0415 | no trend | - |
| N32 | Miryang A | 49.0 | 0.0185 | 0.0333 | upward | ▲ |
| N33 | Miryang B | 5.0 | 0.8457 | 0.0087 | no trend | - |
| N34 | Geumcheon A | 53.0 | 0.0114 | 0.0500 | upward | ▲ |
| N35 | Gilan A | 37.0 | 0.0765 | 0.0174 | no trend | - |
| N36 | Naeseong A | 1.0 | 1.0000 | 0.0000 | no trend | - |
| N37 | Banbyeon A | 14.0 | 0.5209 | 0.0056 | no trend | - |
| N38 | Yongjeon A | 16.0 | 0.4635 | 0.0133 | no trend | - |
| N39 | Wicheon A | -35.0 | 0.0925 | -0.0167 | no trend | - |
| N40 | Ian A | 28.0 | 0.1880 | 0.0387 | no trend | - |
| N41 | Hwanggang A | 47.0 | 0.0245 | 0.0345 | upward | ▲ |

### *3.4 Analysis of TP concentration trends*

Similarly, a long-term trend analysis of TP concentration was conducted. The results are shown in Tables 6, 7 and Figs. 5, 6. The seasonal Mann-Kendall test results showed that the TP concentrations of the 9 watersheds among the 14 mainstream unit watersheds were in statistically significant downward trends. N5 showed an increasing trend of TP concentration during the 1st phase; however, after the addition of TP as the target substance in the 2nd phase, a decreasing trend was observed from 2011 by the LOWESS analysis. Consequently, in the period between 2013~2015, the TWQ (0.053 mg/L) was achieved. N11, which is a representative point of the Nakdong River, also satisfied the TWQ of 0.074mg/L during the period between 2012~2014 and 2013~2015 after the enforcement of the TMDL. As of July 2011, phosphorous treatment plants were installed or operated in the sewage and wastewater treatment facilities at 50 locations in Busan and Gyeongnam (NDG 2012), and




(a) N4 (Nakbon D)

(b) N5 (Nakbon E)

(c) N9 (Nakbon I)

(d) N24 (Geumho C)

(e) N25 (Wicheon B)

(f) N30 (Namgang D)

Fig. 3 Results of trend analysis of BOD concentration in the Nakdong River unit watershed (example)

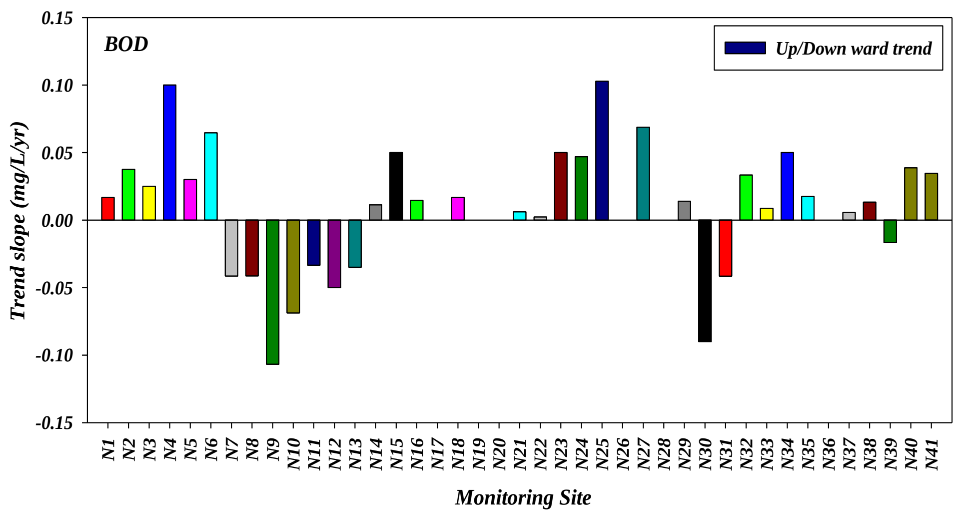
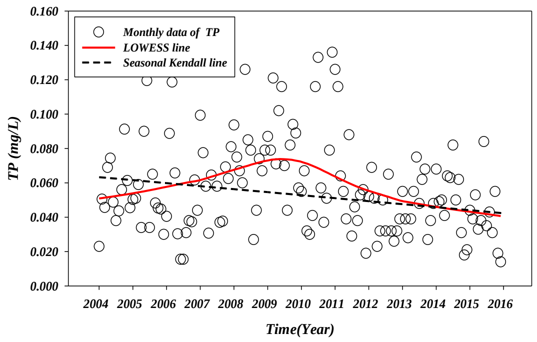
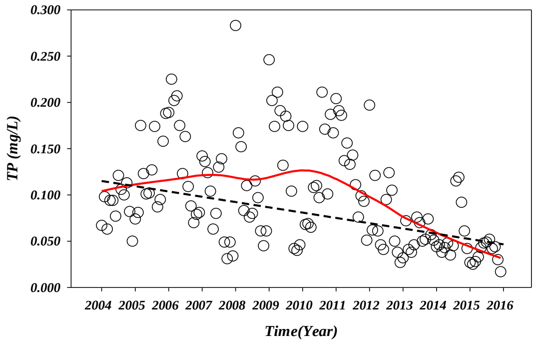


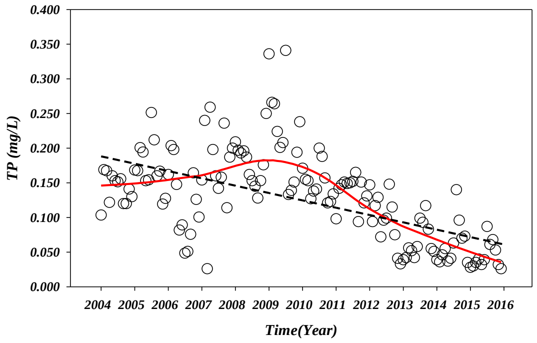

Fig. 4 Slopes of BOD trend at each unit watershed in the Nakdong River



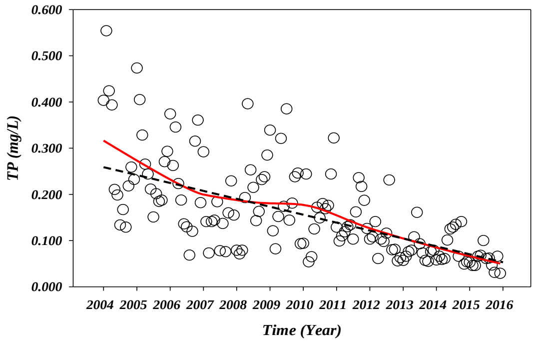

(a) N1 (Nakbon A)



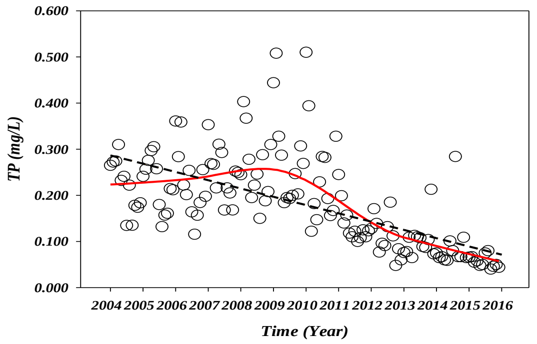

(b) N5 (Nakbon E)



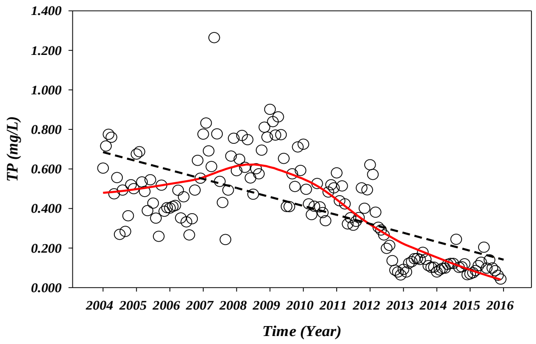

(c) N11 (Nakbon K)




(d) N19 (Byeongseong A)




(e) N21 (Gamcheon A)




(f) N24 (Geumho C)

Fig. 5 Results of trend analysis of TP concentration in Nakdong River unit watershed (example)

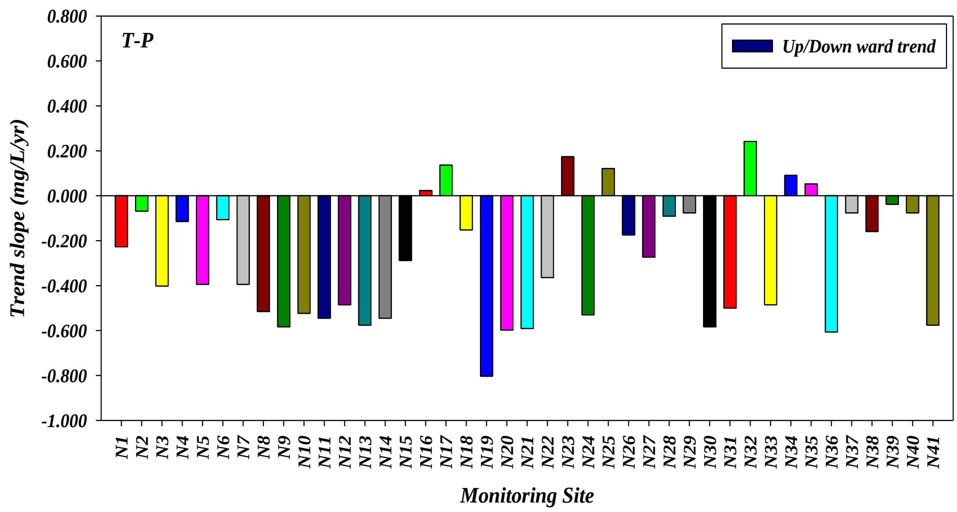



Fig. 6 Slopes of TP trend at each unit watershed in Nakdong River

Table 6 Seasonal Mann-Kendall trend for TP from 2004 to 2015 for 14 unit watersheds on the main stream

| Site code | Unit watershed | Statistic S | p-value | Slope (mg/L/yr) | Trend | |
|---|---|---|---|---|---|---|
| N1 | Nakbon A | -30.0 | 0.1597 | -0.0018 | no trend | - |
| N2 | Nakbon B | -9.0 | 0.6971 | -0.0002 | no trend | - |
| N3 | Nakbon C | -53.0 | 0.0116 | -0.0015 | no trend | - |
| N4 | Nakbon D | -15.0 | 0.4967 | -0.0009 | no trend | - |
| N5 | Nakbon E | -52.0 | 0.0132 | -0.0057 | downward | ▼ |
| N6 | Nakbon F | -14.0 | 0.5285 | -0.0019 | no trend | - |
| N7 | Nakbon G | -52.0 | 0.0134 | -0.0124 | downward | ▼ |
| N8 | Nakbon H | -68.0 | 0.0012 | -0.0106 | downward | ▼ |
| N9 | Nakbon I | -77.0 | 0.0002 | -0.0093 | downward | ▼ |
| N10 | Nakbon J | -69.0 | 0.0010 | -0.0077 | downward | ▼ |
| N11 | Nakbon K | -72.0 | 0.0006 | -0.0080 | downward | ▼ |
| N12 | Nakbon L | -64.0 | 0.0023 | -0.0076 | downward | ▼ |
| N13 | Nakbon M | -76.0 | 0.0003 | -0.0063 | downward | ▼ |
| N14 | Nakbon N | -72.0 | 0.0006 | -0.0087 | downward | ▼ |

Table 7 Seasonal Mann-Kendall trend for TP from 2004 to 2015 for 27 unit watersheds for the tributaries

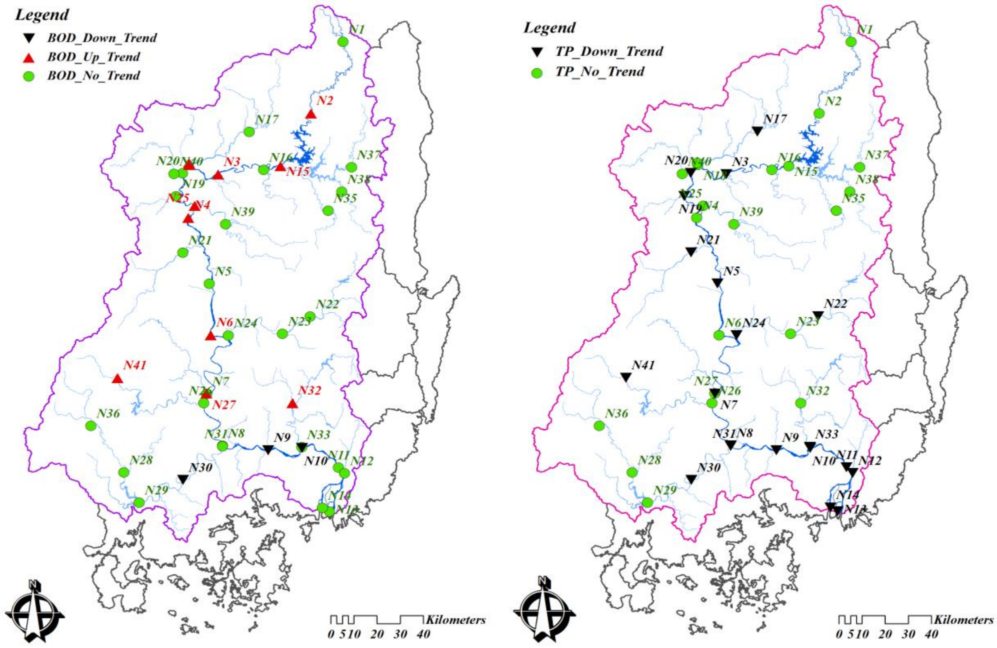
| Site code | Unit watershed | Statistic S | p-value | Slope (mg/L/yr) | Trend | |
|---|---|---|---|---|---|---|
| N15 | Banbyeon B | -38.0 | 0.0728 | -0.0011 | no trend | - |
| N16 | Micheon A | 3.0 | 0.9225 | 0.0001 | no trend | - |
| N17 | Namgang A | 18.0 | 0.4098 | 0.0005 | no trend | - |
| N18 | Naeseong B | -20.0 | 0.3569 | -0.0005 | no trend | - |
| N19 | Byeongseong A | -106.0 | 0.0000 | -0.0172 | downward | ▼ |
| N20 | Yeonggang A | -79.0 | 0.0002 | -0.0027 | downward | ▼ |
| N21 | Gamcheon A | -78.0 | 0.0002 | -0.0179 | downward | ▼ |
| N22 | Geumho A | -48.0 | 0.0227 | -0.0046 | downward | ▼ |
| N23 | Geumho B | 23.0 | 0.2855 | 0.0012 | no trend | - |
| N24 | Geumho C | -70.0 | 0.0008 | -0.0454 | downward | ▼ |
| N25 | Wicheon B | 16.0 | 0.4660 | 0.0004 | no trend | - |
| N26 | Hwanggang B | -23.0 | 0.2844 | -0.0005 | no trend | - |
| N27 | Hoecheon A | -36.0 | 0.0889 | -0.0012 | no trend | - |
| N28 | Namgang B | -12.0 | 0.5929 | -0.0003 | no trend | - |
| N29 | Namgang C | -10.0 | 0.6611 | -0.0003 | no trend | - |
| N30 | Namgang D | -77.0 | 0.0002 | -0.0083 | downward | ▼ |
| N31 | Namgang E | -66.0 | 0.0016 | -0.0063 | downward | ▼ |
| N32 | Miryang A | 32.0 | 0.1310 | 0.0009 | no trend | - |
| N33 | Miryang B | -64.0 | 0.0023 | -0.0083 | downward | ▼ |
| N34 | Geumcheon A | 12.0 | 0.5920 | 0.0006 | no trend | - |
| N35 | Gilan A | 7.0 | 0.7703 | 0.0001 | no trend | - |
| N36 | Naeseong A | -80.0 | 0.0001 | -0.0096 | downward | ▼ |
| N37 | Banbyeon A | -10.0 | 0.6611 | -0.0002 | no trend | - |
| N38 | Yongjeon A | -21.0 | 0.3305 | 0.0004 | no trend | - |
| N39 | Wicheon A | -5.0 | 0.8460 | -0.0002 | no trend | - |
| N40 | Ian A | -10.0 | 0.6626 | -0.0004 | no trend | - |
| N41 | Hwanggang A | -76.0 | 0.0003 | -0.0070 | downward | ▼ |

the TP concentration showed a downward trend compared to the BOD. The other five among the 14 unit watersheds showed no trend as a result of the Seasonal Mann-Kendall Test; however, all of them showed decreasing trends at the slopes of –0.0018, -0.0002, -0.0015, -0.0009, and -0.0019 $mgL^{-1}y^{-1}$. In the case of tributaries, no points showed upward trends. At 10 points, including N19, N20, N21, N30, N33, N36, and N41, the S statistics ranged from −106 to −76 and the p-values indicated statistically significant downward trends. In particular, N19 showed a steady decrease in concentration from the onset, and the decreasing rate was −0.0172 $mgL^{-1}y^{-1}$. N21, which flows to the upstream of the Nakdong River, and N24, which flows into the middle section, showed no change in concentration in the early stage of the TMDL as a result of the LOWESS analysis; however, the concentration increased during the period between 2007 to 2010, and decreased steadily thereafter. As a result of the Seasonal Mann-Kendall Test and the LOWESS analysis for the TP concentration, the S statistics showed a statistically significant downward trend, indicating a positive effect of the TMDL policy. As a result of the Seasonal Mann-Kendall Test during the TMDL period, there were 19 points where a TP concentration change occurred among all the unit watersheds of the Nakdong River system, as shown in Tables 6, 7. Among them, N19 showed the largest decrease whereas N16 and N35 showed the smallest decrease.

### *3.5. Analysis of the effects of TMDL policy on water quality*

In order to analyze the spatial distribution of the water quality change trends during the first and second phases of the TMDL policy, the tributaries and the main stream of the Nakdong River and the analysis results of the Seasonal Mann-Kendall Test are shown in Fig. 7. The results showed that the BOD concentration was nearly constant or increased slightly at most points. In contrast, the TP concentration decreased or was nearly constant at most points. The TP concentration showed downward trends at most of the main stream points. For BOD, 7.8 % of the 41 points showed downward trends, 26.8 % and the rest 65.9% showed upward and no trends. Among the main stream points, 14.3% were in downward trends, 28.6% and 57.1% were in upward and no trends while for the tributaries, 3.7% were in downward trends, 25.9% and 70.4% were in upward and no trends. Although overall trends of BOD were mostly no trend or upward, relatively more points were improved in the main stream compared to the points of the tributaries. This is probably due to additions of new sewage treatment plants intensively near the main stream and tightened discharge standards.

For TP, 51.2% showed no trends and the rest 48.8% showed downward trends. No point showed an upward trend. For the main stream points, 71.4% and 28.6% were in downward and no trends. For the tributary points, 37.0% and 63.0% were in downward and no trends. This improvement may be attributed to the TP chemical




(a) BOD (b) TP

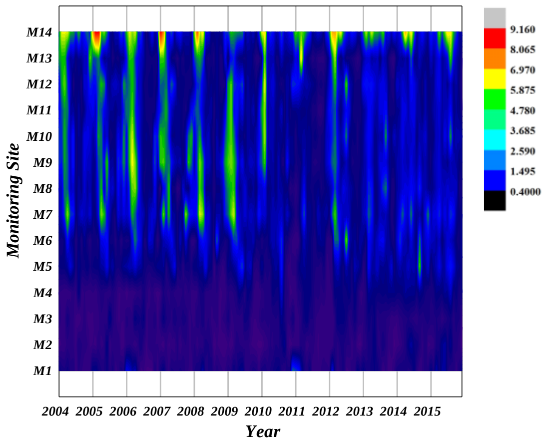
Fig. 7 Results of Seasonal Kendall trend from 2004 to 2015

treatment process introduced to the existing wastewater treatment plants during the analysis period.

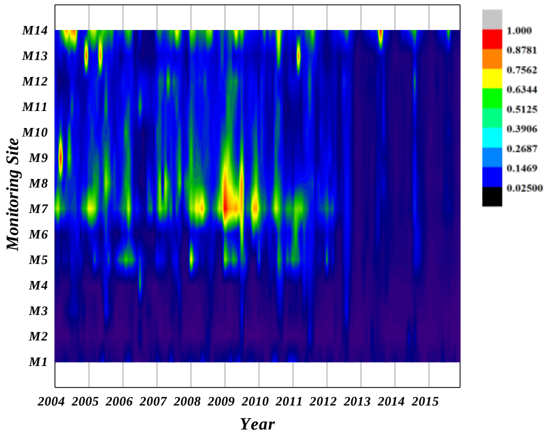
The changes in BOD and TP concentrations are generally influenced by changes in flow rate, water temperature, and algal growth as well as changes in the discharge loads from pollution sources in watersheds. However, we conjecture that the long-term change in trends must be influenced by the decrease in discharge load caused by the enforcement of the TMDL policy.

In the LOWESS analysis results, the up-and-down trends of BOD concentration were observed at some points such as N4, N9, and N25. In particular, the N25 point showed clear changes in water quality beginning from 2011. Moreover, since 2009, N4 also showed a steady increase in rate, thus requiring water quality management. Among the unit watersheds with increasing trends, N2, N3, N15, N32, and N34 showed smaller increases. The implications of these increases are negligible because all these points have met the TWQs. Other points showed no significant changes, which were similar to the results of the Seasonal Mann-Kendall Test. In the case of the TP concentration, since 2007, N21 and N24 showed upward and downward trends, respectively; since late 2011, N7 and N30 showed clear improvement.

Further, the effect of water quality improvement was more conspicuous in the mainstream than in the tributaries. In order to understand the spatial and temporal distribution characteristics of concentrations in the main stream of the Nakdong River, yearly concentration data from upstream to downstream in each unit watershed are shown in Fig. 8. As can be inferred from Fig. 8, the TP concentration showed a clear decreasing trend from 2012 after the enforcement of the second phase of the TMDL policy. The BOD concentration slowly improved through the first and second phases of TMDL and a clear decreasing trend was observed




(a) BOD




(b) TP

Fig. 8 XYZ Triplet Temporal-Spatial contour map of water quality in the main stream of the Nakdong River after 2011. This can be attributed to efforts of the local governments of the unit watersheds, such as installation of large-scale environmental facilities and continuous reduction in discharge load of the point pollution sources, which were made to meet the required TWQ. Further, we conjecture that it is more cost-effective to maintain the current condition rather than to implement the system for BOD and TP water quality improvement at points where the concentration is very low and close to the background concentration inherent in natural streams.

This may be attributed to the fact that the major measure for BOD control is wastewater treatment plants but most of them in the NRB were already in operation even before the policy implementation, making it difficult for local governments find more effective measures. In contrast, chemical treatment process of TP control were recently added to the existing wastewater treatment plants during the analysis period and this turned out to be the key measure of TP reduction.

## 4. Conclusions

The effect of the TMDL policy on water quality was evaluated by applying the seasonal Mann-Kendall Test and the LOWESS analysis method to a long-term BOD and TP data observed at the outlets of the 41 TMDL unit watersheds of the Nakdong River. The main idea for applying the two methods was that the linear trend revealing the overall policy effect can be captured by the Seasonal Mann-Kendal test and the LOWESS can show changes of trend in time due to different implementation phase of the policy. The conclusions are as follows.

• For BOD concentration, 65.9% of the 41 unit watersheds showed no trend, 26.8% and 7.8% were in upward and downward trends. For TP, 51.2% showed no trends and the rest 48.8% were in downward trends.

• Although overall BOD trends were mostly no or upward trends, relatively more points were improved in the main stream compared to the points of the tributaries.

• TP improvement may be attributed to the chemical treatment process of TP control added to the existing wastewater treatment plants.

• The LOWESS analysis results suggested that a root-cause analysis should be conducted for the years that showed an "upward" trend among the analysis items at each point.

• A comprehensive analysis of the effects of the increase or decrease in flow rate should be conducted for further understanding of its effect on water quality change.

The findings from this study can be used as the basic data for better decision making about total load management plans. The research method of this study can also be used for decision making for more reasonable water quality management and policy formulation by applying this method to long-term water quality trend evaluation.

## Acknowledgements

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## References

Bekele, A. and McFarland, A. (2004), “Regression-based flow adjustment procedures for trend analysis of water quality data”, *Transactions of the ASAE*, **47**(4), 1093-1104. https://doi.org/10.13031/2013.16582.

Cleveland, W.S. and Devlin, S.J. (1988), “Locally weighted regression: An approach to regression analysis by local fitting”, *J. American Statistician Assoc.*, **83**, 596-610.

Clow, D.W. and Mast, M.A. (1999), “Long-term trends in stream water precipitation chemistry at five headwater basins in the northeastern Unites States”, *Water Resources Res.*, **35**(2), 541-554. https://doi.org/10.1029/1998WR900050.

Hirsch, R.M., Slack, J.R. and Smith, R.A. (1982), “Techniques of trend analysis for monthly water quality data”, *Water Resource Res.*, **18**(1), 107-121. https://doi.org/10.1029/WR018i001p00107.

Hirsch, R.M. and Slack, J.R. (1984), “A nonparametric trend test for seasonal data with serial dependence”, *Water Resource Res.*, **20**(6), 727-732. https://doi.org/10.1029/WR020i006p00727.

Helsel, D.R. and Hirsch, R.M. (2002), “Statistical methods in water resources techniques of water-resources investigations Book 4, Chapter A3”, *U.S. Geological Survey*, 226-230, 329-335.

Hwang, H.S., Park, B.K., Kim, Y.S., Park, K.J., Cheon, S.U and Lee, S.J.(2011), “Research on the applicability of the load duration curve to evaluate the achievement of target water quality in the unit watershed for a TMDL”, *J. Korean Soc. Water Quality*, **27**(6), 885-895.

Salim, I., Paule-Mercado, M.C., Sajjad, R.U., Memon, S.A., Lee, B.Y., Sukhbaatar, C. and Lee, C.H. (2019), “Trend analysis of rainfall characteristics and its impact on stormwater runoff quality from urban and agricultural catchment”, *Membr. Water Treat.*, **10**(1), 45-55. https://doi.org/10.12989/mwt.2019.10.1.045.

Lu, H., Bryant, R.B., Buda, A.R., Collick, A.S., Folmar, G.J. and Kleinman, P.J. (2015), “Long-term trends in climate and hydrology in an agricultural, headwater watershed of central Pennsylvania”, *J. Hydrology Regional Studies*, **4**, 713-731. https://doi.org/10.1016/j.ejrh.2015.10.004.

Jung, K.Y. (2009), “Advanced control strategies on water quality management in Nakdong river”, M.Sc. Dissertation; Kyungpook National University, Dae-gu, Republic of Korea.

Jung, S.J., Kim, K.S., Seo, D.J., Kim, J.H. and Lim, B.J. (2013), “Evaluation of water quality characteristics and grade classification of Yeongsan river tributaries”, *J. Korean Soc. Water Environ.,* **29**(4), 504-513.

Kim, J.H. (2001), “Non-parametric trend analysis of stream quality in Nakdong river”, M.Sc. Dissertation; Ewha Womans University, Seoul, Republic of Korea.

Kim, J.H. and Park, S.S. (2004), “Long-Term trend analyses of water qualities in Nakdong river based on non-parametric statistical methods”, *J. Korean Soc. Water Quality*, **20**(1), 63-71.

Kim, S. Y. (2008), “Application of Mann-Kendall methods for the performance assessment of the total pollution load management of Geum river”, M.Sc. Dissertation; Hanbat National University, Daejeon, Republic of Korea.

Kim, J.T. (2014), “Lowess and outlier analysis of bio;ogical oxygen demand on Nakdong main stream river”, *J. Korean Data Information Sci. Soc.*, **25**(1), 119-130.

Lettenmaier, D.P. (1988), “Multivariate nonparametric tests for trend in water quality”, *Water Resources Bulletin*, **24**(3), 505-512. https://doi.org/10.1111/j.1752-1688.1988.tb00900.x.

Mann, H.B. (1945), “Nonparametric tests against trend”, *Econometrica*, **13**, 245-249.

Montomery, R.H. and Reckhow, K.H. (1984), "Techniques for detecting trends in lake water quality", *Water Resources Bulletin*, **20**(1), 45-52. https://doi.org/10.1111/j.1752-1688.1984.tb04640.x.

Ministry of Environment (MOE) (2008), "Official test methods of water quality", Notification No. 2008-99; Ministry of Environment, Republic of Korea.

Ministry of Environment (MOE) (2013), "Standard policy of TMDLs", Ministry of Environment, Republic of Korea.

NRERC (2009), "08 Management report of target water quality monitoring system in Nakdong river basin", Nakdong River Environment Research Center, Republic of Korea.

Nakdong River Basin Environmental Office (NDG) (2012), "Technical support casebook of total phosphorus treatment plant", 11-1480354-000058-01; Nakdong River Basin Environmental Office, Republic of Korea.

Nakdong River Environment Research Center (NIER) (2013), "Changes of water environment and phytoplankton community structures in the Nakdong river", 11-1480523-001712-01; National Institute of Environmental Research, Republic of Korea.

National Institute of Environmental Research (NIER) (2014), "Report of the national pollution source survey, based on the 2012", 11-1480523-000429-10; National Institute of Environmental Research, Republic of Korea.

Paul, M.B. and Linfield, C.B. (1997), *Statistics for Environmental Engineers*, CRC Press, Florida, USA.

Park, J.H., Moon, M.J. and Kim, K.S. (2014), "Analysis of relationship between water quality parameters with land use in Yeongsan river basin", *J. Environ. Impact Assessment*, **23**(1), 19-27.

Rodriguez-Murillo, J.C. and Filella, M. (2015), "Temporal evolution of organic carbon concentrations in Swiss lakes: Trends of allochthonous and autochthonous organic carbon", *Sci. Total Environ.*, **520**, 13-22. https://doi.org/10.1016/j.scitotenv.2015.02.085.

Sokal, R.R. and Rohlf, F. J. (1995), *Biometry: The Principles and Practice of statistics in Biological Research*, W.H., Freeman and Co., New York, USA.

U.S. EPA, Office of Wetlands, Oceans and Watersheds (2007), *An Approach for Using Load Duration Curves in the Development of TMDLs*, EPA, USA.

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