Water quality investigation of the main river in Daegu, South Korea

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Abstract. River water quality of Daegu city has been fluctuating for the last several years. This condition requires attention to avoid the possibility of severe water quality degradation. This study aims to identify temporal and spatial distribution, sources of pollutants, and the dominance of specific pollutants on the Nakdong River. River water quality data with a duration of 5 years has been collected and analyzed statistically and combined with Geographic Information System (GIS). The data included BOD, COD, SS, TN, TP, Chl-a, and TOC. The results showed a repetition of a period of decline in river water quality due to the algal bloom phenomenon. This phenomenon closely related to the BOD concentration in the river. Also, the emergence of TOC in high concentrations requires special attention so that it does not become an ongoing problem. COD has the most positive correlation with TOC. This problem becomes serious because it was located at the inlet of water treatment plant in this river. Controlling BOD and COD concentration, especially from effluent of wastewater treatment plant, might become one of the relevant solutions to restrain river water quality degradation. The results of further identification indicate the possibility of nonpoint sources influence, which resulting the river water quality decrease.

1. Introduction

Water is imperative for life and all human activities but also for conserving the environment and its resources [1]. Rapidly growing population, intensification of agriculture, industrialization, urbanization, development of any kind, and climatic factors [2] are the main reasons for water scarcity conditions in many countries of the world. It is widely recognized that many drivers of human activities increasingly affected the quality of water bodies [3]. The problems correlated with several factors, such as inadequately treated sewage, inadequate controls on the discharges of industrial wastewaters [4], a lack of integrated watershed management, incorrect locations of industrial plants, uncontrolled and faulty agricultural practices, poor land-use practices, and excessive use of fertilizers [5].

Daegu is one of the big cities in South Korea after Seoul and Busan. From 1987 to 2014, the total physical area of Daegu increased by 19%; in the 2000s, its urbanized area nearly doubled from that of the previous decade, taking up 30% of the total land by 2014 [6]. However, in the process, environmental pollution is becoming more severe due to the increase in pollutants and pollutant emissions [7].
This research begins with studying of a fluctuating water quality condition in Geumho and the Nakdong River. Young [8] reported that the Nakdong river experiences the most challenging pollution levels around the city or parts of the river that get direct influence from domestic sewage. In the past, the lines of Nakdong, Sincheon, and Geumho rivers lost their ability to self-clean themselves. For this reason, Daegu City has expanded its infrastructure facilities so that the entire amount of sewage generated in the area can be treated [9].

The purposes of this research were to analyze water quality data of the river adjacent to Daegu city. The most dominant pollutant that given attention also explained by discussed the water quality parameters in several points of Nakdong and Geumho River in Daegu.

2. Material and method

2.1. Data collection

Data for this study were collected from the Ministry of Environment data center. These data consist of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Total-Nitrogen (TN), Total-Phosphorus (TP), Total Organic Carbon (TOC), and Chlorophyll-a (Chl-a). There are 16 river points of water quality data provided by the local government (Ministry of Environment). The water quality standard for the river refers to the Korean Government regulation (Table 1). Currently, the Korean government divided river water quality into seven classes; very good (I-a), good (I-b), somewhat good (II), average (III), somewhat poor (IV), poor (V), and very poor (VI). In this paper, the author selected three classes of Korean water quality categories.

| Grade          | pH   | BOD (mg/L) | COD (mg/L) | TOC (mg/L) | SS (mg/L) | DO (mg/L) | TP (mg/L) |
|----------------|------|------------|------------|------------|-----------|-----------|-----------|
| Ia - Very good | 6.5 - 8.5 | ≤ 1 | ≤ 2 | ≤ 2 | ≤ 25 | ≥ 7.5 | ≤ 0.02 |
| Ib - Good      | 6.5 - 8.5 | ≤ 2 | ≤ 4 | ≤ 3 | ≤ 25 | ≥ 5 | ≤ 0.04 |
| II - somewhat good | 6.5 - 8.6 | ≤ 3 | ≤ 5 | ≤ 4 | ≤ 25 | ≥ 5 | ≤ 0.1 |
| III - average  | 6.5 - 8.7 | ≤ 5 | ≤ 7 | ≤ 5 | ≤ 25 | ≥ 5 | ≤ 0.2 |
| IV - Somewhat poor | 6.5 - 8.8 | ≤ 8 | ≤ 9 | ≤ 6 | ≤ 100 | ≥ 2 | ≤ 0.3 |
| V - Poor       | 6.5 - 8.9 | ≤ 10 | ≤ 11 | ≤ 8 | No floating garbage, etc. | ≥ 2 | ≤ 0.5 |
| VI - Very poor | > 10 | > 11 | > 8 | < 2 | > 0.5 |

2.2. Statistical analysis

Data analysis in this study were performed using IBM SPSS Statistic version 25 software. A boxplot shows the five statistics, i.e., minimum, first quartile, median, third quartile, and maximum. It is useful for explaining the distribution of a scale variable and pinpointing outliers. All data were then plotted into a box plot chart based on the date and river monitoring points. Several descriptive statistic parameters also described water quality data more precisely. Pearson correlation of SPSS software was used to make a correlation among several parameters. Chlorophyll-a and Total Organic Content are
the main items in this correlation. The correlation results were divided into three classes, low
correlation, medium correlation, and strong correlation based on $r$-value. This method made it easy for
researchers to draw correlation between pollutants [11].

2.3. Spatial interpolation

We used the Geographic Information System (GIS) program to do spatial pattern analysis of water
quality parameters in the Nakdong and Geumho River. Moreover, We interpolated whole points with
the “Spline with Barriers” toolbox of ArcGIS software. This toolbox uses river body polygon as a
barrier during the interpolation process. It was used to see a broader view of Geumho and Nakdong
River around Daegu City. We, furthermore, used three colored lines to describe river water quality
level, green for level I-b (good), yellow for level III (average), and red for level V (poor).

3. Result and discussion

Table 2 has five years of river-water-quality descriptive statistics. The river has a 2,999 sample
number for BOD, COD, SS, TN, and TP; 2,884 datasets for Chl-a; and 2,316 datasets for TOC. BOD,
COD, SS, TN, TP, Chl-a, and TOC average value of the river are 2.65 mg/L, 7.37 mg/L, 9.94 mg/L, 3.827
mg/L, 0.062 mg/L, 23.76 mg/m³, and 5.06 mg/L respectively. Meanwhile, the minimum and
maximum values show significant variations (Table 2).

Those data appear with different variations. Especially for SS and Chl-a, the data varies dramatically.
One of the most extreme conditions happened when the river reaches the highest SS value at 529.2
mg/L.

| Parameters | Number of data | Minimum | Maximum | Mean  | Std. Deviation |
|------------|----------------|---------|---------|-------|----------------|
| BOD (mg/L) | 2999           | 0.3     | 15.2    | 2.65  | 1.408          |
| COD (mg/L) | 2999           | 2.8     | 24.5    | 7.37  | 2.311          |
| SS (mg/L)  | 2999           | 0.2     | 529.2   | 9.94  | 19.029         |
| TN (mg/L)  | 2999           | 0.463   | 18.384  | 3.827 | 2.105          |
| TP (mg/L)  | 2999           | 0.005   | 0.511   | 0.062 | 0.052          |
| Chl-a (mg/m³) | 2884    | 1.0     | 244.6   | 23.76 | 24.993         |
| TOC        | 2316           | 1.0     | 19.5    | 5.06  | 2.044          |

3.1. Biochemical Oxygen Demand (BOD)

Figure 1 describes Biochemical Oxygen Demand (BOD) concentrations of Nakdong and Geumho
River. The BOD value should be less than 5 ppm so that according to the Grade III standard.
Referring to this standard, most of the river monitoring points meet the requirement by achieving a
low average BOD value. Nevertheless, many of the monitoring points experienced over standard value
events. Two locations fall into the lousy category: Habincheon and Baekcheon. Baekcheon monitoring
point reached the highest BOD value in July 2015 by 12.4 mg/L. In January 2018, BOD concentration
arose at 15.2 mg/L in Habincheon. High BOD concentration (>10 mg/L) still recorded at this
monitoring point until November 2018. It was the worst BOD event for this river and categorized as
grade VI-very poor, followed by Geumho 5, which reached a BOD value of 10.2 mg/L in June 2016.
Meanwhile, some monitoring points show continual stable BOD concentration for five years, such as
Dasa, Dalseong, Seongju, and Nonggong.
3.2. **Chemical Oxygen Demand (COD)**

The COD value should be less than 7 mg/L so that according to the Grade III standard. Several river monitoring points achieved this level by the average COD value except for Chacheon, Geumho 2A, Geumho 6, Goryeong, Habincheon, and Hwawonnraru. Compare to the other monitoring points, Chacheon and Habincheon represent higher COD concentrations (Figure 2). Most elevated COD concentrations took place around the agriculture area. According to [12], forest and agriculture areas have the ability to raise COD concentration on a surface water body.
3.3. Suspended Solid (SS)

In the river, suspended-solid concentration should be less than 25 mg/L to reach the average level (level III) determined by the government. The degree will dramatically decrease when it has 100 mg/L of SS concentration. Based on the average SS concentrations, all river points successfully achieved the Level-III of river water quality. Nonetheless, several events showed the SS concentration increasing. Five river monitoring points expressed the SS concentration above 100 mg/L, i.e., Baekchon, Seongju, Yongam, Habincheon, and Dalseong. The highest SS concentration (529.2 mg/L) was at the Habincheon monitoring point in August 2014. Baekcheon reaches the second highest SS concentration of 452 mg/L in August 2014 (Figure 3).
3.4. Total-Nitrogen (TN)
Total nitrogen represents information about both organic and inorganic nitrogen [13]. Eleven river water monitoring points have an average TN value below 5 mg/L, and the rest of them have an average content below 10 mg/L. Generally, river monitoring points show the maximum TN concentrations below 10 mg/L and around 15 mg/L for Chacheon, Geumho 3, Geumho 4, and Geumho 5 (Figure 4). During this period, Geumho and Chacheon River suffered a TN problem more than the Nakdong River. Based on the seasonal variation, TN concentrations started at the lowest level in summer and reached the highest point in winter. We can see a similar condition in the Suprasl River [14] and an urban area close to Fenghe River [15]. The higher TN concentration (exceed 3 to 4 mg/L) can be an indicator that nitrate-N will be higher than the organic-N. Nitrogen source also might be derived from soil microbial nitrification or leaching of nitrate from mineral fertilizers [16].
3.5. Total-Phosphorus (TP)

In the river monitoring points, measured Total-Phosphorus concentrations represent a relatively high variation (Figure 5). Most of the average TP levels meet the requirement as grade III/average, and four river monitoring points were classified to grade I-b/good. Moreover, several TP values increase significantly and come near to level V/poor condition, particularly at Baekcheon and Habincheon. The highest TP concentration was 0.496 mg/L at the Baekcheon monitoring point in August 2016. Besides, Habincheon represents several high TP concentrations in the same pattern with Baekcheon. They have elevated TP levels at these 2 locations strongly correlated with high SS concentration. It might be affected by agriculture activities close to the river. Figure 6 shows the distribution of the industrial
complex area (40.52 km$^2$) and agriculture activities (57.89 km$^2$) around the Nakdong and Geumho River. Nonpoint sources also considered as a main TP contributor in the upstream part and outer river basin of Min River [17].

Figure 5. Total phosphorus concentration at river monitoring points in Daegu
3.6. Chlorophyll-a (Chl-a)

In Nakdong and Geumho River, Chl-a reached the lowest concentration in the winter season and became higher after the end of this season. Based on data collected from 2015 – 2018, we can see these everyday phenomena. Table 3 describes a correlation between several water quality parameters. Compare to the other pollutants, BOD has the strongest correlation with Chl-a concentration (Pearson Correlation value: 0.614). Also, the correlation between Chl-a and COD increases in the summer.

Meanwhile, the others exhibit a lower correlation with Pearson Correlation value ranged from 0.043 to 0.338. During the algal peak season, Pearson Correlation values of Chl-a and entire pollutants increased except for SS. This correlation pattern has a similarity with the Stagnant Lake Basin condition [18]. Although TN and TP are considered as the main factor for algal growth [19], they did not have any significant correlation with Chl-a during this period (2014 – 2018). This result could have been affected by weather factors such as rain, the depth of sampling locations, and sunlight, which make algae either float on the water or sink [18]. Figure 7 describes a similar pattern between BOD and Chl-a in the Nakdong and Geumho River. The meeting point between the Nakdong and Geumho river severely attacked by Chl-a for the last five years.

Moreover, the Habincheon area started suffering Chl-a from 2017 and become more severe in 2018. According to land use condition, industrial complex and farming might be considered as a contributor to Chl-a growth. Controlling BOD concentration, especially from wastewater treatment plant effluent, might become one of the relevant solutions to restrain algal bloom on this river. Moreover, COD should be released at low concentrations in summer to prevent the algal bloom in the river. Significant inflow events followed by warm periods may lead to algal bloom development [20].
Table 3. The primary pollutant correlations on The Nakdong River and Geumho River

**Pollutant Correlations (daily)**

|          | Chl-a | TOC  | BOD  | COD  | SS   | TN   | TP   |
|----------|-------|------|------|------|------|------|------|
| **Chl-a** Pearson Correlation |       |      |      |      |      |      |      |
|          | 1     | 0.199** |      | 0.614** | 0.304** | 0.092** | 0.053** | 0.152** |
| Sig. (2-tailed) |      |      |      |      |      |      |      |
|          | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **TOC** Pearson Correlation | 0.199** | 1     | 0.393** |      | 0.840** | 0.278** | 0.336** | 0.418** |
| Sig. (2-tailed) |      |      |      |      |      |      |      |
|          | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **N** | 2884 | 2201 | 2884 | 2884 | 2884 | 2884 | 2884 |

**Pollutant Correlations (summer)**

|          | Chl-a | TOC  | BOD  | COD  | SS   | TN   | TP   |
|----------|-------|------|------|------|------|------|------|
| **Chl-a** Pearson Correlation |       |      |      |      |      |      |      |
|          | 1     | 0.387** |      | 0.728** | 0.467** | 0.051 | 0.284** | 0.157** |
| Sig. (2-tailed) |      |      |      |      |      |      |      |
|          | 0.000 | 0.000 | 0.000 | 0.176 | 0.000 | 0.000 | 0.000 |
| **TOC** Pearson Correlation | 0.387** | 1     | 0.442** |      | 0.769** | 0.329** | 0.377** | 0.481** |
| Sig. (2-tailed) |      |      |      |      |      |      |      |
|          | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| **N** | 719  | 552  | 719  | 719  | 719  | 719  | 719  |

**. Correlation is significant at the 0.01 level (2-tailed).**
Figure 7. BOD and Chl-a distribution from 2014 to 2018 on the main river of Daegu
3.7. Total Organic Carbon (TOC)

Organic matters are considered as a Trihalomethanes (THMs) precursor usually occurs when inadequately removed NOM reacts with the disinfectant during chlorination and chloramination [21]. Figure 12 reflects the TOC condition at several monitoring points on Nakdong and Geumho River. The majority exhibit average TOC concentration below 5 mg/L. Nonetheless, specific locations also represent high TOC concentrations. The highest TOC concentration recorded in Chacheon at 19.5 mg/L (Figure 8). High TOC concentration also can be found at Geumho 4, Geumho 5, Geumho 6, and Habincheon. Pearson Correlation values exhibit that TOC had a strong correlation with COD and a weaker correlation with BOD. This correlation probably due to the presence of non-biodegradable organic content, which is more dominant in the river.

![Figure 8. TOC concentration at several river monitoring points of Nakdong and Geumho River](image-url)
Based on the result, we can see that Chl-a and TOC are chronic problems that occur in the Nakdong River. Graham et al. [20] reported that an algal bloom might be called harmful because of resulting alterations in aquatic food webs, reductions in dissolved oxygen concentrations, unsightly scums along shorelines, production of taste-and-odor compounds that cause unpalatable drinking water and fish flesh, or the creation of toxins potent enough to poison aquatic and terrestrial organisms. Drinking water sources in many areas are subject to the proliferation of toxic cyanobacteria (CB). Chlorination of source water containing toxic cyanobacterial cells for various treatment purposes might cause cell damage, toxin release, and disinfection by-products (DBP) formation [22]. Chl-a and TOC exhibit their domination at Habincheon and the vicinity. It is necessary to give more attention to the Habincheon area because the water will be the source of two water treatment plants.

4. Conclusion

This study set out to determine a correlation amongst river pollutants. Nakdong and Geumho river in Daegu city, showed a high fluctuation pollutant concentration. Several monitoring points were classified as an adverse condition after pollutants recorded at a high concentration. Compare to the other location, Habincheon experienced the most polluted condition. This area should be managed carefully because of it serve water source for two water treatment plants. During 2015 – 2018, algal bloom occurs continuously and strongly correlated with BOD (Pearson Correlation value: 0.614). Meanwhile, COD become the most related pollutant for TOC concentration in Nakdong and Geumho River around Daegu City (Pearson Correlation value: 0.840). Controlling BOD and COD concentration, especially from wastewater treatment plant effluent, might become one of the relevant solutions to restrain river water quality degradation. According to land use condition, industrial complex and farming might be considered as a pollutant contributor in this river.

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