Effects of multifunctional weir construction on key water quality indicators: a case study in Nakdong River, Korea

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Abstract
In this study, changes in water quality characteristics were compared before and after the construction of eight multifunctional weirs in the Nakdong River Basin in South Korea. A cluster analysis of spatial variation showed that the locations classified as Cluster 1 pre-construction (sites ND7 and ND8) shifted into Cluster 2 post-construction, indicating that spatial cluster types changed after the construction of multifunctional weirs. Principal component and factor analyses revealed that nitrogen and phosphorous nutrients at the pre-construction stage (total nitrogen, total phosphorous, and phosphate-phosphorus) and electrical conductivity were extracted in principal component 1, while biochemical oxygen demand, chemical oxygen demand, pH, and chlorophyll-a were extracted in principal component 2. However, biochemical oxygen demand, chemical oxygen demand, total organic carbon, and chlorophyll-a at the post-construction stage were extracted in principal component 1, while total nitrogen, nitrate-nitrogen, and dissolved oxygen were extracted in principal component 2. The key water quality indicators transitioned from nutrients to organic pollutants after the construction of the multifunctional weirs. A water quality trend analysis with seasonal Mann–Kendall testing and locally weighted scatter plot smoothing methods showed that organic pollutant indicators such as chemical oxygen demand and total organic carbon tended to increase after the construction of multifunctional weirs. Therefore, the key quality indicators for water quality improvement and management should be chemical oxygen demand and total organic carbon.

Keywords Cluster analysis · Factor analysis · Organic pollutant indicators · Principal component analysis · Water quality management

Introduction
Water quality standards are necessary to continuously maintain the health of ecosystems while ensuring that water quality remains at a usable level. Therefore, the natural environmental conditions of a country or region should be largely reflected in its water quality standards, while economic and technical support is essential to meet these standards. Additionally, environmental standards should be designed to suit regional characteristics, as their forms and contents may be manifested differently depending on the level of public awareness (Hajigholizadeh and Melesse 2017; Wu et al. 2018). Therefore, water quality standards need to be consistently reviewed and supplemented to reflect changing environmental conditions.

In South Korea, the water quality management policy centered around biochemical oxygen demand (BOD) has significantly reduced BOD concentration, which is representative of biodegradable organic pollutants (Kim et al. 2013; Park et al. 2013). However, it is known that the concentrations associated with chemical oxygen demand (COD) and total organic carbon (TOC), which are management indicators of non-biodegradable organic matter (NOM), are increasing. Accordingly, numerous studies have elucidated the need for NOM management (Lee et al. 2011; Jung et al. 2015; Heo et al. 2017), and the limitations of the existing management techniques centered around BOD have been recognized. In South Korea, the Four Major Rivers Project was promoted from 2009 to 2011 for the purpose of preventing drought and flood damage by adapting to global climate
change, securing water resources, and improving water quality. Various projects were completed along the major sections of the four rivers, including dredging of sedimentary soil, construction of multifunctional weirs, and development of small and medium-sized dams. Consequently, the environment has changed significantly, that is, the water depth and storage capacity have increased, while there has been an improvement in the possibility of artificially controlling the flow of rivers through the operation of multi-functional beams, upstream dams, and reservoirs (Na et al. 2015; Lee et al. 2019). Eight multifunctional weirs have been constructed in the Nakdong River basin from 2009 to 2011, and the resulting environmental changes have caused lake-like characteristics to emerge, such as increased water depths and retention times. Eutrophication and algal blooms have also occurred after the construction of these weirs, which have become social issues (Lee et al. 2014; Park et al. 2019).

Multivariate statistical techniques, such as cluster analysis (CA), factor analysis (FA), and principal component analysis (PCA), have been widely used to interpret water quality data. These techniques can identify factors and sources that can influence water systems; they are valuable tools for the reliable management of water resources (Brümelis et al. 2000; Shrestha and Kazama 2007; Fan et al. 2010; Barakat et al. 2016; Varol 2020). Multivariate statistical techniques have been used to reduce errors in interpreting diverse and uncertain river water quality data and analyze the characteristics and correlations of each water quality indicator. Various studies have performed statistical analyses of the water quality characteristics of the Nakdong River, which is the target basin for this study (Kim et al. 2010; Choi et al. 2011; Seo et al. 2019; Kang et al. 2020). Most of these studies were conducted to determine the substances that should be managed for the target basin and tributary streams flowing into the main stream, or for the purposes of watershed management and water quality assessment.

Owing to the installation of multifunctional weirs in the Nakdong River basin, the river environment has changed greatly, and no comparative studies have been conducted before and after the changes in the river environment. Therefore, in this study, it was determined that the key water quality indicators need to be altered according to the change in the river environment due to the construction of multifunctional weirs. Long-term monitoring data from 2007 to 2019 were analyzed to compare the changes in water quality characteristics before (2007–2011); after (2012–2019) the installation of the multifunctional weirs. In addition, the necessity of modifying the key indicators to reflect the changing natural characteristics and river environment was determined using long-term monitoring data and statistical techniques, such as CA, PCA, FA, seasonal Mann–Kendall (MK), and locally weighted scatterplot smoothing (LOESS) tests. The results of this analysis are expected to be used for managing polluting substances and setting environmental standards to establish efficient water quality management policies in the future.

### Materials and methods

#### Current status of multifunctional weirs in the subject locations and basin

The Nakdong River is the longest river in South Korea. It originates in the Taebaek Mountains in Gangwon-do before passing through Gyeongsangbuk-do, Daegu-si, Gyeongsangnam-do, and Busan-si, and then flowing into the South Sea. The Nakdong River has a total length of 510.4 km (400.7 km of which is the main stream) and has many tributary streams, such as the Naeseongcheon, Kumho River, Hwang River, Nam River, and Miryang River. Its basin area is 23,384 km², which accounts for approximately 25% of South Korea’s national territory. The upstream section, which has a high proportion of forest and agricultural areas, is exposed to non-point source pollution such as livestock wastewater, sewage, and effluent from agricultural lands. The midstream and downstream sections experience point and non-point source pollution in various forms such as major cities, industrial complexes, and sewage treatment plants that are located nearby; this results in difficulties regarding water quality management. A total of eight multifunctional weirs were constructed in the Nakdong River from 2009 to 2011; their specifications are shown in Table 1. Each weir was constructed to fit the width of the river at its location, ranging from 286.0 to 953.5 m. The capacity for the furthest upstream multifunctional weir (MW1) is $27.4 \times 10^6$ m³, and

| Type                      | MW1  | MW2  | MW3  | MW4  | MW5  | MW6  | MW7  | MW8  |
|---------------------------|------|------|------|------|------|------|------|------|
| Total length (m)          | 335.0| 286.0| 374.3| 400.0| 953.5| 580.0| 328.0| 549.3|
| Water level management (EL. m) | 47.0 | 40.0 | 32.5 | 25.5 | 19.5 | 14.0 | 10.5 | 5.0  |
| Reservoir capacity (million m³) | 27.4 | 34.7 | 52.7 | 75.3 | 92.3 | 58.6 | 70.0 | 100.9 |

MW1, MW2, MW3, MW4, MW5, MW6, MW7, and MW8 are the eight multifunctional weirs. MW1 is the upstream multifunctional weir, and MW8 is the downstream multifunctional weir. EL. m: height above sea level.
that of the furthest downstream multifunctional weir (MW8) is $100.9 \times 10^6$ m$^3$. Furthermore, water level management has been specified and implemented for flow maintenance and agricultural water usage, depending on the environmental and regional conditions of each weir. As water intake stations (three stations at MW1, one at MW2, three at MW4, five at MW5, and one at MW8) are operated at some of the weirs to use the river as a raw water source, changes in the river environment can be a sensitive issue for citizens that rely on the Nakdong River as a water source.

**Method of water quality analysis**

This study used water quality data analysis (monthly average data) from 15 locations (Fig. 1) of the National Water Quality Measurement Network located on the Nakdong River from 2007 to 2019. Among the water quality variables analyzed, pH, dissolved oxygen (DO), water temperature (WT), and electrical conductivity (EC) were directly measured onsite (YSI 6600 EDS, USA). The BOD, COD, TOC, total nitrogen (TN), ammonia–nitrogen (NH$_3$–N), nitrate-nitrogen (NO$_3$–N), total phosphorus (TP), phosphate-phosphorus (PO$_4$–P), chlorophyll-a (Chl-a), and total suspended solids (SS) were analyzed in a laboratory according to the official test methods for water pollution (MOE, 2008); the analysis methods used are listed in Table 2.

**Method of statistical analysis**

Water quality data analysis was performed using CA, PCA, and FA techniques, which were standardized on a z-score to prevent errors among data resulting from different units of measurement. All the statistical calculations, including LOWESS, were performed using SPSS 24.0. Furthermore, the MK test was carried out using XL-STAT 2020.
Cluster analysis

Cluster analysis is a statistical technique that divides data into clusters using the differences (distance) or similarities between observations of a population. It can be classified as hierarchical or non-hierarchical according to the clustering method. Based on the data correlation (Vega et al. 1998), a hierarchical CA wherein clustering occurs sequentially is mainly used to classify the clusters as temporally or spatially homogeneous; this analysis is generally represented as a dendrogram (Mckenna 2003). In this study, CA was performed before and after construction of multifunctional weirs to confirm whether the spatial characteristics of the river changed. Hierarchical clustering was used as the classification approach, and the distance between the cluster targets was used as the Euclidean distance (Otto 1998). Furthermore, the clusters were combined using Ward’s method. Ward’s method uses a distributed approach to minimize data loss (Fan et al. 2010).

Principal component analysis and factor analysis

Principal component analysis is a statistical technique that uses correlations between multivariate variables to find the principal component, a new variable represented by linear combinations of variables (Sârbu and Pop 2005; Barakat et al. 2016). Eigenvalue refers to the magnitude of the variance that the principal component can account for; if the eigenvalue is greater than 1.0, it implies that the one principal component can account for more than one variable. Therefore, the principal components are extracted based on the eigenvalue of 1.0 or higher. The FA is a statistical technique that analyzes the interrelationships between variables by extracting the common embedded factors and grouping them into one homogeneous factor around the commonality of highly correlated variables (Simeonov et al. 2003; Varol et al. 2012). Kaiser–Meyer–Olkin (KMO) and Barrett’s tests are generally performed to verify the appropriateness of the variables used for FA (Shrestha and Kazama 2007; Li et al. 2018). The KMO test is a measure of how well the correlation between variables is explained by other variables; the closer the p-value is to ‘1’, the higher the validity of the FA, and the highest minimum value should be more than ‘0.5’. Barlett’s test implies that if the p-value is less than ‘0.05’, a FA can be performed by rejecting the unit matrix as a way of verifying whether the variable used is a unit matrix or not. In this study, PCA and FA were used to identify the effects of the construction of multifunctional weirs on river water quality variables and extract the key water quality factors from these variables. Factor extraction used PCA and only considered values of ‘1.0’ or higher that represented the magnitude of the variance, and the validity of the analysis was verified by running KMO and Barlett’s tests. Later, factors were rotated using the Varimax rotation method (Brūmelis et al. 2000; Singh et al. 2004), which made it easier to grasp and interpret the meaning of the factors.

Seasonal Mann–Kendall and locally weighted scatterplot smoothing tests

Seasonal Mann–Kendall is a nonparametric statistical method that analyzes trends through correlation measures between observations (Mann 1945; Kendall 1975); it independently conducts the Kendall test for each season, and then obtains a weighted sum of each result to produce a single trend analysis result (Burn and Hag Elnur 2002; Liu et al. 2011). Generally, it is used to identify trends in simple time series data such as climate, weather, and hydrologic data. The MK test can verify the significance of the trend through Kendall’s tau, determine the presence or absence of the trend, and determine the degree of trend by obtaining the accompanying the seasonal Kendall slope estimator. Typical parametric statistical methods can produce false results because water quality data observed in streams represent non-normal distributions and exhibit strong seasonality (Kim and Park 2004). The LOWESS is a curved trend analysis method that is used to compensate for the monotonic increase and decrease in straight-line trend analysis

Table 2

| Variable                        | Abbreviation | Unit   | Analysis method                                                      |
|---------------------------------|--------------|--------|---------------------------------------------------------------------|
| Biochemical oxygen demand       | BOD          | mg/L   | Winkler-azide method (5-day)                                        |
| Chemical oxygen demand          | COD          | mg/L   | Potassium permanganate (KMnO₄)                                      |
| Total organic carbon            | TOC          | mg/L   | High temperature combustion method                                   |
| Total nitrogen                  | TN           | mg/L   | Continuous flow analysis (UV/visible spectrometry)                  |
| Ammonia–nitrogen                | NH₃–N        | mg/L   | Continuous flow analysis (UV/visible spectrometry)                  |
| Nitrate-nitrogen                | NO₃–N        | mg/L   | Continuous flow analysis (ion chromatography)                       |
| Total phosphorus                | TP           | mg/L   | Continuous flow analysis (UV/visible spectrometry)                  |
| Phosphate-phosphorus            | PO₄–P        | mg/L   | Continuous flow analysis (ion chromatography)                       |
| Chlorophyll-a                   | Chl-a        | mg/m³  | UV/visible spectrometry                                             |
| Total suspended solids          | SS           | mg/L   | Filtration methods (GF-C)                                           |
for determining the trend variation during the target period. This method fits and estimates the response values of subsets of data that are located close to each point in the data, with low-dimensional polynomial functions at each point in the data (Cleveland 1979; Cleveland and Devlin 1988). The MK tests were conducted to identify trends in water quality during the study period. Furthermore, MK and LOWESS were used together because MK test cannot reflect changing trends during the analysis period.

Results and discussion

Analysis of changing water quality characteristics at subject locations

The concentration changes and variabilities of the water quality variables were compared and analyzed following the environmental changes in the studied watershed (Table 3, Fig. 2). In the case of TP and Chl-a, the variability in their concentrations decreased after the construction of the multifunctional weirs. In the case of TN, the variability in its concentration decreased after site ND8. These results (Fig. 2) show that at the pre-construction stage, the stronger influences of the natural characteristics of the river caused highly varied water quality concentrations; however, post-construction, this variability decreased due to artificial interferences such as the flow volume control and the rate through sluice gate operation. Additionally, the TP and Chl-a concentrations significantly decreased after the construction of the weirs, based on their median values. This can be attributed to the sewerage Act in 2012, which strengthened the TP limit in discharges from sewage treatment facilities (MOE 2012) and increased the number of advanced treatment facilities.

Regarding the water quality characteristics of each survey site representing spatial differences, the variability of the mean concentration value for each water quality variables was large as it passes the ND9 site, both before and after construction. In the post-construction stage of the multifunctional weirs, variables such as BOD, COD, and TOC showed a tendency to increase in the upstream section with regard to their concentrations and variability. Their variability in the downstream section decreased slightly, while the median value generally either remained constant or increased slightly. In particular, the concentration and variability of COD, which is an indicator for persistent organic pollutants, increased downstream both before and after the construction of the multifunctional weirs. This may be attributable to the Geumho River, which flows into the ND8 and ND9 sites. The effects of the Geumho River on the Nakdong River can be confirmed using the results of various domestic studies. The Geumho River penetrates industrial complexes and urban areas, and more than 40% of the stream’s maintenance flow is discharged from basic environmental treatment facilities. The discharged effluent contains high concentrations of nutrients; therefore, it has been reported to have a significant effect on the main stream of the Nakdong River (Jeon 2012; Jung et al. 2016). In addition, due to the expansion of other cities and the overall industrial development in response to economic growth, the types of organic pollutants present in this river have diversified and increased in volume. It has been reported that most of the treatment facilities currently operating in South Korea use biological treatments that feature microorganisms. Therefore, the amount of NOM flowing into the river gradually increases (Park et al. 2013; Jung et al. 2015).

Cluster analysis of spatial changes due to construction of the multifunctional weirs

Cluster analysis was conducted on the subject locations (ND1–ND15) to analyze their varying characteristics based on the spatial classifications observed before and after the construction of the multifunctional weirs (Fig. 3). The subject locations before and after the construction were mainly divided into two clusters (1, 2). In the pre-construction stage (from 2007 to 2011), ND1–ND8 were classified into Cluster 1, and ND9–ND15 were classified into Cluster 2. In the post-construction stage (from 2012 to 2019), ND1–ND6 were classified into Cluster 1, while ND7–ND15 were classified into Cluster 2. Cluster 1 can be determined as an upstream basin consisting of forest and agricultural areas, and Cluster 2 is a middle-downstream basin consisting of urban and industrial complex areas. The ND7 and ND8 sites showed varying spatial characteristics after construction and thus were moved to Cluster 2. Numerous industrial complexes are located around ND7, showing that its land-use characteristics featured a high urbanization rate. Previous studies also stated that if the inflow of industrial waste and living sewage increases in a particular location, then that location is classified according to the degree of water pollution following various spatial characteristics (Singh et al. 2004; Han et al. 2009; Jung et al. 2016).

Principal component analysis and factor analysis of changes in key water quality indicators due to construction of the multifunctional weirs

The PCA and FA were implemented to extract the factors that have the greatest impact on water quality changes due to the construction of the multifunctional weirs. The KMO and Bartlett’s test results for verifying the suitability of the FA were 0.769 and 0.000 before the multifunctional weirs construction and 0.737 and 0.000 after construction, respectively; these values confirmed the validity of the analysis. The FA results (varifactor (VF), factor loading,
| Variable | ND1 | ND2 | ND3 | ND4 | ND5 | ND6 | ND7 | ND8 |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|
| pH | R | 6.9–8.6 | 7.2–8.5 | 6.9–8.8 | 7.2–9.2 | 7–8.9 | 7.1–9.4 | 7.1–9.1 | 7.3–8.9 |
| M ± SD | 7.7±0.4 | 7.8±0.3 | 7.9±0.3 | 8.2±0.4 | 7.9±0.4 | 8.2±0.4 | 8±0.3 | 8.1±0.3 |
| DO | (mg/L) | R | 3.9–15.6 | 6.8–16.8 | 6.7–19.2 | 6.3–19.1 | 6.3–16.1 | 6.8–20.5 | 7.1–15.9 | 6.7–15.8 |
| M ± SD | 10.1±2.5 | 11±2.2 | 10.7±2.6 | 10.9±2.7 | 10.8±2.3 | 11.1±2.8 | 10.9±2.2 | 10.7±2.4 |
| WT | (°C) | R | 4–28.3 | 2.8–28.5 | 1–30 | 1–32.4 | 0.5–30.0 | 1–30.9 | 1.5–30.2 | 1.5–31.3 |
| M ± SD | 12.8±5.8 | 14.8±6.9 | 16.1±8.4 | 16.9±9.1 | 15.5±8.6 | 16.2±9.1 | 16.2±8.5 | 16.1±8.7 |
| EC | (µS/cm) | R | 110–306 | 132–613 | 121–427 | 93–366 | 94–384 | 94–342 | 87–578 | 102–467 |
| M ± SD | 174±28 | 193±48 | 201±43 | 204±48 | 222±47 | 206±48 | 284±85 | 267±77 |
| Chl-a | (mg/L) | R | 0.9–33.7 | 1.1–17.5 | 0.7–55.3 | 0.7–52.5 | 1.2–57.3 | 0.3–62.5 | 1.2–150.6 | 1.6–100.1 |
| M ± SD | 5.1±5.3 | 4.9±2.8 | 5±4.9 | 14.1±10.7 | 13.2±9.2 | 16±12 | 20.1±17.4 | 21.5±15.3 |
| SS | (mg/L) | R | 0.4–20.2 | 0.9–44.1 | 0.8–51.5 | 0.4–76.3 | 1.6–121.7 | 1–81.5 | 1–176.2 | 1.4–148.7 |
| M ± SD | 3.1±3.3 | 7.4±7.6 | 8.7±8.4 | 10.5±13.1 | 12.4±15.4 | 10.6±13.2 | 15.1±21.4 | 14.6±19.3 |
| BOD | (mg/L) | R | 0.4–1.8 | 0–1.8 | 0–1.7 | 0.5–3.3 | 0.5–2.8 | 0.6–2.9 | 0.5–4.9 | 0.7–3.5 |
| M ± SD | 0.8±0.2 | 1.1±1.2 | 1±1.2 | 1±0.6 | 1±0.4 | 1.5±0.6 | 1.9±0.6 | 1.8±0.5 |
| COD | (mg/L) | R | 1.9–8.5 | 2.5–8.9 | 2.4–7.6 | 1.8–9.4 | 2–8.2 | 1.8–8.9 | 2.4–9.4 | 2.9–9.2 |
| M ± SD | 4±0.9 | 4.7±1 | 4.3±1.1 | 4.5±1.3 | 4.6±1.2 | 4.9±1.5 | 5.5±1.3 | 5.6±1.1 |
| TOC | (mg/L) | R | 1.3–4.5 | 1.5–4.7 | 0.8–5.5 | 1–7.5 | 1.7–6.3 | 1.1–5.6 | 1.9–6.2 | 1.5–6.9 |
| M ± SD | 2.3±0.5 | 2.7±0.7 | 2.4±0.8 | 2.7±1.1 | 3.2±0.9 | 3.8±0.9 | 3.2±1.1 |
| TN | (mg/L) | R | 1.158–3.727 | 1.355–4.428 | 1.241–4.454 | 0.831–3.946 | 0.778–3.675 | 0.688–4.14 | 1.484–4.555 | 1.479–4.39 |
| M ± SD | 1.718±0.356 | 2.129±0.487 | 2.326±0.601 | 2.409±0.587 | 2.423±0.52 | 2.303±0.589 | 2.838±0.682 | 2.756±0.607 |
| NH₃-N | (mg/L) | R | 0.008–0.298 | 0.017–0.468 | 0.002–0.483 | 0.008–0.35 | 0.01–0.224 | 0.003–0.526 | 0.02–0.102 | 0.025–1.303 |
| M ± SD | 0.079±0.051 | 0.141±0.091 | 0.093±0.075 | 0.086±0.073 | 0.063±0.038 | 0.092±0.076 | 0.147±0.171 | 0.177±0.157 |
| NO₂-N | (mg/L) | R | 0.75–3.675 | 0.79–4.025 | 0.84–4.229 | 0.44–3.433 | 0.366–2.798 | 0.254–3.152 | 0.764–3.728 | 0.753–3.362 |
| M ± SD | 1.352±0.333 | 1.661±0.496 | 1.918±0.588 | 1.925±0.601 | 1.922±0.521 | 1.877±0.62 | 2.144±0.623 | 2.13±0.58 |
| TP | (mg/L) | R | 0.000–0.11 | 0.007–0.162 | 0.003–0.269 | 0.005–0.13 | 0.011–0.136 | 0.005–0.157 | 0.015–0.283 | 0.014–0.199 |
| M ± SD | 0.021±0.015 | 0.027±0.018 | 0.027±0.03 | 0.035±0.023 | 0.041±0.025 | 0.033±0.022 | 0.076±0.056 | 0.06±0.04 |
| PO₄-P | (mg/L) | R | 0.001–0.056 | 0.001–0.119 | 0.001–0.068 | 0.001–0.215 | 0.001–0.063 | 0.001–0.218 | 0.001–0.251 | 0.001–0.154 |
| M ± SD | 0.007±0.009 | 0.01±0.012 | 0.01±0.011 | 0.014±0.021 | 0.014±0.013 | 0.013±0.021 | 0.037±0.048 | 0.03±0.031 |

Table 3: Range, mean, and standard deviation of water quality variables based on 15 locations in the Nakdong River from 2007 to 2019.

- **Variable**: Various water quality parameters including pH, DO, TN, EC, Chl-a, SS, BOD, COD, TOC, and TN.
- **ND1** to **ND8**: Different sets of data for each variable.
- **M ± SD**: Mean ± Standard Deviation.
- **R**: Range.
The PCA for the period prior to the construction of the multifunctional weirs indicated four components with an eigenvalue of 1.0 or higher, accounting for 80.378% of the total variance (Table 4). When the Varimax rotated method was applied in the FA conducted after the project, the eigenvalue and total variance of VF1 were found to be 3.420 and 24.431%, respectively. The PO4–P and TP were “strong” (0.913 and 0.781, respectively), while the EC (0.699), TN (0.823), and DO (0.736) were “strong,” and pH (0.689) and COD (0.663) were “moderate.” The Chl-a (0.906) and BOD (0.849) were “strong,” and pH (0.689) and COD (0.663) were “moderate.” These results are indicative of various organic pollution factors and metabolic factors in the river. The coefficient value of BOD was very high compared to those of COD and TOC, showing that the water quality characteristics were influenced by biodegradable organic pollutants. In VF3, DO (0.883) and WT (−0.924) were “strong,” and in VF4, SS (0.891) was “strong.”

The PCA conducted for the period after the construction of the multifunctional weirs showed four components with an eigenvalue of 1.0 or higher, accounting for 71.686% of the total variance (Table 4). When the Varimax rotated method was applied in the FA conducted after the project, the eigenvalue and total variance of VF1 were found to be 3.340 and 23.859%, respectively. The Chl-a (0.906) and BOD (0.849) were “strong,” and pH (0.689) and COD (0.663) were “moderate.”

Analysis of concentration trends of key water quality variables before and after the construction of the multifunctional weirs

The MK test was used to check the change in the water quality trend due to the construction of multifunctional weirs (Table 5). Prior to the construction of the multifunctional weirs, BOD and Chl-a showed a decreasing trend; however, COD showed an increasing trend, while other variables showed no fixed trends. After construction, COD and TOC increased while TP decreased; however, other variables did not change. During the analysis period, LOWESS was conducted to identify the trend in the temporal changes in water quality variables (Fig. 5). The BOD showed no apparent trend by repeating the decrease and increase during the analysis period; however, the COD showed a steady rise, and the TOC sharply increased after the construction of the multifunctional weirs. In addition, the TN decreased smoothly but did not show significant changes; meanwhile, the TP decreased considerably immediately after the multifunctional
Fig. 2 Comparisons of characteristics using water quality factors before and after the construction of multifunctional weirs in the Nakdong River: In the boxplot, the left (blue) shows pre-construction values (2007–2011) and the right (red) shows post-construction values (2012–2019). The middle line of each box represents the median value, lower line represents the first quartile (25%), upper line represents the third quartile (75%), lower bar represents the minimum (median – 1.5 × IQR) value, and upper bar represents the maximum (median + 1.5 × IQR) value; points show outliers. Here, IQR is the third quartile minus the first quartile. a. Biochemical oxygen demand, b. chemical oxygen demand, c. total organic carbon, d. total nitrogen, e. total phosphorus, f. chlorophyll-a.
weirs construction while decreasing gradually afterwards. The Chl-a decreased before construction, and there was no significant change after construction. Analyses of the MK and LOWESS test results showed that organic pollutants continued to increase, while phosphorus nutrients decreased.

**Discussion**

In this study, a comparative analysis was conducted for the data obtained before and after the construction of multifunctional weirs in the Nakdong River basin. The results of the study showed that the concentration and variability of each water quality variable at the monitoring sites (Fig. 1) were significantly changed due to artificial environmental changes such as an increase in the water depth and a decrease in the flow rate of the river (Fig. 2, Table 3). Furthermore, CA results showed the trends of the monitoring sites, which made up the cluster groups before and after the construction of the multifunctional weirs; sites in Cluster 1 decreased, while those in Cluster 2 increased (Fig. 3). This implies that multifunctional weir construction affected the spatial classification due to these changes in the surrounding environment. Prior to the construction of the multifunctional weirs, the river flowed naturally and spread rapidly downstream, diluting the concentration of contaminated water. However, after construction, the flow rate of the river decreased; further, when the floodgates of the reservoir were inoperative, stagnant water areas were formed, which exhibited similar characteristics to that of a lake.

The PCA and FA conducted before the construction of the multifunctional weirs resulted in the extraction of TN, TP, PO4–P, and EC variables from PC1 (Fig. 4). Before the construction of the multifunctional reservoir, there were many unauthorized farmlands in the floodplains of the Nakdong River; the fertilizers used in these farmlands flowed into the river during rainfall along with various untreated pollutants. Fertilizers and livestock manure used on farmlands near rivers are known to contaminate rivers by leaking nitrogen and phosphorus into non-point pollutants along with surface runoff in the case of rainfall (Carpenter et al. 1998; Nam et al. 2012). The PCA and FA conducted after the construction of the multifunctional weirs resulted in the extraction of BOD, COD, TOC, and Chl-a variables from PC1 (Fig. 4). These results indicate that the key water quality factors changed after construction, that is, they were dependent on the organic pollutants rather than the nitrogen or phosphorous nutrients, as observed during the pre-construction stage.

The South Korean government revised the Sewerage Act in 2012 to prevent and improve the inflow of nutrients. Efforts were made to strengthen the allowable concentration of TP emissions from sewage treatment facilities and expand the advanced treatment facilities through large-scale financial support. The results of these efforts are evident because the water quality trend changed, TP concentration reduced (Fig. 2), and a sharp declining trend was observed since 2012 in the MK and LOWESS
Table 4 Principal component analysis and factor analysis before and after the construction of multifunctional weirs (Varimax rotated)

| Period                  | Variable | Component | VF 1  | VF 2  | VF 3  | VF 4  |
|-------------------------|----------|-----------|-------|-------|-------|-------|
|                         |          |           |       |       |       |       |
| Pre-construction (2007–2011) | pH       | −0.001    | 0.689 | 0.010 | −0.383|
|                         | DO       | 0.031     | 0.166 | 0.883 | −0.161|
|                         | WT       | −0.094    | 0.044 | −0.921| 0.168 |
|                         | EC       | 0.699     | 0.509 | 0.233 | −0.051|
|                         | Chl–a    | 0.046     | 0.906 | 0.194 | 0.111 |
|                         | SS       | 0.003     | −0.067| −0.125| 0.891 |
|                         | BOD      | 0.312     | 0.849 | 0.107 | 0.219 |
|                         | COD      | 0.325     | 0.663 | −0.111| 0.573 |
|                         | TOC      | 0.313     | 0.519 | −0.174| 0.609 |
|                         | TN       | 0.697     | 0.309 | 0.514 | 0.220 |
|                         | NH₃–N    | 0.560     | −0.220| 0.303 | −0.088|
|                         | NO₂–N    | 0.612     | 0.174 | 0.584 | 0.176 |
|                         | TP       | 0.781     | 0.369 | −0.063| 0.376 |
|                         | PO₄–P    | 0.913     | 0.110 | −0.116| 0.061 |
|                         | Eigenvalue| 3.420    | 3.340 | 2.504 | 1.988 |
|                         | Total variance (%) | 24.431 | 23.859| 17.885| 14.203|
|                         | Cumulative variance (%) | 24.431 | 48.291| 66.175| 80.378|
| Post-construction (2012–2019) | pH       | 0.384     | −0.042| −0.376| 0.195 |
|                         | DO       | −0.067    | 0.736 | −0.233| −0.206|
|                         | WT       | 0.335     | −0.808| 0.263 | 0.071 |
|                         | EC       | 0.457     | 0.559 | −0.218| 0.337 |
|                         | Chl–a    | 0.804     | 0.213 | 0.031 | −0.205|
|                         | SS       | 0.300     | −0.091| 0.683 | −0.149|
|                         | BOD      | 0.859     | 0.152 | 0.077 | 0.099 |
|                         | COD      | 0.830     | −0.127| 0.355 | 0.028 |
|                         | TOC      | 0.715     | −0.075| 0.286 | −0.021|
|                         | TN       | 0.313     | 0.823 | 0.193 | 0.272 |
|                         | NH₃–N    | −0.063    | 0.113 | −0.008| 0.882 |
|                         | NO₂–N    | 0.145     | 0.859 | 0.168 | 0.222 |
|                         | TP       | 0.381     | −0.030| 0.784 | 0.033 |
|                         | PO₄–P    | −0.011    | −0.054| 0.845 | 0.124 |
|                         | Eigenvalue| 3.487    | 2.983 | 2.353 | 1.190 |
|                         | Total variance (%) | 24.396 | 21.708| 17.062| 8.519 |
|                         | Cumulative variance (%) | 24.396 | 46.104| 63.167| 71.686|

Bold and italic values represent strong and moderate loadings, respectively.

VF Varifactors; DO dissolved oxygen; WT Water temperature; EC Electrical conductivity; Chl-a Chlorophyll-a; SS Total suspended solids; BOD Biochemical oxygen demand; COD Chemical oxygen demand; TOC Total organic carbon; TN Total nitrogen; NH₃–N Ammonia–nitrogen; NO₂–N Nitrate–nitrogen; TP Total phosphorus; PO₄–P Phosphate–phosphorus
analyses (Table 5, Fig. 5). As such, water quality improvement effects can be enhanced through the tracking and management of major pollutants in rivers. The results of this study imply that after the multifunctional weir construction in the Nakdong River, management policies and countermeasures for organic pollutants are needed. Furthermore, to measure the concentration of organic pollutants, it is deemed necessary to switch from water quality management techniques based on BOD to those based on COD and TOC. However, this study used limited monitoring sites in the Nakdong River basin and lacked appropriate survey intervals.

### Conclusion

In this study, various statistical techniques were applied for determining the need to change the major indicators used for water quality assessment after environmental changes were caused by the construction of eight multifunctional weirs along the Nakdong River in South Korea. After the construction of the artificial structures, it was confirmed that the concentration changes in the water quality variables greatly depended on the variations in the river environment. After the construction of multifunctional weirs, it was decided that management policies and countermeasures for organic pollutants should take precedence over nutrient substances. In particular, among organic pollutants, COD and TOC concentration showed a continuous increase. This study determined that the main variables governing the improvement and management of water quality should be changed from BOD to COD and TOC. The key water quality standards used in the water quality management policy should be modified and supplemented according to the changes in the river environment. Therefore, it is necessary to continuously track the key water quality variables that significantly impact a river’s environment, using data accumulated through long-term monitoring. This will serve as the basis for decision-making when establishing policies for the improvement and efficient management of changes in river water quality. In addition, relevant surveys and research will be required for quickly responding to the changing natural characteristics of rivers in order to maintain their water quality; this is aimed at maintaining the health of aquatic ecosystems and minimizing their impact on human health. In future studies, it is necessary to conduct enhanced monitoring surveys and subsequently analyze them using various water quality variables and data obtained from other works.

### Table 5

| Variable | Pre-construction (2007–2011) | Post-construction (2012–2019) |
|----------|-----------------------------|-------------------------------|
|          | Statistic S | p-value | Trend | Statistic S | p-value | Trend |
| BOD      | −268   | 0.004   | Decrease | −102 | 0.525 | No change |
| COD      | 183    | 0.045   | Increase | 639  | 0.0001 | Increase |
| TOC      | −39    | 0.537   | No change | 1067 | 0.0001 | Increase |
| TN       | −14    | 0.880   | No change | −144 | 0.369 | No change |
| TP       | −147   | 0.095   | No change | −677 | 0.0001 | Decrease |
| Chl–a    | −302   | 0.001   | Decrease | 36   | 0.826 | No change |

Bold values indicate an increase or decrease in the trend of a particular variable

*BOD* Biochemical oxygen demand; *COD* Chemical oxygen demand; *TOC* Total organic carbon; *TN* Total nitrogen; *TP* Total phosphorus; *Chl–a* Chlorophyll-a
Fig. 5 LOWESS analysis performed using the water quality variables for Nakdong River (2007–2019): The vertical dotted line in the middle indicates the time of completion of the multifunctional weirs. Data to the left of this line represent the pre-construction stage (2007–2011), and data to the right represent the post-construction stage (2012–2019): a biochemical oxygen demand, b chemical oxygen demand, c total organic carbon, d total nitrogen, e total phosphorus, f chlorophyll-a. LOWESS: locally weighted scatterplot smoothing.
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Authors’ contributions All authors contributed to the planning and structuring of the study. Chang Dae Jowrote the manuscript and analyzed the data. Chul Gu Lee conducted data collection. Heon Gak Kwon reviewed the initial manuscript and provided suggestions. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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