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CASE STUDY

water ENVIRONMENT RESEARCH

Assessment of the impacts of constructing artificial structures on the water quality and hydrological environment of a meandering river

Yongju Kwon[1] | **Jongyeong Kim**[1] | **Joowon Choi**[1] | **Taeyang Kim**[1] | **Sung Min Cha**[2] | **Soonchul Kwon**[1]

[1]Pusan National University, Busan, Republic of Korea
[2]Green Land & Water Research Institute, Busan, Republic of Korea

Correspondence
Soonchul Kwon, Pusan National University, 2, Busandaehak-ro 63beon-gil, Geumjoeng-gu, Busan, 46241, Republic of Korea.
Email: sckwon@pusan.ac.kr

Funding information
Pusan National University

Abstract

When an artificial structure is built in a river, the river changes significantly in water quality and hydraulic properties. In this study, the effects of the weirs constructed in the middle section of a river as a four major rivers restoration project in Korea on water quality and hydrological characteristics were analyzed. For multi-dimensional data analysis, a self-organizing map was applied, and statistical techniques including analysis of variation were used. As a result of analysis, the cross-sectional area of the river increased significantly after the construction of the weir compared to before the construction of the weir, and the flow velocity decreased at a statistically significant level. In the case of water quality, nitrogen, phosphorus, and suspended solids tended to improve after weir construction, and chlorophyll-a and bacteria tended to deteriorate. Some water quality parameters such as chlorophyll-*a* were also affected by seasonal influences. In order to improve the water quality deteriorated by the construction of the weir, it is necessary to consider how to improve the flow velocity of the river through partial opening or operation of the weir. In addition, in order to determine the effect of sedimentation of particulate matter due to the decrease in flow rate, it is necessary to conduct investigations on sediments around weirs in the future.

Practitioner Points

- Compared to before the construction of the weir, there was no significant change in the flow rate of the river after the construction of the weir.
- In the case of chlorophyll-*a* and bacteria, the water quality was deteriorated after weir construction.
- To improve the deteriorated water quality, it is required to consider the fundamental management of each pollutant source and the flexible operation of both weirs.
- For some improved water quality parameters, further research is needed to determine whether these improvements are directly attributable to the construction of a weir.

KEYWORDS
artificial weir, hydrological environment, self-organizing map, water quality changes

INTRODUCTION

The four major rivers (Han, Nakdong, Geum, and Yeongsan) in Korea have undergone many changes in water quality due to the 16 weirs built by the Four Major Rivers Restoration Project (FMRRP) from 2009 to 2012 (Bae, 2013; Cha et al., 2011; Lee et al., 2018). The objectives of the FMRRP were to secure the water resources, to protect against flood risk and drought caused by climate change, and to expand investments in social overhead capital (Lee & An, 2019). To secure the capacity of the water, natural wetlands in existing rivers have been removed, and artificial structures, including weirs and river banks, have been constructed (Bae, 2013). These artificial structures in the river system can have potential impacts on river ecosystems and can also affect biodiversity (Bryan et al., 2013; Cha et al., 2014; Cisowska & Hutchins, 2016; Lee et al., 2018; Lee & An, 2019; Li et al., 2012).

The hydrological and water quality changes experienced by the four major rivers in Korea underscore the necessity for a comprehensive review and reassessment of the various methods currently used in water quality management. While the construction of weirs has played a crucial role in securing and maintaining adequate water resources in these river systems, it has also been accompanied by a range of water quality issues (Ahn et al., 2014; Lee & An, 2019; Tekile et al., 2015). Specifically, the completion of these weir projects has led to a series of challenges, including frequent and problematic algal blooms, elevated concentrations of nutrients, and an increase in nonpoint source pollution originating from the surrounding watershed areas. These water quality problems have become increasingly apparent and persistent in the aftermath of the water conservation projects, indicating that the existing management approaches may need to be revised and updated. It is essential to develop and implement more effective and adaptive strategies to address these emerging issues and ensure the long-term health and sustainability of the river ecosystems. In addition, changes in the hydrological characteristics associated with the transport of contaminants may cause potential environmental issues. To solve these problems, the Ministry of Environment, Korea, is attempting to operate the weir gates constructed from FMRRP at all times (Jo, 2018).

The installation of weirs or dams is done in many rivers globally, including in China, Australia, the United States, and European countries (Harris & Evans, 2014; Kingsford, 2000; Punys et al., 2019; Wang et al., 2012). These artificial structures damaged many wetlands during the construction of weirs or dams. Damage to wetlands not only affects biodiversity, but it can also have a negative impact on water quality. Kingsford (2000) and Wang et al. (2012) reported issues related to water quality and biodiversity due to the decrease in the flow velocity and the accumulation of pollutants that occurred from the removal of wetlands. In addition, many researchers reported that wetlands affecting the positive impacts on the self-purification of a river system have been removed in recent decades across the world (Hollis, 1990; Sparks, 1995; Wang et al., 2012). To improve deteriorated water quality from artificial structures, including weirs and dams, flexible operations, such as opening water gates and the removal of structures, have been attempted in the European Union (EU) (Cisowska & Hutchins, 2016).

The weirs constructed in Korea, including the YS River, have various impacts on aquatic systems. It is necessary to evaluate the impact on a river through an accurate spatio-temporal analysis of the changes in water quality. Recently, studies analyzing the relationship between water quality and quantity from various perspectives after the construction of weirs have been conducted in Korea as well (Kakore et al., 2023; Kim et al., 2024).

Based on the results of applying the statistical analysis for the water quality and hydrological data, the objectives of this study were (1) to compare the changes of water quality before and after weir construction (AC) in the YS River by applying the self-organizing map (SOM) with various spatial and temporal data interpretation abilities and (2) to suggest ways to improve water quality as well as the sites and seasons where water quality has deteriorated. Various methods for the water quality management of the YS River, where the weir is constructed, can be developed and utilized based on the results.

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MATERIALS AND METHODS

Description of study area and artificial weirs

The YS River is located in the southwest part of Korea and is one of its four largest rivers. The YS River flows from Yongso located in Damyang to the Yellow Sea in

Mokpo. The watershed area and the length of the mainstream are about 3,471 km^2 and 130 km, respectively (Cha et al., 2009). The watershed is mainly surrounded by the agricultural area, including paddy fields, and passes through a densely populated urban area. Gwangju (GJ) city is an urbanized area located in the YS River basin. When the YS River passes through this area, the water quality sharply deteriorates. The primary reasons for the deterioration are well known: (1) inflow of the GJ River, which is heavily contaminated by urban nonpoint source pollutants and combined sewer overflows (CSOs) during rainfall, and (2) inflow of effluents of the waste water treatment plant. In 2012, the Seungchon weir was constructed in the midstream of the YS River, which passes through these urbanized areas.

The YS River has several artificial facilities related to water flow, such as dams and weirs. Upstream and downstream areas of the YS river have four dams, Damyang (DY), Jangsung (JS), Naju (NJ), and Gwangju (GJ) dams, and one dike dam (see white trapezoids and gray rectangle in Figure 1a,b). These facilities were constructed by the Yeongsan River Development Project 2nd Step, which was funded by the International Bank for Reconstruction and Development (IBRD) loan from 1978 to 1981. Four dams and one dike dam were constructed to secure irrigation water and to prevent flood damage. Two artificial weirs, Seungchon (SC) and Juksan (JS), were constructed by four major river restoration projects of the Korean Ministry of Land, Transport, and Maritime Affairs for 3 years from 2009 to 2011 (Cha et al., 2014). Both weirs are located in the mid-stream of the YS River. Both weirs were constructed to secure stable water resources and to prevent flood damage.

There are urbanization areas and two sewage treatment plants (GJ1 and GJ2) in the upstream area of the SC weir, and the NJ sewage treatment plant is located in the upstream area of the JS weir river (see Figure 1a,b). This implies that two artificial weirs can be stored in sewage treatment plant effluents, suggesting that a review of existing water quality management methods is needed.

Monitoring data acquisition and locations

The water quality of the mainstream in the YS River is being monitored by the Ministry of Environment (ME) at seven stations (see Figure 1a) more than one time per month. In this research study, water quality data for 10 years from 2002 to 2006 and from 2013 to 2017 at seven water quality monitoring stations were acquired from the National Institute of Environmental Research (NIER) database (http://water.nier.go.kr/publicMain/mainContent.do). Monthly water quality data of the YS River were measured by the standard method (APHA, American Public Health Association, 1995). Eighteen water quality parameters, including pH, chlorophyll-*a*, BOD_5, soluble-TP, suspended solid, NH_3-N, total phosphorus, total coliform, fecal coliform, specific conductivity, temperature, soluble TN, total nitrogen, NO_3-N, chemical oxygen demands, PO_4-P, and dissolved oxygen (DO), were implied for the spatio-temporal assessment. Hydrological data including water flow, velocity, and cross-sectional area of YS river at two hydrological data monitoring stations, M2 and M3, were acquired from the Water Resources Management Information System (WAMIS) database (http://www.wamis.go.kr/wkw/wkw_flwsrrs_lst.aspx).

Monitoring stations M1, M2, and M3 are located in the upstream area of the SC weir and in the most populous urbanized area (GJ city) of the YS watershed. And also, monitoring station M3 is located at the boundary between GJ city and NJ city in relation to the total maximum daily load (TMDL) program. Monitoring stations M4 and M5 are located in the upstream area of the JS weir and are surrounded by urban and rural areas. Monitoring stations M6 and M7 are located in the downstream area of the JS weir and are surrounded by paddy fields and forests (Table 1).

Self-organizing map

Multivariate analysis techniques, including the principal component analysis (PCA), cluster analysis (CA), factor analysis (FA), and SOM techniques, can be applied for spatial and temporal analyses of a watershed. To evaluate water quality changes due to artificial weir construction, the SOM was applied based on the water quality data of the YS River, which is well known as the most deteriorated river in Korea. The SOM, which is an unsupervised algorithm of an artificial neural network (ANN), can be powerful in analyzing multi-dimensional data (Kohonen, 1997). The network normally can make a two-dimensional mapping or projection of the data group (Siddharth et al., 2020). Based on the analysis ability of the data pattern, the SOM has the capability to adjust the weight vectors of adjacent units in the competitive layer to a similar vector by competitive learning and to approximate the distribution of the target patterns using total weight vectors acquired as the results. A competitive layer of neurons arranged in a lattice is connected to all the inputs via adjustable weights. The input-hidden layer therefore identifies similar patterns and groups them into clusters as the assignment of an alternative value instead of a null value (Figure 2).

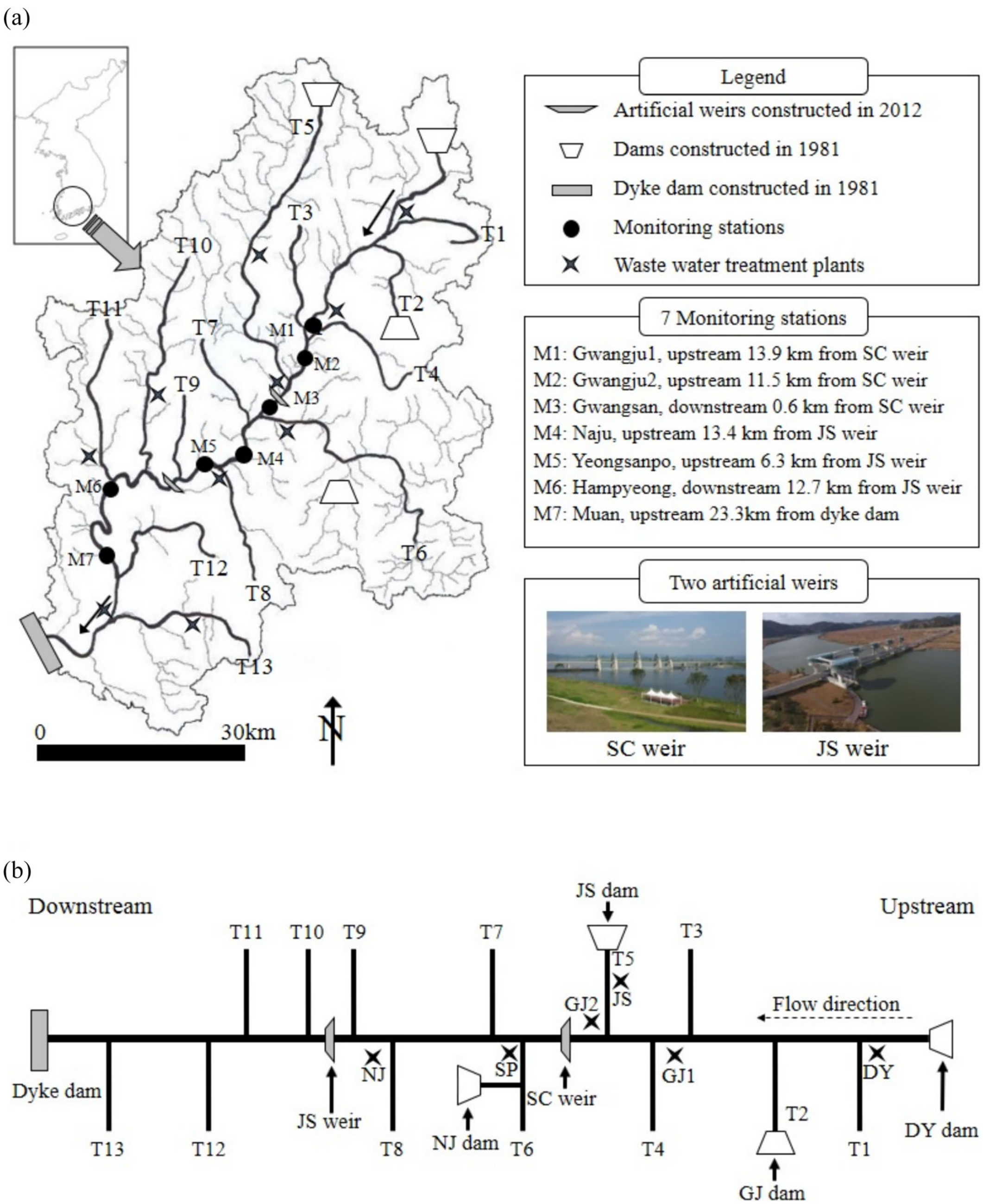

FIGURE 1 (a) Location of the Yeongsan River basin in South Korea, indicating the artificial structures, such as two weirs, including Song-Chon (SC) and Juk-San (JS); four dams; one dike dam; seven monitoring stations; and six waste water treatment plants. (b) A simplified map of the mainstream, the tributaries, artificial structures, and waste water treatment plants in the Yeongsan River basin.

The descriptions of input, output, and training process for SOM are as follows.

The input data, X^i_j, are in vector form with a catchment information at a site (j) in a season (i) (where i and $j = 1, ..., n$). All data were normalized to reduce the difference of the order of magnitude with respect to variables because the range of each variable varies greatly from water quality parameters, and it can affect the final map structure.

In the training of SOM network, data are sequentially introduced to the SOM network. Initial weights of neurons are estimated using small random values with respect to Euclidean distance at the beginning of training process by Equation (1).

$$D_{i,j} = \sqrt{\sum_{k=1}^{n} \left(x_{i\,or\,jk} - m_{i\,or\,jk}\right)^2},\ i=1,2,3,4,\ j=1,2,\ldots,7, \quad (1)$$

TABLE 1 Description of the Yeongsan (YS) river basin.

(a) YS River basin characteristics[a]							
River basin area (km^2)							3,371.4
Total length (km)							136
Agricultural and forest area (km^2)							2,909
Industrial and urban area (km^2)							242
Other area (km^2)							304
Population (person)							1,895,073
(b) Characteristics of artificial structures in YS River							
	SC weir	**JS weir**	**JS dam**	**DY dam**	**GJ dam**	**NJ dam**	**Dike dam**
Watershed area (km^2)	0.0020	0.0024	122.8	65.6	41.3	104.7	-
Capacity (million ton)	9	26	90	67	17	113	250
Height (m)	7.5	3.5	36	46	25	31	20
Length (m)	512	184	603	316	505	496	4,300
Completion (year)	2,012	2,012	1,976	1,976	1,976	1,976	1,981

(c) Descriptions of waste water treatment plants located upstream of weirs

	Geographic coordinates		
Station	**Latitude**	**Longitude**	**Capacity(m^3/day)**
GJ1	35°09′21.8″N	126°49′46.3″E	600,000
GJ2	35°05′25.7″N	126°47′33.6″E	120,000
DY	35°18′34.2″N	126°57′32.7″E	9,000
JS	35°16′33.4″N	126°45′42.0″E	11,000
NJ	34°59′41.5″N	126°41′56.3″E	22,500
SP	35°02′46.8″N	126°48′05.6″E	3,000

[a]Ki et al. (2007).

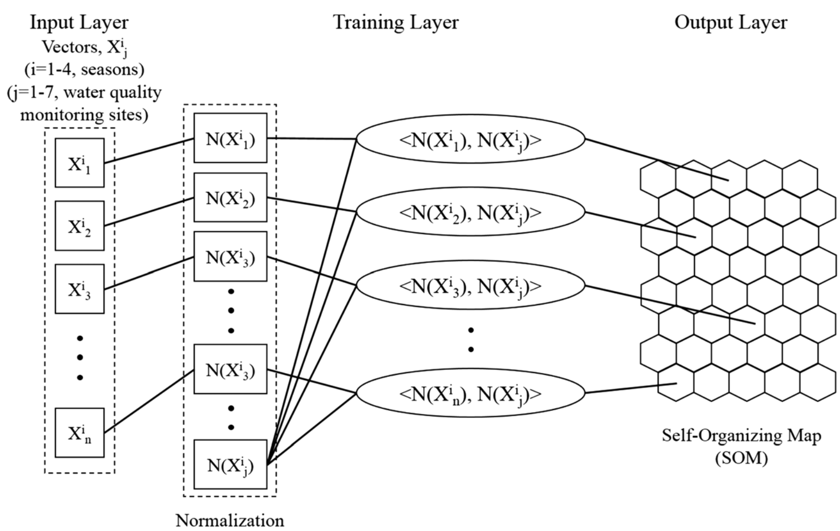

FIGURE 2 The algorithm of self-organizing map (SOM)n.

where $D_{i,j}$ is Euclidian distance between the input vector and the weight vector i (seasons), j (monitoring sites), and x_{ik} and m_{ik} indicate kth element of the current input vector and the weight vector i, respectively. The Euclidean distance is the distance measurement method that provides the most accurate data representation on the map. The Davies–Bouldin index (DBI) is calculated to identify the optimum number of clusters (Davies & Bouldin, 1979).

In the iteration, the weight of winner or best matching unit (BMU) and surrounding neurons are closest to be more similar to the input vectors. BMU is selected by Equation (2).

$$\left\|X_j^i - m_b\right\| = min_i\{\|z - m_i\|\}, \tag{2}$$

where X_j^i is input vector, m_b is the selected center, BMU, and m_i is the current center in the evaluation.

Then, the weight vectors are updated by Equation (3):

$$m_i(t+1) = m_i(t) + \alpha(t) h_{bi}(t)\left[X_j^i - m_i(t)\right]. \tag{3}$$

The output of the final SOM process has a rectangular grid with a hexagonal or rectangular lattice, which represents clusters with similar water quality variations. Clustering is based on the ANN algorithm, which computes the Euclidean distance between sample vectors (from raw data) and virtual vectors (to set the location of sample vectors on the SOM) as mentioned above.

Determination of map size

There is no standard for determining the size of a map in the SOM, but if the map is too large or too small, the interpretation of spatio-temporal data cannot be detected (Li et al., 2018). To select the optimal map size of the SOM, it is necessary to evaluate the quantization error (QE) and topographic error (TE) through the network training of different map sizes (An et al., 2016; Li et al., 2018). This means that QE is a quantitative value of the error that can occur when the training process of the SOM processes the input data to derive the SOM result, and TE is the quantitative value of the error that can be generated by visualizing the SOM result on the map.

To determine the optimal map size of the SOM applied to this study, the QE and TE of the cases of the combinations of the number of rows and the number of columns were calculated in a reasonable range of the number of cells determined by SOM ($5\sqrt{n}$, where n is the number of input data points), except for extreme cases (such as 1 × 84 or 84 × 1) outside the reasonable range. In addition, among the combinations of the number of rows and the number of columns for comparison, the comparison and evaluation were performed for the similar cases that the number of empty cells on the map which input data points were not assigned after SOM training.

Analysis of variance test and coefficient of variation

The analysis of variance (ANOVA) test is a method used to assess whether there is a significant difference between the means of two or more groups. The ANOVA test can be used to evaluate the effect of interactions within independent variables and to present the result as a p value. The p values presented as a result of the ANOVA test serve as tools of decision making regarding whether there is a difference between the two mean values at a statistically significant level based on 0.05. In this study, the ANOVA test was used to evaluate the hydrological characteristics and water quality changes before and after the construction of the weirs.

Coefficient of variation (CV) is well known as a standardized measure of data dispersion of a probability distribution. CV can be defined as the ratio of the standard deviation $\boldsymbol{\sigma}$ of the mean $\boldsymbol{\mu}$.

RESULTS

Analysis of hydrological characteristic changes

To identify how the construction of the weir hydrologically affected the YS River, flow velocity, flow rates, and cross-sectional areas of YS river for the before weir construction (BC), under weir construction (UC), and AC

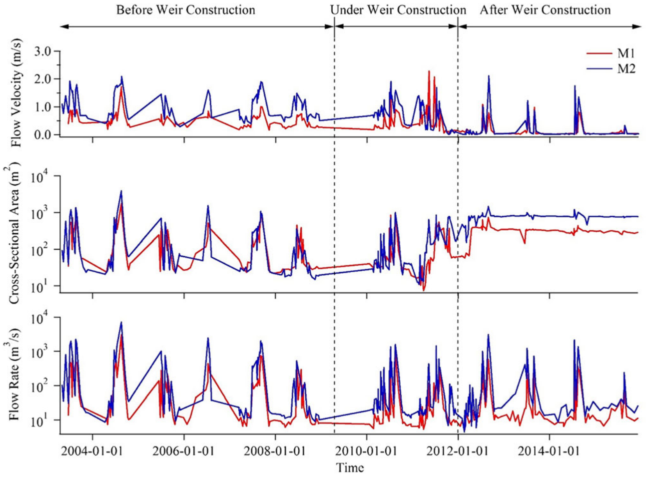

FIGURE 3 Analysis on flow velocity, flow rates, and cross-sectional areas of YS river for the before weir construction (BC), under weir construction (UC), and after weir construction (AC).

were analyzed. Figure 3 shows the cross-sectional area, flow velocity, and flow rate of the M2 and M3 sites. The period between 2009 and 2011, when the construction of weirs began in earnest, was divided into BC and AC.

Cross-sectional area changes

The cross-sectional area of YS river increased as the water level increased with the construction of the weirs, and the ANOVA test showed a statistically significant difference (see Table 3c) between weir construction stages. The mean cross-sectional area of the M2 and M3 site of BC was 293.56 and 195.26 m^2, respectively, but the average cross-sectional area of the M2 and M3 site of AC increased by 6.26 and 1.57 times to 663.85 and 306.96 m^2, respectively. The post hoc test also showed that there is a statistically significant difference between BC and AC (see Table 3d). In Table 3d, comparing AC and BC, it can be seen that p value is less than 0.05 in both M2 and M3 site. In addition, the CV of AC was 0.378 and 0.353 at the M2 and M3 points, respectively. This shows values that are significantly lower by 20.7% and 25.8%, respectively, compared to the CV of 1.823 for M2 and 1.368 for M3 in BC. These results indicate that the cross-sectional area was significantly increased with the weir construction and that the water level in AC was maintained more stable than in BC. An increase in cross-sectional area under constant flow conditions indicates a decrease in flow velocity, which means that the water flow becomes significantly stagnant and can affect water quality. The relationship between water flow and water quality has been presented in various studies. Macura et al. (2016) identified that flow rate and water level influence biological habitats, while Han et al. (2019) simulated that a decrease in flow velocity can impact the deposition of particulate matter. The deposited sediments can ultimately affect water quality through processes such as leaching. In other words, changes in water flow due to the installation of artificial structures in the river can impact water quality, and the increase in cross-sectional area and decrease in flow velocity in the study area may result in changes in water quality compared to before the construction of the weirs.

Flow velocity changes

The ANOVA test showed a statistically significant difference in flow velocity according to the weir construction. The average flow velocities of the M2 and M3 points in BC were 1.04 and 0.53 m/s, respectively. However, the average flow velocities of M2 and M3 points of AC were 0.25 and 0.17 m/s, respectively, which decreased by about 76% and 68%, respectively. A post hoc test was performed to confirm the specific differences according to the weir construction stage. As a result of the post hoc test, there was a difference in flow velocity decrease at statistically significant level in M2 area of UC, but no difference in flow velocity at statistically significant level in M3 area (see Table 3d). In Table 3d, comparing AC and BC, it was confirmed that the p value was less than 0.05 in both M2 and M3. The CV of AC was 1.760 and 1.529 at M2 and M3, respectively. Unlike the cross-sectional area, the flow velocity showed an CV value of 1.5 or more in AC. This is because a rapid flow rate change occurs due to the operation of weir gates installed on the weir.

Flowrate changes

The flow rate was found to decrease AC compared to BC. The average flow rates in the M2 and M3 sites of BC were 471.74 and 163.82 m^3/s, but decreased by 57% and 62%, respectively, to 201.63 m^3/s and 61.83 m/s in AC. As shown in Table 3d post hoc test results, there was a significant difference between BC and AC at both M2 and M3 sites ($p < 0.05$). It means that the average flow rate decreased in AC but there was no difference in the degree of flow rate change.

Analysis of water quality changes using SOM

Optimized map size

Generally, comparing the QE and TE values for cases with different numbers of rows and columns and a similar number of empty cells, the smaller the number of cells determined by the default function of the SOM ($5\sqrt{n}$, where n is the number of input data points), the larger the QE value, and the smaller the number of empty cells, the smaller the TE value (Table 2). Consequently, considering all the QE and TE values simultaneously, it was determined that the optimal map size for the SOM result is reasonable when the total number of cells is 84, the number of rows is 12, and the number of columns is seven.

General descriptions of the SOM analysis

The SOM results of the water quality changes before and after the construction of the YS River weirs largely comprised four clusters (see Figure 4a,b). Cluster A consisted

TABLE 2 Comparison of the QE and TE values for different map sizes.

Number of cells	Number of rows	Number of columns	Number of empty cells	QE value	TE value
84	12	7	10	2.042	0.039
80	16	5	8	2.060	0.032
80	8	10	9	2.063	0.036
78	6	13	11	2.075	0.046
78	13	6	9	2.100	0.046

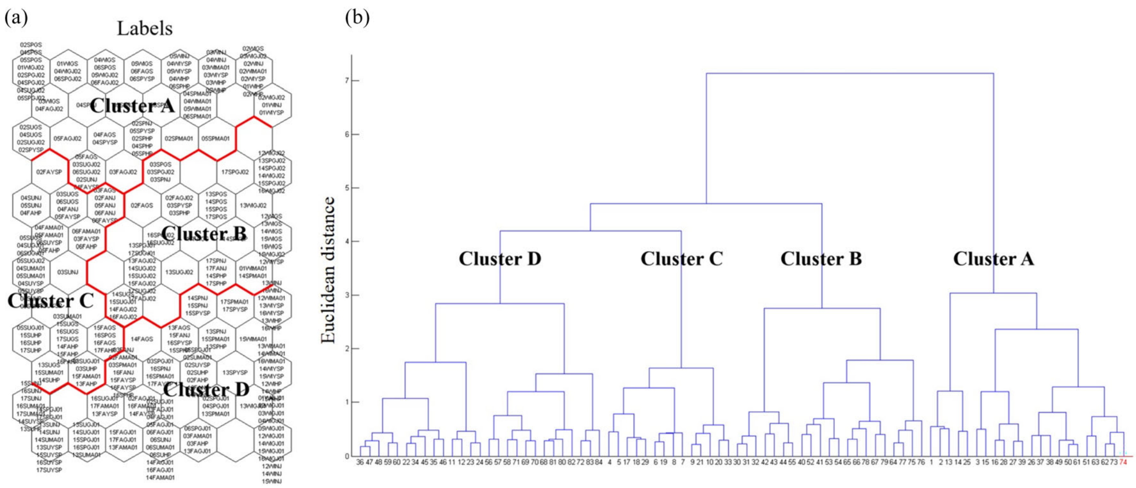

FIGURE 4 Visualization for self-organizing maps (SOM) through the U-matrix along with 17 component layers.

of a total of 68 neurons and was mainly characterized by pre-construction, winter, and spring (see Table 3a). Cluster A included water quality monitoring points M2 to M7, which are mainly urbanized and agricultural areas. Cluster B was composed of 49 neurons in total and was seasonally characterized by winter and spring AC (see Table 3a). Cluster B mainly included water monitoring points M1 to M3, which are located in the most densely populated GJ City in the YS River basin. Cluster B also included the area where the GJ1 wastewater treatment plant, which has the greatest influence on the quality of YS River water, joins the GJ Stream, which is the most polluted area of the YS River. Cluster C was composed of a total of 50 neurons and summer and fall before and AC (see Table 3a). Cluster C was mainly clustered from monitoring points M3 to M7. In general, there were many neurons that represented BC. For the M3 site, the characteristics of BC and AC were included in cluster C. Cluster D included all seasons in AC for a total of 113 neurons (see Table 3a). Overall, Cluster D showed the AC trends. For the M1 site, there were characteristics of BC and AC included in Cluster D.

The hexagonal cells in Figure 4a illustrate the clustering and similarity of the input data (water quality data). Each cell represents a specific data pattern, with adjacent cells indicating similar characteristics. These cells encapsulate temporal (season, year, before-, and after-weir construction) and spatial (monitoring locations) characteristics. Figure 5 reflects these water quality characteristics within the cells. As depicted in Figure 5, the similarity among cells for a total of 17 water quality parameters is expressed as relative values. For instance, DO exhibits low levels in Cluster C, which, according to Table 4a, represents the seasonal characteristics of summer and autumn and contains data primarily from BC. Conversely, DO shows relatively high levels in Cluster D, which lacks specific seasonal characteristics but is indicative of the after-weir construction period, as noted in Table 4.

When interpreting Figure 5, it becomes evident that the water quality parameters requiring attention for management after-weir construction (Clusters B and C) are total coliform, fecal coliform, NH_3-N, and COD. While not all cells within Clusters B and C present issues, fecal coliform and total coliform share the commonalities of being seasonal (spring, summer, and autumn), after-weir construction, and situated in urban areas. NH_3-N and COD are characterized by being seasonal (spring and winter), after-weir construction, and also located in urban sections.

TABLE 3 ANOVA and post hoc test results for hydrological characteristics.

(a) Descriptive analysis

	M2						M3					
	BC		UC		AC		BC		UC		AC	
	n	Average	*n*	Average	*n*	Average	*n*	Average	*n*	Average	*n*	Average
Cross-sectional area (m^2)	106	293.56 (±535.34)	69	140.97 (±201.97)	98	663.85 (±251.09)	101	195.26 (±267.17)	70	144.48 (±199.74)	91	306.96 (±108.46)
Flow velocity (m/s)	106	1.04 (±0.51)	69	0.83 (±0.42)	98	0.25 (±0.44)	101	0.53 (±0.25)	70	0.51 (±0.40)	91	0.17 (±0.26)
Flowrate (m^3/s)	106	471.74 (±1008.16)	69	157.71 (±319.54)	98	201.63 (±487.36)	101	163.82 (±368.78)	70	82.82 (±183.68)	91	61.83 (±120.76)

(b) Coefficient of variation

	M2			M3		
	BC	UC	AC	BC	UC	AC
Cross-sectional area	1.823	1.433	0.378	1.368	1.382	0.353
Flow velocity	0.490	0.506	1.760	0.472	0.784	1.529
Flowrate	2.137	2.026	2.417	2.251	2.218	1.953

(c) *p* values for ANOVA test results for each factor

	M2	M3
Cross-sectional area	0.000	0.000
Flow velocity	0.000	0.000
Flowrate	0.005	0.017

(d) *p* values for post hoc test results on the situation of weir construction (*Scheffe*)

		M2			M3		
Factor 1	Factor 2	Cross-sectional area	Flow velocity	Flowrate	Cross-sectional area	Flow velocity	Flowrate
BC	UC	**0.036**	**0.013**	**0.018**	0.285	0.924	0.132
	AC	**0.000**	**0.000**	**0.027**	**0.001**	**0.000**	**0.025**
UC	BC	**0.036**	**0.013**	**0.018**	0.285	0.924	0.132
	AC	**0.000**	**0.000**	0.926	**0.000**	**0.000**	0.877
AC	BC	**0.000**	**0.000**	**0.027**	**0.001**	**0.000**	**0.025**
	UC	**0.000**	**0.000**	0.926	**0.000**	**0.000**	0.877

Note: The bold text within the table indicates *p* values less than 0.05, signifying a statistically significant difference between the two groups.
Abbreviations: AC, after weir construction; BC, before weir construction; UC, under weir construction.

The relationship between seasonal variations and water quality can also be discerned from Figure 5. Aside from the four previously mentioned water quality parameters, the remaining parameters exhibit seasonal specificity. In particular, BOD, TN, and TP show relatively high values concentrated in the upper left corner of Cluster A. Cluster A, representing the before-weir construction period, corresponds to the spring and winter seasons (see Table 4a). Typically, spring and winter coincide with the dry season when river water levels are lower, and reduced flow rates increase the likelihood of water quality deterioration. This observation aligns with previous studies that have identified reduced flow during the dry season as a primary factor in water quality degradation (Cha et al., 2009). Therefore, regardless of weir construction, water quality tends to deteriorate during the dry season due to decreased flow.

Effective water quality management after-weir construction necessitates an understanding of not only the changes in water quality but also the seasonal and spatial characteristics. Figure 5 serves as a valuable tool for identifying these characteristics.

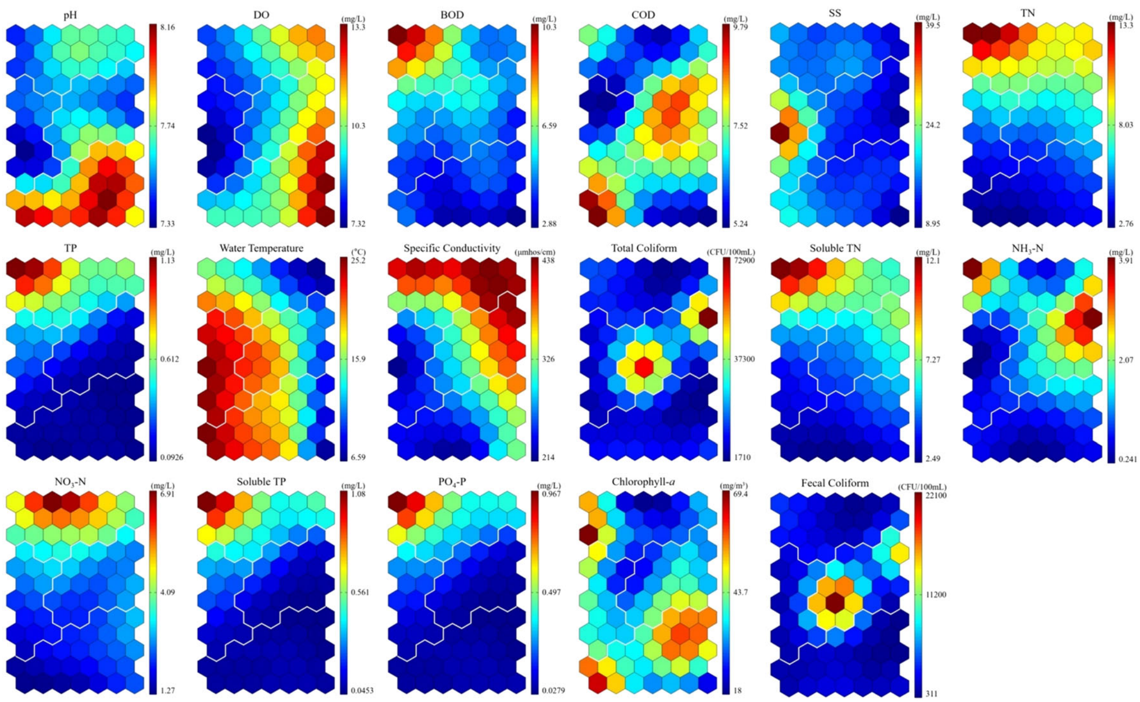

FIGURE 5 The color bar in each contour plot indicates concentrations of each water quality parameter, such as pH, DO, BOD_5, COD, SS, TN, TP, water temperature, specific conductivity, total coliform, soluble TN, NH_3-N, NO_3-N, soluble TP, PO_4-P, chlorophyll-*a*, and fecal coliform, as the color goes from blue to red.

Statistical characteristics of water quality parameters between clusters

Table 3b shows the ANOVA test results for water quality parameters. There were significant differences between each cluster for water quality parameters ($p < 0.05$). To determine the specific differences in the water quality parameters between clusters, the post hoc (*Scheffe's*) test was conducted. Table 3c shows the post hoc test results for each cluster for the water quality parameters. The comparison results of the water quality parameters between clusters are as follows.

- Chlorophyll-a

The post hoc test result for chlorophyll-*a* showed that there was no significant difference between each cluster except for Clusters A and D and Clusters B and D. The significant difference between Clusters A and D can be explained by weir construction and seasonal variations affecting the changes in water quality. In addition, the significant difference between Clusters B and D can be explained by seasonal variations affecting water quality because they occurred in AC. This implies that chlorophyll-*a* may be affected by weir construction and seasonal factors.

- Bacteria

When comparing Clusters A and B and Clusters B and C, the difference in the total coliform and fecal coliform concentrations seemed to have been affected by seasonal effects and weir construction. Clusters B and D had common features of AC but have different seasonal specificities. There were also significant differences between Clusters B and D. For Clusters A and C, there was a common feature of BC, but the seasonal characteristics of the clusters were different. In addition, Clusters A and C had no statistically significant difference. These results indicate that both bacteria, total coliform and fecal coliform, are primarily affected by weir construction and secondarily by seasonal factors.

- Nutrients

For nutrients, such as TN, soluble TN, NO_3N, TP, soluble TP, and PO_4P, in some cases, there was no statistically significant difference between each cluster without exceptional cases (see Clusters C and D for soluble TN and NO_3N and Clusters B and C for TP and PO_4P in Table 3c). In general, there were significant differences between BC and AC (see Clusters A and B, A and D, C and D, and B and C in Table 2c). This means that weir

TABLE 4 ANOVA and post hoc test results on water quality parameters in each cluster.

(a) Cluster characteristics

Cluster	Weir construction (before/after)	Total number of neurons	Number of neurons by season			
			Spring	Summer	Fall	Winter
A	Before	68	24	7	8	29
B	After	49	20	8	9	12
C	Before	50	1	28	21	0
D	After	113	25	27	32	29

(b) ANOVA test results on water quality parameters

	BOD_5	COD	SS	TN	TP	Cond.	Total *Coli.*	Soluble TN	NH_3N	NO_3N	Soluble TP	PO_4P	Chl-*a*	Fecal *Coli.*
p value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000

(c) Post hoc test results on water quality parameters (*Scheffe*)

Factor 1	Factor 2	*p* value													
		BOD_5	COD	SS	TN	TP	Cond.	Total *Coli.*	Soluble TN	NH_3N	NO_3N	Soluble TP	PO_4P	Chl-*a*	Fecal *Coli.*
A	B	0.000	0.000	0.409	0.000	0.000	0.035	0.000	0.000	0.184	0.000	0.000	0.000	0.996	0.000
	C	0.000	0.999	0.000	0.000	0.000	0.000	0.999	0.000	0.000	0.000	0.000	0.000	0.914	0.993
	D	0.000	0.015	0.993	0.000	0.000	0.000	0.988	0.000	0.000	0.000	0.000	0.000	0.012	0.944
B	A	0.000	0.000	0.409	0.000	0.000	0.035	0.000	0.000	0.184	0.000	0.000	0.000	0.996	0.000
	C	0.917	0.000	0.000	0.014	0.055	0.000	0.000	0.009	0.000	0.997	0.014	0.052	0.847	0.000
	D	0.011	0.001	0.469	0.000	0.293	0.000	0.000	0.000	0.000	0.317	0.902	0.942	0.015	0.000
C	A	0.000	0.999	0.000	0.000	0.000	0.000	0.999	0.000	0.000	0.000	0.000	0.000	0.914	0.993
	B	0.917	0.000	0.000	0.014	0.055	0.000	0.000	0.009	0.000	0.997	0.014	0.052	0.847	0.000
	D	0.092	0.030	0.000	0.004	0.000	0.069	0.998	0.600	0.788	0.457	0.000	0.002	0.176	0.997
D	A	0.000	0.015	0.993	0.000	0.000	0.000	0.988	0.000	0.000	0.000	0.000	0.000	0.012	0.944
	B	0.011	0.001	0.469	0.000	0.293	0.000	0.000	0.000	0.000	0.317	0.902	0.942	0.015	0.000
	C	0.092	0.030	0.000	0.004	0.000	0.069	0.998	0.600	0.788	0.457	0.000	0.002	0.176	0.997

construction significantly affected the water quality of nutrients.

- Organics

The post hoc test results for organics, such as BOD_5 and COD, are similar to those of nutrients. Except for some cases (see Clusters B and C for BOD_5 and Clusters C and D for BOD_5 in Table 3c), there was a significant difference between BC and AC (see Clusters A and B, A and D, and B and D), and there were differences due to the seasonal factors (see Clusters A and C for BOD_5 in Table 3c). These results indicate that similar to nutrients, weir construction significantly affected the water quality of organics.

- Suspended solid (SS)

The post hoc test results for SS shown in Table 3c suggest that SS concentration changes may or may not be different in BC and AC. In particular, there was a significant difference between Cluster C and other clusters. This can be explained by seasonal characteristics primarily affecting the SS concentration changes regardless of weir construction.

확인 필요. 이유: 시즌에 따라 많이 다를 수 있음.

DISCUSSION

In this study, the effects of weirs constructed in a river on water quality parameters and hydrological characteristics were analyzed. Although the water level in the river increased with the construction of the weir, there was no significant difference in the flow rate changes, and the flow velocity was statistically significantly lowered after the construction of the weir. In the case of water quality parameters, nutrients and organics showed a tendency to improve after the weir construction, but in algae, related parameters such as chlorophyll-*a* showed a tendency to worsen.

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The improvement effect in some water quality parameters according to the construction of the weir needs to be correlated with the decrease in flow rate. In the case of the YS watershed that was applied in this study, there was no special removal of pollutant sources in the watershed, and the self-purification function was lowered due to dredging of the river bottom. The effect of improving water quality under these conditions can be estimated because nutrients and organic substances are precipitated together when particulate matters are deposited at the bottom of the river as the flow rate decreases. In addition, in some water quality parameters, other water quality changes occurred not only before and after the construction of the weir but also due to seasonal effects. These seasonal characteristics also affect the pollution characteristics of sediments at the bottom of the river. Lee et al. (2018) investigated the difference in SOD depending on the seasonal temperature difference AC.

These findings imply that it is necessary to analyze not only the relationship between flow velocity and water quality but also the relationship between sediment and water, and temperature in order to clarify the improvement of water quality by weir construction. Therefore, in order to clearly judge the impact of beam construction, it seems that changes in water quality, changes in hydrological conditions, and sediments deposited at the bottom of the river must be comprehensively considered.

온도, 방류량 조절을 이용한 결과가
우리들의 이전논문 결과로 담겼음.

CONCLUSION

The construction of a weir has led to significant alterations in the water quality and hydraulic conditions of the YS River, impacting water quality based on seasonal characteristics and geographical locations. Post-construction, the river's flow rate remained largely unchanged, yet the cross-sectional area increased significantly, resulting in reduced flow velocity. This has influenced water quality by promoting the precipitation of suspended solids and altering sunlight penetration. Notably, the levels of chlorophyll-a and bacteria deteriorated, likely due to changes in residence time, sediment dredging, and wetland environment alterations. Addressing this requires fundamental pollutant source management and flexible weir operation. Further research is essential to verify whether some observed improvements in water quality are directly attributable to the weir's construction.

이 부분에 일부 답이 이전 논문과
죽산보 논문에헤서 답하고 있음.

AUTHOR CONTRIBUTIONS

Yongju Kwon: Conceptualization; writing—original draft. **Jongyeong Kim:** Software; writing—review and editing. **Joowon Choi:** Validation; writing—review and editing. **Taeyang Kim:** Validation; writing—review and editing. **Sung Min Cha:** Visualization; writing—original draft. **Soonchul Kwon:** Writing—review and editing; conceptualization; validation.

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DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article

ORCID

Yongju Kwon https://orcid.org/0000-0001-7935-8416

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