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Research Article

Effect of Water Quality Improvement Through Reclaimed Wastewater Supply in Gulpo River

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Abstract

In the case of urban rivers, there is a shortage of water to maintain the stream in case of drought, and there are problems caused by worsening water quality due to pollutants coming from urban areas. In the case of Korea, focus on ecological rivers and waterfront spaces has been increasing recently, and governments are making efforts to improve the water environment by actively promoting urban river restoration projects. Gulpo River is a national stream connected from Bupyeong-gu, Incheon to Gimpo-si, Gyeonggi-do, and reclaimed wastewater that has been ozone-treated in Gulpo sewage treatment water has been supplied as maintenance water in the upper section of Gulpo River since March 2019.

In this study, concentration of major water quality factors was quantitatively compared by utilizing the river water quality standards to analyze the effects of water quality improvement before and after the supply of ozone-treated reclaimed wastewater in the Gulpo River. Analysis sections within the Gulpo River were divided based on discharge points of water supply and sewage treatment wate, and major water quality concentrations were compared for each year before and after the supply of reclaimed wastewater. The results of quarterly water quality analysis centered on DO, BOD, TOC, SS and T-P used for environmental water quality standards showed that the DO concentration increased on average at all sections of Gulpo River, and the concentration of other major water quality parameters decreased, resulting in high water quality improvement effects.

Keywords: *Urban River, Ozonation, Reclaimed Wastewater, Water Quality Analysis*

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Introduction

Currently, the annual precipitation is not evenly distributed due to the nature of rainfall in Korea, resulting in a very low water quality, water shortages, and imbalanced water distribution between regions in December to February, compared to June to August, when the flow rate is very high (Choi, 2019; Ministry of Environment, 2009). In addition, unsanctioned discharge of wastewater and domestic sewage into urban rivers has led to deterioration of water quality and odor. The decrease of underground water and river water levels caused by excessive underground water development, and the decrease in river flow due to the increase in sewage supply rates have led to lack of water in urban rivers, and 134 urban rivers, i.e., 36.3% of 369 urban rivers in Korea, are in danger of becoming dried out (Jee et al., 2012). A plan to secure water for maintenance has been established and is in the process of being implemented to solve the depletion problem of rivers. In the case of domestic urban rivers, the study on comparing the effects of groundwater, treated sewage water, and reservoir discharge water supplied as maintenance water showed that treated sewage water having the highest contribution to stream maintenance (Lee et al., 2005). As a result, various studies were conducted to utilize the reclaimed sewage effluent for urban rivers (Cho et al., 2017; Kim & Kim, 2009; Lee et al., 2006) Sufficient pre-treatment is required to use reclaimed sewage effluent. In the existing studies, sand filtration, ozone treatment, cohesion, sedimentation, activated carbon absorption, and membrane filtration processes were utilized (Choi et al., 2011; Jung, 2009; Seo, 1998). In particular, the ozone oxidation process is being widely used in water treatment other than the role of disinfection, and it has also shown its effectiveness in bleaching and deodorization, oxidation of organic and inorganic matters, and biodegradation (Mori et al., 1998; Park et al, 2003; Park et al., 2001; Park & Ahn, 2001).

In this study, we intend to quantitatively analyze the effects of these methods on the actual streams. For this purpose, the study was conducted on Gulpo River, which uses reclaimed wastewater sewage effluent that is treated with ozonation. Water quality and water ecology environmental standards have future-oriented, administrative policy goals to maintain sound water ecology from water pollution and to preserve water quality suitable for the purpose of water use. The water areas are classified into rivers and lakes, and the items are classified into living environment items and health protection items. In particular, living environment items may be classified into seven ratings to establish goals for each stage. The environmental water quality standard used in this study is a parameter presented by the Ministry of Environment to evaluate the water quality of domestic rivers and establish a river management plan. In this study, the level of water quality was derived by using the concentration of observed water quality factors. In the case of reclaimed wastewater discharged into Gulpo River, water treated at the sewage treatment plant was further processed with ozonation to improve water quality. Ozonation was introduced to Gulpo River for the first time in Korea due to the high cost of facility construction and operation, and through this study, we aimed to clarify the effects of water quality improvement achieved with the use of ozonation in the wastewater treatment.

Theoretical Background

Ozonation Overview and River Water Quality Factors

Ozone treatment is a purification treatment achieved through a strong oxidative activity and is often used in the final treatment of wastewater. Ozone is unstable gas composed of three oxygen atoms, with a sterilization speed of 3,600 times and a sterilizing force of seven times as much as chlorine. It also kills the cell membranes of bacteria and viruses by destroying them, and has a function to decompose harmful substances, and passes through the cell membranes of cells to inhibit the absorption enzymes and stops cell assimilation. Also, there is no controversy over the harmfulness of residual substances because no harmful secondary by-products other than oxygen exist.

The reaction with ozone in alkaline results in a rapid reaction, resulting in low-grade fatty acids, and the solution neutralizes. In acid solutions, ozone has a high potential difference in oxidative reductivity, which consumes water ions in water and causes oxidation, which also neutralizes the acid solution and lessens the pH level. There is a wide range of other effects as well, including chromaticity, odor, TOC, COD removal, oxidation of iron and manganese, and increased dissolved oxygen (Environmental Engineering Research Association, 2002)

Hwang et al. (1995) conducted a study comparing color changes after the ozone treatment. The results showed that the colorimetric removal effect was shown, and in the case of COD, the processing efficiency was insignificant (Hwang et al., 1995). Hong et al. (2004) conducted experiments by fixing the ozone contact time of effluent during ozone injection and changing only the ozone injection rate, which resulted in improvements in color, BOD, COD, and turbidity depending on the ozone injection rate (Hong et al., 2004). In the case of ozone treatment, it was shown that increasing the injection rate and contacting for more than a certain period of time tend to yield higher efficiency. The treatment method of ozone treatment facilities installed at the Gulpo sewage treatment plant uses the application of the AOP process called FULL STEAM, which deals with non-degradable organic material and chromaticity that are difficult to handle biologically.

There are many factors that determine the water quality of a stream, but among them, the water quality factors corresponding to the river living environmental standards are DO, BOD, TOC, T-P, and SS.

BOD (biochemical oxygen demand) refers to the amount of oxygen consumed by the aerobic microorganisms in the water, and it is a method of indirectly measuring the amount of organic matter through the change of DO (dissolved oxygen) concentration in the process of biodegrading the organic matter (Kang, 2009). The rate of decomposition and the rate of oxygen consumption of organic matter can be shown by measuring the BOD, and a high BOD means a high pollution level of the organic matter.

TOC (total organic carbon) is generally the sum of DOC (dissolved organic carbon) and POC (particle organic carbon). It was prompted from the fact that it was difficult to analyze the causes of pollution by simply measuring BOD and COD (chemical oxygen demand), the traditional measurement methods, when identifying the causes of organic pollution in rivers.

T-P is a measure of the total amount of phosphorus (P) present in the water, such as particulate phosphorus, organic phosphorus, polyphosphate and phosphate ion. As one of the indicators representing the eutrophication of lakes, streams, etc., phosphorus acts as a limiting substance in the eutrophication of closed waters such as nitrogen and is contained in synthetic detergents in large amounts. In particular, livestock and agricultural wastewater contain very high concentrations of phosphorus.

SS (suspended solid) is a solid-phase substance that exists in the form of fine particles in water, and in natural water, it is a substance that does not dissolve in water and floats in small particles with diameter less than 2mm, mainly generated by clay minerals. Floating suspended solids in the water increase turbidity, making the water appear dirty and causing water pollution, such as reducing dissolved oxygen (Kim, 2000; Water Encyclopedia).

Table 1

River Water Quality Standards

Rating		pH	Criteria							
			BOD mg/L	COD mg/L	TOC mg/L	SS mg/L	DO mg/L	T-P mg/L	Total Coliforms Group/100mL	Fecal Coliforms Group/100mL
Very Good	Ia	6.5~8.5	Under 1	Under 2	Under 2	Under 25	More Than 7.5	Under 0.02	Under 50	Under 10

Good	Ib	6.5~8.5	Under 2	Under 4	Under 3	Under 25	More Than 5.0	Under 0.04	Under 500	Under 100
Slightly Good	II	6.5~8.5	Under 3	Under 5	Under 4	Under 25	More Than 5.0	Under 0.1	Under 1,000	Under 200
Normal	III	6.5~8.5	Under 5	Under 7	Under 5	Under 25	More Than 5.0	Under 0.2	Under 5,000	Under 1,000
Slightly Bad	IV	6.5~8.5	Under 8	Under 9	Under 6	Under 100	More Than 5.0	Under 0.3	-	-
Bad	V	6.5~8.5	Under 10	Under 11	Under 8	No trash, etc. floating	More Than 2	Under 0.5	-	-
Very Bad	VI	-	More Than 10	More Than 11	More Than 8	-	Under 2	More Than 0.5	-	-

*source : Water Environment Information System

Table 1. is an administrative policy standard for maintaining a healthy water ecosystem from water pollution and preserving water quality suitable for the purpose of water use. In this study, before and after the supply of Ozone-treated reclaimed wastewater to Gulpo River was compared and analyzed according to the river water quality standards. The analysis was conducted on six items according to the criteria of the Ministry of Environment as follows: pH, BOD, TOC, SS, DO and T-P.

Methodology

Area selection for Experiment and the Current Status

Gulpo River is a stream with a distance of 15.3 km and a basin area of 131.75 km2 starting at 193-61, Galsan-dong, Bupyeong-gu, Gyeonggi-do. The upstream of Gulpo River is a typical urban river that passes through the sections of new towns in Incheon and Bucheon due to the expansion of urban development since the 1990s. The downstream of Gulpo River is located where farmland is widely distributed (Seol, 2013).

Gulpo River was originally a stream that caused many complaints such as odors and algae. The water supplied to Gulpo River had been from the Han River from Pungnap Intake Station in Songpa-gu, Seoul until 2018. To improve water quality in Gulpo River, more than 75,000 tons of water must be discharged per day. However, due to economic problems, only 20,000 tons of water have been supplied per day, which is less than a third of the supply plan (Rye, 2019). In particular, due to the nature of rainfall in Korea, sufficient supply of flow is needed from

December to February, which is period of shortage of river water and the period that significantly affects the water quality, compared to June to August when the flow rate is very high.

Under the project to create natural ecological streams in the Gulpo River area, ozone-treated reclaimed wastewater has been supplied from the Gulpo Sewage Treatment Plant to the upper Gulpo River since March 2019. Using reclaimed wastewater from the Gulpo Sewage Treatment Plant as discharge water, it is possible to reduce maintenance costs and supply more water than using the water from the Han River.

Data Collection and Research Method

To analyze the effects of water quality improvement before and after supplying water processed with ozonation in the Gulpo River, concentration of major water quality factors was quantitatively compared by season by using the water quality standards for rivers. First, water quality was analyzed by dividing the main analysis points into the upstream, which is after joining Cheongcheon River, midstream, which is before joining Gyesan River, and downstream, which is after joining Gyesan River. In addition, the measurement points were referred to as Point 1, Point 2, and Point 3. This is shown in Figure 1.

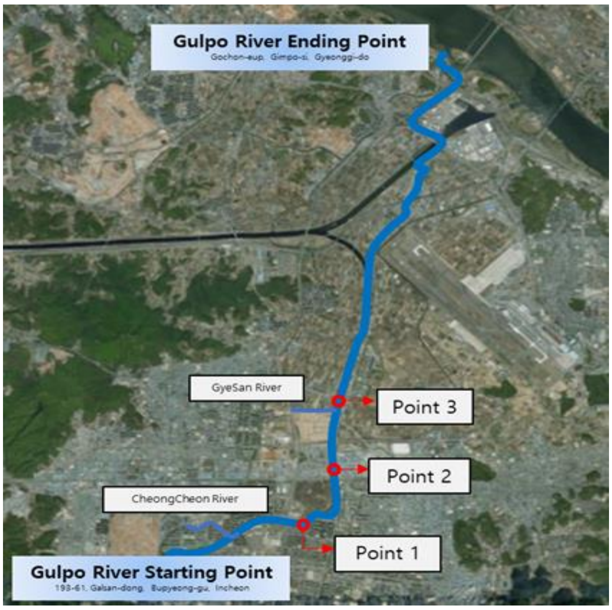

Figure 1. Analysis Points in Gulpo River

To analyze the degree of improvement in river water quality, BOD, DO, and TOC, which are environmental standard factors of river water quality, were investigated, and seasonal measurements including dry season and flood season were taken into consideration to study the relationship between environmental factors and flow rates. Since ozone treatment facilities were completed and have been operating since March 2019, year before and the year after March 2019 were compared by season. Water quality factor information from the Water Environment Information System (http://water.nier.go.kr/)) from April 2018 to March 2020 was used as the data. Since data of pH, BOD, DO, SS, TOC, and T-P, which are included in the water quality ratings, are provided on a monthly basis by the water environment information system, they were grouped and compared quarterly. It is difficult to accurately compare the flow rate since summer has a rainy season and the flow rates are not temporally equal. By taking measurements 1 to 4 times per month, results were compared on a monthly basis, and the analysis locations were Point 1 and Point 3.

Table 2
Water Quality after Treatment of the Gulpo Sewage Treatment plant

		pH	BOD	COD	SS	T-N	T-P	Total Coliforms	DO	Turbidity
	4	6.5	0.6	6.4	0.6	9.088	0.308	Non-detection	8.97	0.5
	5	6.5	0.5	5.2	0.5	8.117	0.249	Non-detection	8.9	0.4
	6	6.5	0.6	5.4	0.4	8.294	0.234	Non-detection	8.84	0.4
	7	6.5	0.7	5.1	0.4	7.468	0.175	Non-detection	8.82	0.5
2018	**8**	6.5	0.7	5	0.3	7.925	0.222	Non-detection	8.8	0.4
	9	6.5	0.8	5	0.4	8.616	0.258	Non-detection	8.73	0.3
	10	6.5	0.4	5.2	0.5	8.467	0.262	Non-detection	8.73	0.3
	11	6.5	0.4	5	0.4	7.767	0.192	Non-detection	8.75	0.3
	12	6.4	0.8	5.5	0.5	9.884	0.231	Non-detection	8.83	0.4
	1	6.4	0.7	6.2	0.6	11.178	0.291	Non-detection	9.02	0.4
	2	6.4	0.8	5.9	0.7	11.719	0.27	Non-detection	9.1	0.5
	3	6.4	0.4	6	0.4	10.398	0.214	Non-detection	9.13	0.5
	4	6.4	0.6	5.7	0.4	9.121	0.145	Non-detection	9.12	0.4
	5	6.4	0.6	5.6	0.6	8.85	0.215	Non-detection	9.03	0.9
	6	6.4	0.7	5.3	0.5	8.448	0.159	Non-detection	8.99	0.5
2019	**7**	6.3	0.7	5	0.5	8.304	0.186	Non-detection	8.93	0.5
	8	6.3	0.7	4.8	0.5	8.135	0.155	Non-detection	8.81	0.6
	9	6.4	0.6	4.9	0.4	8.14	0.103	Non-detection	8.84	0.4
	10	6.3	0.5	4.9	0.4	8.72	0.13	Non-detection	8.75	0.4
	11	6.4	0.7	4.6	0.6	8.514	0.107	Non-detection	8.86	0.5
	12	6.5	0.9	5.7	0.7	9.909	0.088	Non-detection	8.99	0.6
2020	**1**	6.4	0.8	5.5	0.6	11.428	0.122	Non-detection	9.11	0.6

2	6.4	0.7	5.9	0.9	11.958	0.153	Non-detection	9.04	0.8
3	6.3	1.1	6.2	0.8	11.819	0.222	Non-detection	9.04	1.0
Discharge water quality standard	-	Less than 10.0	Less than 40.0	Less than 10.0	Less than 20.0	Less than 0.5	Less Than 3000	-	-

Table 2 shows the water quality after ozonation of sewage effluent at the Gulpo Sewage Treatment Plant. pH levels remained constant, and BOD, COD, SS, T-N, T-P, and E. coliform groups all appeared to be below the discharge water quality standard.

Comparative Analysis of Observed Water Quality Concentrations

To analyze the level of improvement of water quality before and after supply of maintenance water in Gulpo River, water concentrations were compared by season, as shown in Table 3. Spring is categorized as April-June, summer as July-September, fall as October-December, and winter as January-March.

Table 3

Water Quality Factor Value at Each Point (Unit : mg/L)

Point1 (Upstream)		DO	BOD	SS	T-P	TOC
Before Supply	4-6	4.70	5.97	11.77	0.27	5.27
	7-9	4.30	3.47	9.40	0.24	5.27
	10-12	7.33	4.53	16.53	0.14	3.90
	1-3	11.73	2.00	6.97	0.05	3.30
After Supply	4-6	9.10	2.73	7.63	0.12	4.87
	7-9	7.17	1.93	5.27	0.14	3.57
	10-12	9.60	1.43	4.37	0.12	3.87
	1-3	7.43	2.47	7.77	0.14	4.57
Comparison	4-6	94%	-54%	-35%	-56%	-8%
	7-9	67%	-44%	-44%	-44%	-32%
	10-12	31%	-68%	-74%	-10%	-1%
	1-3	-37%	23%	11%	182%	38%

Point3 (Downstream)		DO	BOD	SS	T-P	TOC
Before Supply	4-6	6.67	6.47	15.70	0.26	5.73
	7-9	6.63	5.80	13.83	0.22	6.37
	10-12	3.20	8.87	10.60	0.46	6.97
	1-3	9.30	4.90	5.63	0.20	5.50
After Supply	4-6	9.47	5.87	12.30	0.15	5.97
	7-9	8.23	5.37	11.37	0.21	3.93
	10-12	6.70	3.20	4.37	0.21	3.80
	1-3	5.13	6.13	8.07	0.24	5.43
Comparison	4-6	42%	-9%	-22%	-40%	4%
	7-9	24%	-7%	-18%	-4%	-38%
	10-12	109%	-64%	-59%	-54%	-45%
	1-3	-45%	25%	43%	19%	-1%

Table 3 shows that in all four seasons, the DO concentrations at points 1, 2, and 3 have increased, and the concentrations of the remaining water quality factors have shown declining trends, indicating that the water quality is improving. In particular, DO and BOD have been improved significantly, and water quality has been improved by factor and by quarter. In the upstream of Gulpo River (point 1), DO increased significantly by 94% in spring (April to June), 67% in summer (July to September), and 109% in fall (October to December) in the

Point2 (Midstream)		DO	BOD	SS	T-P	TOC
Before Supply	4-6	9.13	6.70	15.30	0.27	12.03
	7-9	12.47	20.37	21.13	0.20	6.00
	10-12	6.30	7.37	8.13	0.34	4.40
	1-3	9.23	8.17	9.30	0.16	4.63
After Supply	4-6	9.40	4.73	9.07	0.19	4.23
	7-9	9.13	14.23	19.87	0.50	5.93
	10-12	9.13	2.47	6.50	0.14	3.83
	1-3	10.10	2.60	6.67	0.16	4.47
Comparison	4-6	3%	-29%	-41%	-31%	-65%
	7-9	-27%	-30%	-6%	151%	-1%
	10-12	45%	-67%	-20%	-59%	-13%
	1-3	9%	-68%	-28%	0%	-4%

downstream of Gulpo River (point 3). However, the midstream of Gulpo River (point 2) showed a slight increase of 3% and 9% in spring (April-June) and winter (January-March), respectively. When DO increased significantly, the concentration values before the supply of maintenance water were 4.70 mg/L, 4.30 mg/L, and 3.20 mg/L, but when DO increased slightly, the concentration values before the supply of maintenance water were 9.13 mg/L, 9.23

mg/L. Also, BOD decreased to 67% and 68% in winter and spring, respectively, in the midstream of Gulpo River (point 2) but showed slight decrease with 9% and 7% in spring and summer, respectively, in the downstream of Gulpo River (point 3). At this time, BOD concentration was relatively high during the period of the significant decrease, and BOD concentration was also relatively high during the time of small decrease.

The change in concentration during the analysis period shows that the greater the pollution, the greater the effect of water quality improvement. On the contrary, if the water quality is stable to a certain extent, the effect of improving water quality was insignificant. In addition, the water quality of the upstream of Gulpo River (point 1) worsened during certain periods and in spring. Figure 3 shows factors that are difficult to be regarded as water improvement effects during certain periods before and after the supply of maintenance water. Higher concentration represents better water quality in the case of DO, while lower concentration represents better water quality in the cases of BOD, TOC, and T-P.

Figure 2 shows a comparison of five water quality items at three observation points (upper, middle, and lower) before and after the supply of ozone-treated reclaimed wastewater by using the Environment Ministry's water quality assessment criteria in Table 1.

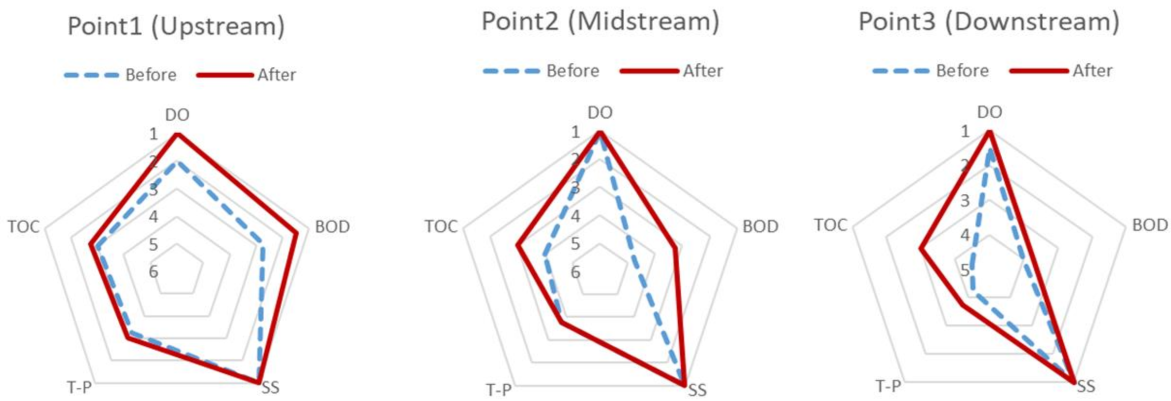

Figure 2. Changes Water Quality Rating in Rivers

The ratings were given based on the average of the ratings by quarter, with 1a rating labeled as 1 and 1b labeled as 1.5 rating. A total of 6 ratings were allocated. Overall, out of Point 1 (upper), Point 2 (middle), and Point 3 (lower), upstream had the highest quality ratings. Additionally, it was found that the water quality rating fell as the water passed through midstream and downstream, and the effect of the water quality improvement dropped as well. This trend may have been observed due to the pollutants flowing into the midstream and downstream from the city in the case of Gulpo River,

In the upstream, DO showed good water quality with average ratings of 2.13, 1.125, and 1.75 in the upper, middle and lower streams, respectively, and when maintenance water was supplied, the ratings improved to 1.25, 1, and 1.25, respectively. TOC was slightly improved from rating of 3 to 2.75 in the upstream, and improved from 4 and 4.5 to 3 in both the midstream and downstream, maintaining a constant TOC concentration at all points. The BOD improved from 2.75 to 1.75 on average in the upstream, and from 4.75 to 3.25 in the midstream, but only improved slightly from 4 to 3.75 in the downstream. T-P averaged rating below 3 at all points and was not significantly improved after the supply of maintenance water. SS was found to be very good in water quality before and after the supply of maintenance water at all points.

Conclusion

In this study, the target stream, Gulpo, was selected to analyze the effect of river water quality improvement when sewage effluent treated with ozonation was supplied as river maintenance water, and the water quality before and after the supply of ozone-treated reclaimed wastewater was compared using the river living environment standards. As a result, conclusions were drawn as follows.

First, the overall water quality improvement of Gulpo River was observed through the improvement of DO, BOD, and SS after supplying maintenance water treated with ozonation. In particular, the concentration of DO and BOD has been improved significantly, and the BOD rating according to the standard of living conditions has also been improved significantly.

Second, when analyzing the concentration of water quality factors on a quarterly basis, the effect of water quality improvement was found to be more significant when the contamination was more severe, and on the contrary, if the water quality is stabilized to a certain extent, the effect of water quality improvement was found to be insignificant. Accordingly, it is expected that the water treatment efficiency can be increased by operating ozonation facilities mainly during times of poor water quality.

Third, there was a time when the water quality worsened after supplying ozone-treated water. However, since water quality concentration of Gulpo River is maintained at a constant level in contrary to when there were seasonal changes before supplying maintenance water, it will be advantageous for water quality management of Gulpo River.

Overall, it can be seen that the upstream of Gulpo River has a higher water quality compared to the downstream, and all water quality factors except DO and SS becomes worse as we move down the stream. To make the water quality of downstream commensurate with that of upstream in Gulpo River, it is necessary to manage pollutants flowing into the city and to put in place measures to keep the water quality constant. It is expected that accurate comparison will be possible if a river water quality analysis is conducted through a numerical analysis simulation to clearly determine the effects of water quality improvement using ozone-treated reclaimed wastewater in the future.

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