

ORIGINAL ARTICLE

An Analysis of Long-term Changes in Water Quality of Geumho River using Statistical Techniques

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Abstract

In this study, water quality data of eight main sites in the Geumho River watershed were collected and analyzed for long-term changes in water quality over the period from 2005 to 2015. The results showed that BOD concentration was gradually improved by the Total Maximum Daily Load (TMDL), stages 1 and 2. Recently, a tendency of increasing BOD concentration was observed in the downstream section of the river. The concentration of COD was analyzed to be contaminated throughout the water system regardless of the water quality improvement project, and the TN concentration tended to increase in the midstream of the river from 2013. The TP concentration has clearly decreased from 2012 after the second stage of TMDL. For the statistical analysis of PCA ordination, monthly water qualities (pH, DO, Electrical Conductivity (EC), Water Temperature (WT), BOD, COD, TN, TP, TOC, and SS) and flow rate data for 5 years from 2012 to 2016 were used. Seasonally the Geumho River showed an increase in the TN concentration at point sources during the dry season (December to February). TP showed the effect of non-point sources in the summer, because rainfall has caused a rise in flow rate in the upstream. Besides, the origin of pollution source was changed from non-point sources with BOD, COD, and TOC.

Key words : Regional/seasonal Kendall test, Geumho river, PCA ordination statistical analysis

1. Introduction

In the last 1990s, water quality improvement projects were actively performed for the Geumho River as part of the government controlled project to supply fresh water. As a result, water quality was improved to BOD 3.6 mg/L in 2014 in which the quality of water corresponding to Class III environmental standards has been greatly improved

(NEWSWIRE, 2015). In addition, local governments installed buffer storage facilities for the readjustment of sewage and water pollution from industrial complexes and continued to make efforts to improve water quality by creating ecological streams and expanding sewage treatment facilities (Yang and Bae, 2012). As a result, the water quality in Geumho River has improved significantly, resulting in the highest water quality improvement rate among the

Received 11 October, 2018; **Revised** 23 October, 2018;
Accepted 23 October, 2018

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contaminated stream in the nation. However, Geumho River is still the main cause of the rise in water pollution of Nakdong River and is also still one of the most important rivers in terms of water quality management of the Nakdong River watershed (Jung, 2018). Meanwhile, efforts to improve water quality need to be made more scientific and systematic as development pressure continues to rise in the Geumho River watershed (Lee, 2013; Yun, 2014; Kim, 2016). The role and importance of Geumho River in the Nakdong River watershed remains unchanged in the present day, and we are still making a lot of effort to maintain improved water quality. However, detailed researches and investigations for changing the water quality of Geumho River according to efforts to improve the river are still not complete.

In this study, 11 years of water quality data were collected from 2005 to 2015 at eight main sites of the Geumho River watershed to analyse the trend of long-term water quality changes. The improvement effects of the water quality improvement project and the variation characteristics were evaluated using the Seasonal Kendall test for each site of the main stream of Geumho River, and the locally weighted scatter plot smoother (LOWESS) method was used to analyze the change during the period in order to compensate for the shortcomings of the Seasonal Kendall test with linear trends as the underlying assumption and to identify changing trends within a specific period of time. In addition, a regional trend (Regional Kendall test) analysis that evaluates a whole trend through combining trend tests for each site was performed, and specific trends in the water quality of the main stream of Geumho River were expressed in detail through temporal and spatial graphs during the period. Moreover, a main component analysis PCA ordination statistical method was used to analyze the temporal and spatial characteristics centered on Geumho River in order to

help the water quality management of Geumho River in the future by providing clear analysis of the current water condition.

2. Materials and methods

2.1. Target watersheds

The target watershed of the Geumho River flows westward through Yeongcheon city after entering from Yeongcheon Dam, located in the upstream, and passes Gyeongsan city and Daegu Metropolitan city. Then, it makes a smooth circuit to the north with slow flows and joins the main stream of the Nakdong River at Jukgok-ri, Dasa-myeon, Dalseong-gun. The administrative district consists of Daegu Metropolitan city, a large urban area with a large population of 2,500,000, and Gyeongsan city, North Gyeongsang Province, Yeongcheon city, Pohang city, and Chilgok-gun where many industrial complexes are located (Jung, 2018). There are about 20 tributary streams such as Nam stream, Sin stream, Palgeo stream, and Dalseo stream in the Geumho River watershed. It is the second largest of the tributaries of Nakdong River, with a total length of 118 km and an area of 2,092.3 km² covering about 9% of the entire the Nakdong River area of about 23,326.3 km², and represents a shape factor of 1.32 with a smooth slope in the main stream and a steep tributary stream line (Choi, 2002; Hwang and Jeong, 2002; Jung et al., 2012(a)). The annual average rainfall in the Geumho River watershed is 1,056.6 mm, about 253.4 mm less than the national average of 1,310.0 mm. Due to the geographical influence of the Nakdong River inland area, rainfall is less than that of other areas. The flow rate shows severe differences between the flood and the dry periods and that leads to flooding caused by heavy rain during the flood period, and the water quality during the dry period, April-December, is worsening due to the lack of water for river maintenance on Geumho River (Choi, 2004).

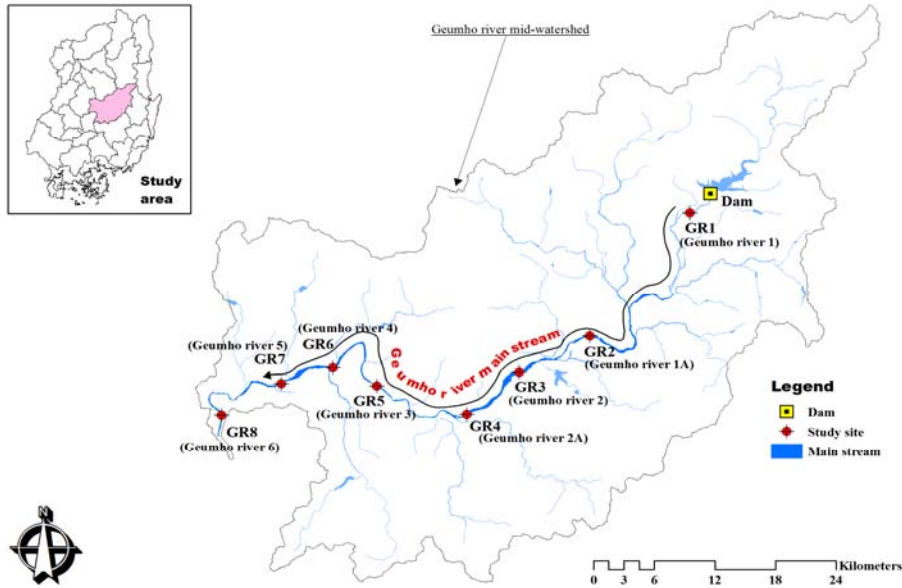


Fig. 1. Study area and monitoring sites in the Geumho River watershed.

The water quality and flow data were collected from the Water Environmental Information System of the Ministry of Environment (WEIS, 2018) for a total of eight stations including five national water monitoring networks of the main Geumho River and three water pollution monitoring stations of the total water pollution load management network. Fig. 1 illustrates the subject sites in detail.

2.2. Status of land use

The water quality of a stream shows differences depending on land uses, such as urban, industrial, agricultural, forest, and grasslands, because stream water quality may be affected by the land use patterns. Land use types are directly related to human activities and govern environmental pollution. Therefore, to properly manage water quality in watersheds, it is necessary to identify the effects of spatial water quality and the characteristics of land uses in relation to topographic conditions, land cover, and distribution of pollutants. In this study, the land

use status was analyzed with the Level-2 land use data provided by the Ministry of Environment to identify the land use status of Geumho River. The land use classification was implemented as eight different types such as Forest, Agriculture, Field, Urban, Industrial, Water, Grass, and Others and was mapped using the buffering function of Arc GIS 9.3. Fig. 2 shows the map. Residential areas, commercial areas, transport areas, and public facilities areas were integrated into Urban, and facility plantation, orchards, and other farmlands were also integrated into Field. The upper reaches of the Geumho River watershed are the largest areas of the forest (Forest), and the midstream area of the watershed is the highest percentage of rice paddies (Agriculture) and fields (Field) by 24.84% excluding the forest. The area and area ratio were calculated based on the division of the entire Geumho River watershed as upstream, midstream, and downstream (Table 1). The total area of the Geumho River watershed is 2,062.49 km², and the upper reaches of the Geumho River

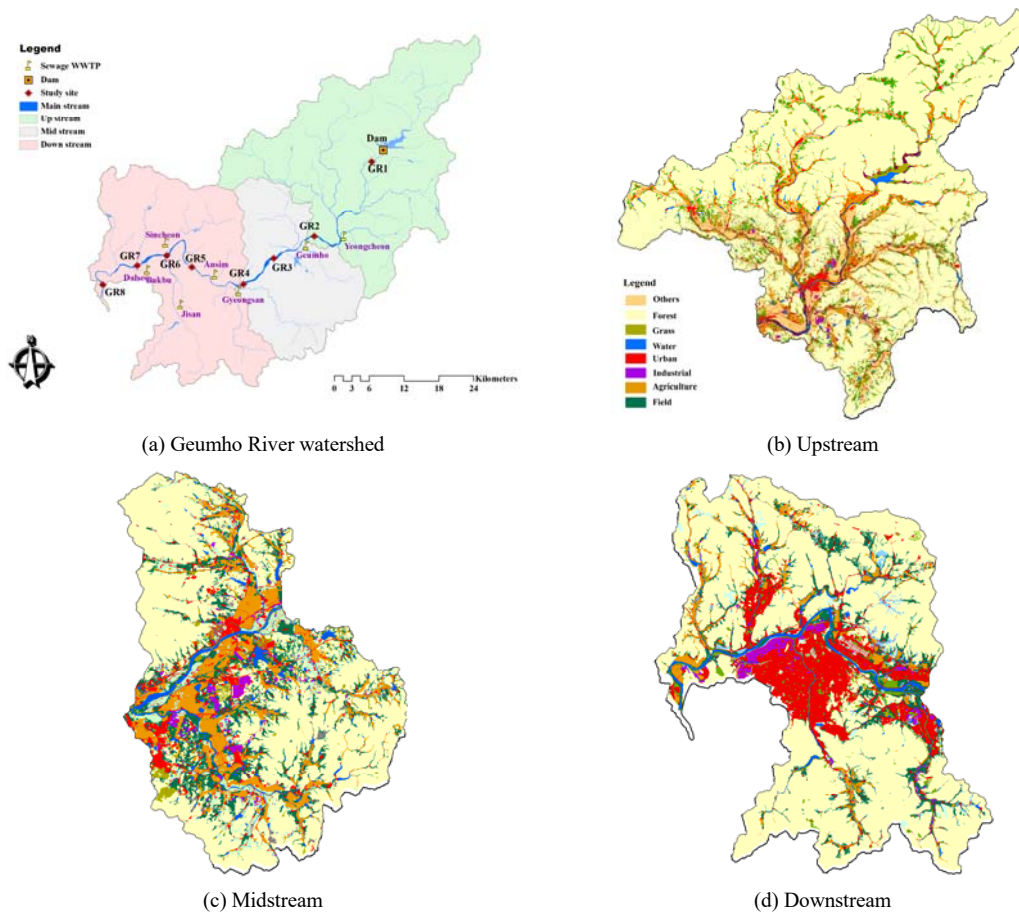


Fig. 2. Classification of the Geumho River watershed.

watershed are 921.13 km², where forests account for the largest amount of land. The midstream area of the Geumho River is 436.80 km², it shows the highest percentage of rice paddies (Agriculture) and fields (Field) by 24.84% except for the forest. Urban areas (Urban) are similar to the upper reaches, but the area of the industrial complex is twice as large as that of midstream areas and the number of businesses that have moved in there is twice as large. More than 70% of the farmland in the entire watershed is located in the midstream area of Geumho River, and agriculture is developed in the midstream area of Geumho River (Daegu regional environmental agency, 2005). The

downstream area of Geumho River is 704.56 km², urban areas account for 15.12% as shown on the map, and covers 40.29% of the total area except the forest. In the downstream area, four industrial complexes are located such as the Industrial Complex 3, the Geomdan Industrial Complex, the Dyeing Industrial Complex, and the Western Daegu Industrial Complex, which cover 10.45 km² and are the same as the complexes located in the downstream and midstream areas of Geumho River.

Recently, GIS analysis tools are largely used for the spatial analysis of environmental pollutants such as non-point sources based on the cadastral

Table 1. Upstream, midstream, and downstream land use types of the Geumho River watershed

Land use	Up stream		Mid stream		Down stream	
	km ²	%	km ²	%	km ²	%
Forest	646.99	70.24	218.87	50.11	440.16	62.47
Agriculture	81.14	8.81	56.00	12.82	30.18	4.28
Field	65.64	7.13	52.52	12.02	52.41	7.44
Urban	28.87	3.13	28.11	6.43	106.53	15.12
Industrial	3.41	0.36	7.04	1.61	10.45	1.49
Water	24.86	2.70	16.60	3.80	17.65	2.51
Grass	13.99	1.52	10.42	2.39	20.24	2.87
Others	56.24	6.11	47.25	10.82	26.94	3.82
Sum	921.13	100.00	436.80	100.00	704.56	100.00

information according to usage for watersheds or business areas by using the information of the land use caused by these land use conditions (Jung et al., 2012(b); Park et al., 2014; Jung et al., 2015).

Barringer et al. (1990) suggested that using GIS mapping to analyze the space in a watershed is a simple and effective way to explain the relationship between land use and water quality.

2.3. Statistical analysis methods

2.3.1. Water quality trend analysis

The Regional Kendall test (Helsel and Frans, 2006) and the Seasonal Kendall test (Hirech and Slack, 1984) were applied to quantitatively analyze changes in the water quality of the main stream of Geumho River. The Regional Kendall test is a method used to identify changes in spatial water quality across subject points. This method provides full scale test statistics to verify whether a consistent trend is evident across the region, and it is possible to determine if there is a consistent regional trend in environment variables. The Seasonal Kendall test is an extended version of the Mann-Kendall test for testing linear trends by calculating the sum of Kendall's S statistics based on monthly and seasonal data. In this study, data were divided monthly, and the monthly average was calculated for the water

quality data with an interval of eight days in order to apply the Seasonal Kendall test method. In addition, the magnitude of the change was analyzed through obtaining the Seasonal Kendall slope statistic (Seasonal Kendall slope estimator). If $p\text{-value} > 0.05$ for a significant level ($\alpha=0.05$) in both 95% confidence intervals, the null hypothesis (H_0) that there is no trend will be accepted. If $p\text{-value} < 0.05$, however, the null hypothesis is to be rejected and the alternative hypothesis (H_1) will be accepted (Kim, 2001). After calculating the statistics of S and Z-value, the p-value was obtained to determine trends by testing its significance. Then, the LOWESS analysis was applied to identify the characteristics of the variation in water quality over the period of interest for each point for supplementing the reduction of the monotony of linear trend analysis using a curve trend method. The LOWESS analysis is a simple but suitable tool for fitting smoothing curves for real data, and it is useful to fit data with a regression model without assumptions about the primary or secondary regression model (Jacoby, 2000). Based on Cleveland (1993), the LOWESS analysis is an easy to calculate and easy to use statistical method and has been largely used as a long-term water quality trend analysis tool (Kim and Park 2004; Lee and Park 2008; Kim et al., 2014; Jung

et al., 2016).

2.3.2. PCA ordination statistical analysis

The PCA ordination statistical technique is applicable to interpreting and evaluating water quality factors for the observation points of streams with complex water quality properties by combining two or more environmental variables and the characteristics of the observation sites. Recently, JM Dabrowski and LP de Klerk et al.(2013) applied the PCA ordination method for assessing the water quality effects of various land uses in the upstream area of Mozambique Olifants River in South Africa.

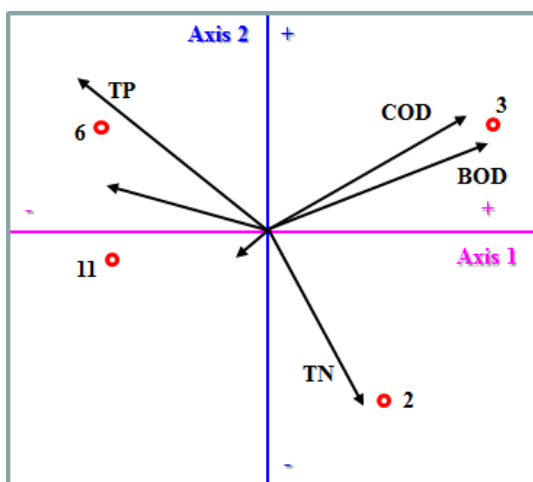


Fig. 3. PCA ordination analysis biplot.

In the PCA ordination method, two axes (axis1, axis2) describe the temporal and spatial distribution characteristics of most water quality variables in all monitoring points. The biplot shown in Fig. 3 represents that the horizontal axis is axis1, the vertical axis is axis2, and the direction of the arrow (the water variable) means the direction of the maximum change of the variable. The longer the arrow, the greater the impact on the site characteristics, and each arrow can be extended in all directions through its central origin. Therefore, the vertical projection point or corresponding month (red

circle) beyond the end or the end of the arrow is strongly correlated positively with the environmental variable represented by the arrow and is affected by the environmental variable. The sites with projections near their origin are less affected by the variables in question.

3. Results and discussion

3.1. Analysis of water quality change trends

It is necessary to accumulate long-term observations for analyzing and assessing the trend of long-term water quality changes in streams using statistical methods. Hirsch and Slack(1984) proposed reliable and accurate trend analysis using data values of at least 10 years for reliable and accurate trend analysis. In the analysis process, first, the regional Kendall test was used to identify the change trends for all eight points of the main stream of Geumho River; second, the trend of change for each of the eight points was analyzed using the Seasonal Kendall test. Also, the LOWESS analysis was implemented for each point to identify the characteristics of the variation in water quality over the period of interest.

3.1.1. Regional Kendall test

For four items of BOD, COD, TN, and TP, excluding TOC due to insufficient long-term observational data, the monthly data for 11 years were collected from 2005 to 2015, and the long-term variation in water concentrations was investigated. The level of trends was investigated using the Kendall slope estimator, and the slope is a calculation of the Kendall slope statistic, which is the level of the change (Kim, 2014). The Regional Kendall test result according to water quality terms is presented in Table 2 and is specified by upward, downward, and no trends.

The Regional Kendall test result for BOD showed that the BOD concentration for the entire Geumho River represented a constant trend of "maintain"

Table 2. Regional Kendall tests results for the Geumho River watershed

Item	N	Regional Kendall test					
		Statistic S	p-value	Kendall's tau	Slope (mg/L/yr)	Trend	
BOD	8	-41.0	0.2596	-0.093	0.00000	no trend	-
COD	8	82.0	0.0248	0.186	0.05000	upward	▲
TN	8	114.0	0.0190	0.259	0.06440	upward	▲
TP	8	-179.0	0.0000	-0.407	-0.00575	downward	▼

Note : p-value < 0.05 statistically significant trends

without any variations in the slope (Kendall slope statistic) with 0.00000 mg/L/yr by accepting the null hypothesis (H₀) in which there exists no trend with S statistic of -41 and p-value of 0.2596. In the case of the COD concentration, it showed a very significant trend of "increase" across the watershed by accepting the alternative hypothesis (H₁) that rejects the null hypothesis (H₀) and there exists a trend with S statistic of 82.0 and p-value of 0.0248 based on the Regional Kendall test result. Here, the trend of increase was clearly presented with a slope of 0.05000 mg/L/yr. The TN concentration showed a significant trend of "increase" with S statistics of 114 and p-value of 0.0190 as a result of the Regional Kendall test analysis in which the slope showed a trend of increase as 0.06440 mg/L/yr. The TP concentration presented a significant trend of "decrease", i.e., "improvement" with S statics of -179 and p-value of 0.0000 as a significant level (α) of less than 0.05 based on the Regional Kendall test analysis. In addition, the Kendall slope statistic showed a clear "decrease" as -0.00575 mg/L/yr. These results are considered to be the effect of water quality improvement according to the implementation of the total water pollution load management system.

3.1.2. Seasonal Kendall test

The results of a long-term change trend analysis on the water quality data of eight main sites the Geumho River watershed are presented in Fig. 4 and Table 3 by item. In the case of the BOD concentration, the

"decrease" trend was significant at the GR5 point as the p-value significant level (α) 0.05 among the eight main sites of the Gemho River watershed. On the other hand, at the GR4 point only, the S statistic was 36 and the p-value showed a significant level (α) 0.05 with a significant trend of "increase". The GR4 point was the only increase in the Geumho B-section among the main Geumho River reaches, which is consistent with the preceding study (Park et al., 2013; Jung et al., 2016). Other points showed no trends. In the case of the COD concentration, The points of GR1, GR2, GR3, and GR4 located upstream of the Geumho River watershed showed a significant trend of "increase". However, the only of the eight main sites indicated a significant trend of "decrease" in the GR5 point, while the GR6, GR7, and GR8 points located at the downstream showed no increase or decrease trend. In particular, in the COD concentration, it showed a significant trend of "increase" centered on the upstream area. The TN concentration represented a trend of "increase" in the points of GR3, GR4, GR5, and GR7, and there was no point with a trend of "decrease". Except for them, there were no trends of increase or decrease in other branches. In the case of the TP concentration, the points of GR1, GR2, GR3, GR5, GR6, GR7, and GR8 showed a very significant trend of "decrease" with p-value of 0.0092~0.0003. The GR4 point did not show any trends of increase or decrease, and no point was found to show a trend of "increase". For the TP concentration, the trends of "decrease" were

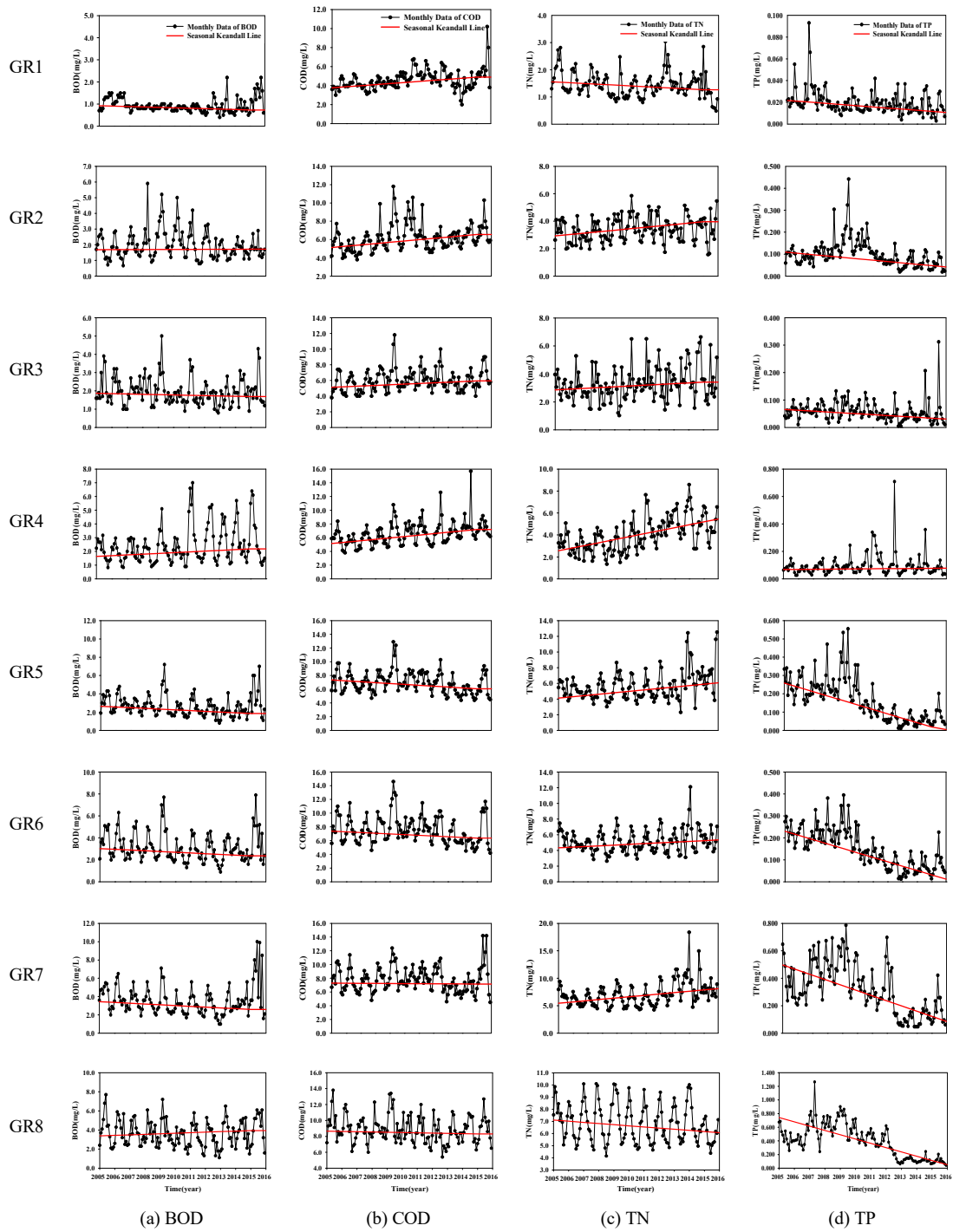


Fig. 4. Trend graphs of the water quality for each site in Geumho River.

Table 3. Seasonal Kendall tests results BOD, COD, TN, and TP

Monitoring site	Seasonal Kendall trend											
	BOD			COD			TN			TP		
	Slope (mg/L/yr)	p-value	Trend	Slope (mg/L/yr)	p-value	Trend	Slope (mg/L/yr)	p-value	Trend	Slope (mg/L/yr)	p-value	Trend
GR1	-0.01937	0.0617	no trend	0.1118	0.0472	upward	-0.02922	0.1372	no trend	-0.00100	0.0092	downword
GR2	0.00313	0.8680	no trend	0.1419	0.0006	upward	0.10310	0.1372	no trend	-0.00614	0.0179	downword
GR3	-0.01833	0.5787	no trend	0.08167	0.0502	upward	0.05562	0.0240	upward	-0.00316	0.0058	downword
GR4	0.05500	0.0533	upward	0.2050	0.0002	upward	0.26250	0.0050	upward	0.00087	0.5814	no trend
GR5	-0.08000	-0.0540	downword	-0.1292	0.0313	downword	0.17680	0.0179	upward	-0.02394	0.0002	downword
GR6	-0.06667	-0.1360	no trend	-0.1000	0.1360	no trend	0.09142	0.0879	no trend	-0.01981	0.0001	downword
GR7	-0.08542	-0.0768	no trend	-0.01250	0.9122	no trend	0.24310	0.0029	upward	-0.03740	0.0070	downword
GR8	0.05556	0.3210	no trend	-0.03452	0.3210	no trend	-0.09462	0.1372	no trend	-0.06284	0.0003	downword

Note : p-value < 0.05 statistically significant trends

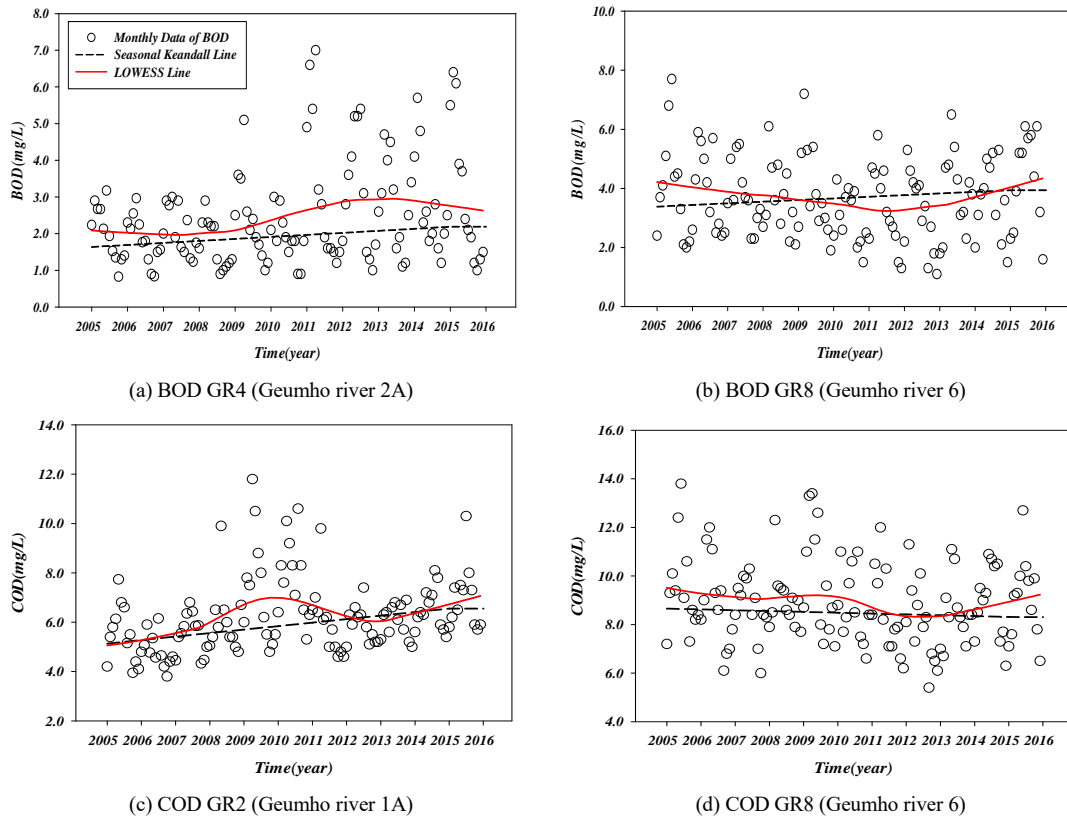


Fig. 5. Results of the trend analysis of BOD, COD concentrations in the main stream of Geumho River (example).

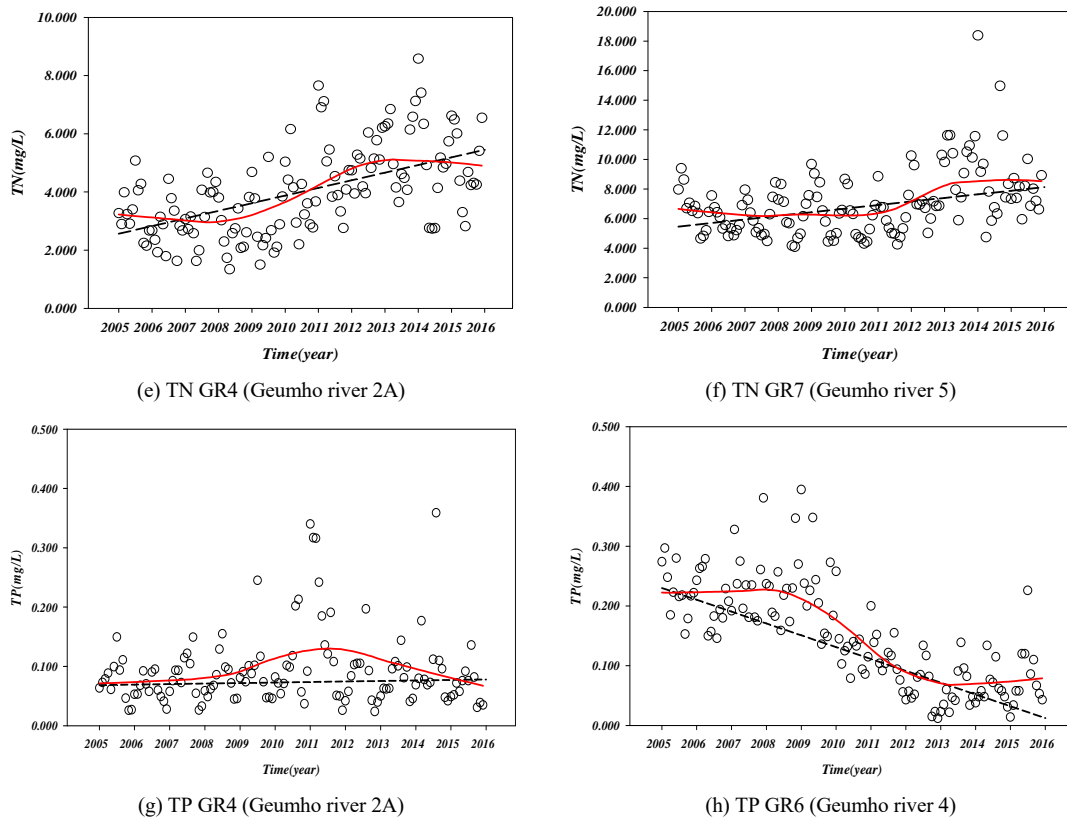


Fig. 6. Results of the trend analysis of TN, TP concentrations in the main stream of Geumho River (example).

considerable compared to other items, and the overall Geumho River watershed, excluding the GR4 point that did not show the trend of increase or decrease, showed a clear tend of "decrease".

3.1.3. LOWESS analysis

The LOWESS analysis was implemented to identify the specific water quality change characteristics for each point of interest. In the results of the analysis, it shows that changes in water quality are identified during the target period and the points in which the variation in the water quality of BOD and COD is presented in Fig. 5, and of TN and TP is presented in Fig. 6. Also, the characteristics of specific changes were analyzed for the points presented as examples.

The BOD concentration at the GR4 point represented a trend of "increase" in the Seasonal Kendall test results, but the LOWESS analysis showed a tend of "decrease" after "increase" in 2010. The GR8 (Geumho River 6) point showed a trend of "maintain" without increasing or decreasing trends in the Seasonal Kendall test results, but the LOWESS analysis showed a trend of decrease to 2011 and a trend of increase again from 2012. As a result of the LOWESS analysis at the remaining sites, the BOD concentration was continuously reduced, but recently showed a trend of increase from late 2013. The GR8 (Gumho River 6) point is a Geumho C unit watershed and is a point of the national water quality network and that shows the most polluted load due to its location, which is the lower reach of Geumho River.

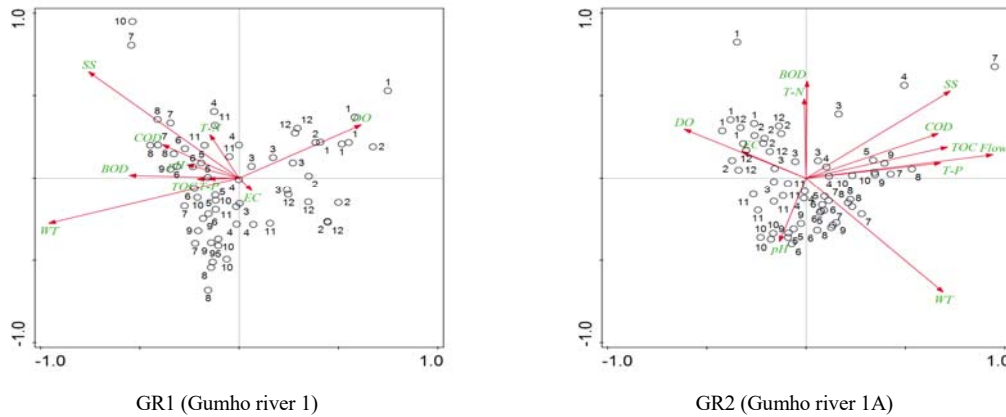


Fig. 7. PCA ordination of water quality variables (arrow) and months (black point) at each point of Geumho River (Continued).

The GR8 point has been maintained below the target quality within the period of implementation of the total pollution control system based on the assessment of the quality according to the current regulations for the past five years and evaluation of achievement compared to the target quality value of 4.0 mg/L determined in the second stage. However, the LOWESS analysis results indicate a trend of increase since 2012. The COD concentration of the GR2 (Geumho river 1A) point, which is the upstream area of Geumho River, showed a continuous "increase" in the LOWESS analysis results, as shown in Seasonal Kendall test. The GR8 point represented a state of "maintain" in the results of the Seasonal Kendall test in Geumho River, but the LOWESS analysis showed a trend of "increase" again in 2013. According to the LOWESS analysis of the COD concentration in Geumho River, the upstream area that showed a trend of "increase" represented an increase in the concentration continuously, and the downstream areas where the slope is expressed as (-) have also been analyzed as a trend of increase again since 2013.

In the case of the TN concentration, although the results of the Seasonal Kendall test at the GR4 (Geumho River 2A) point showed a trend of

"increase", the LOWESS analysis represented a steady increase from 2008 to 2012 and showed a trend of maintain again. Although the GR7 point also showed a trend of "increase", the LOWESS analysis showed a trend of maintain since 2013. As the TP concentration showed a significant trend of "decrease" in the Regional Kendall test, the LOWESS analysis also showed a trend of "decrease" steadily from the time the TP was selected and implemented as the total control item at the entire points of Geumho River as well as the GR6 point shown in Fig. 6. The TP concentration at the GR4 point, which is the only point of increase or decrease, showed steadily a trend of "decrease" as of 2012 based on the LOWESS analysis.

3.1.4. PCA ordination statistical analysis

Geumho River is greatly influenced by the distribution of pollutants and watershed characteristics, and rainfall increases the possibility of serious pollution. Also, the water quality characteristics represent a very diverse pattern for each stream and point due to the combination of the water quality in non-rainfall and the seasonal characteristics. For implementing the PCA ordination statistical analysis, monthly water quality data (pH, DO, EC, WT, BOD,

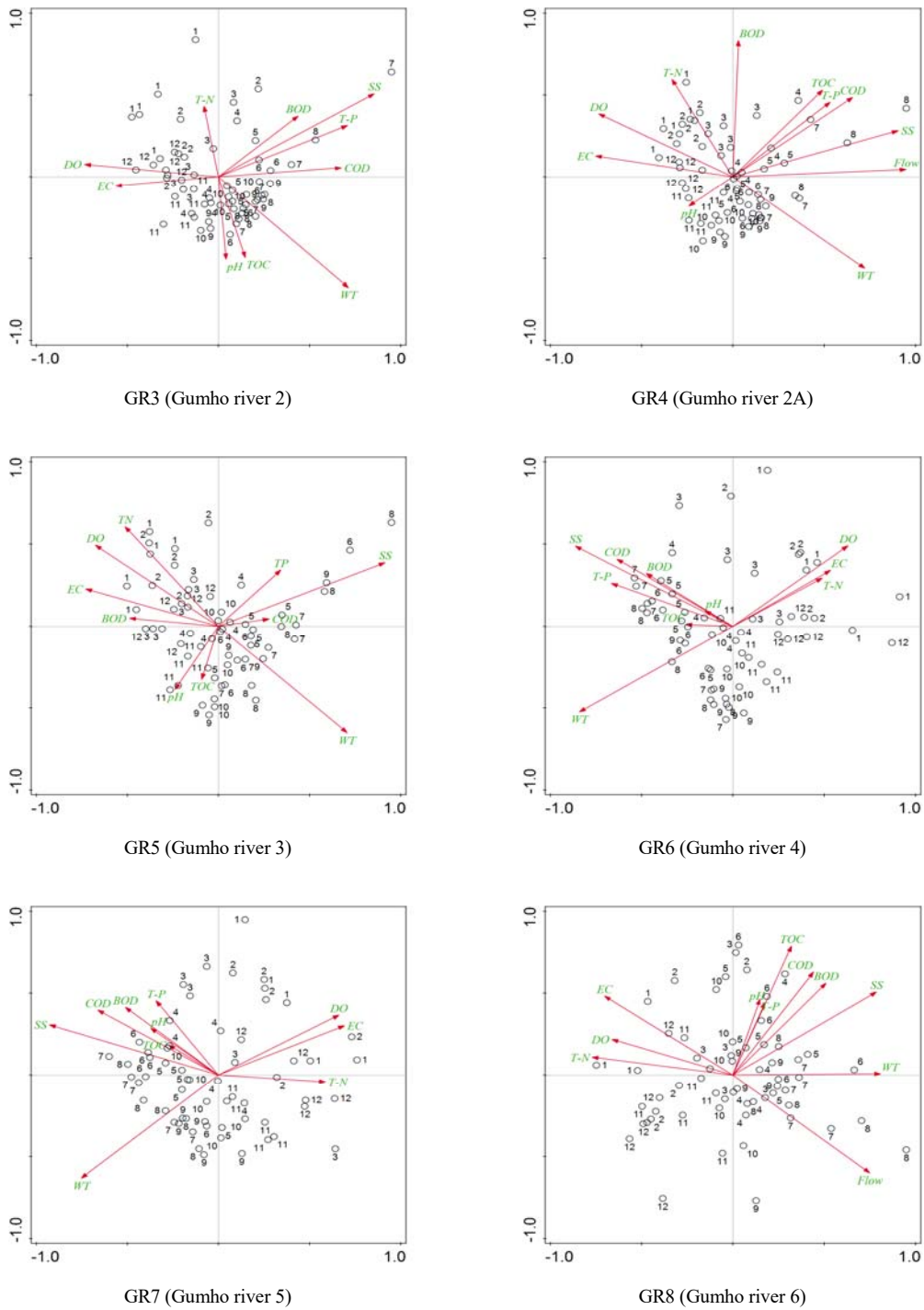


Fig. 8. PCA ordination of water quality variables (arrow) and months (black point) at each point of the Geumho River.

Table 4. Descriptions of the water quality parameters by the PCA ordination analysis of the Geumho River

	GR1		GR2		GR3		GR4		GR5		GR6		GR7		GR8	
	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2	Axis1	Axis2
WT	-0.960	-0.277	0.690	-0.695	0.714	-0.678	0.723	-0.563	-0.239	-0.388	-0.842	-0.526	-0.754	-0.634	0.810	0.006
DO	0.615	0.324	-0.615	0.297	-0.737	0.076	-0.737	0.386	-0.677	0.495	0.630	0.491	0.662	0.367	-0.664	0.218
pH	-0.264	0.081	-0.135	-0.387	0.042	-0.507	-0.242	-0.180	-0.490	0.049	-0.153	0.096	-0.373	0.286	0.175	0.443
EC	0.064	-0.078	-0.325	0.161	-0.566	-0.057	-0.754	0.128	0.278	0.045	0.535	0.341	0.692	0.302	-0.705	0.483
BOD	-0.555	0.016	0.004	0.588	0.438	0.373	0.030	0.835	0.915	0.388	-0.476	0.322	-0.512	0.415	0.510	0.563
COD	-0.387	0.203	0.666	0.271	0.675	0.055	0.657	0.486	-0.514	0.607	-0.636	0.409	-0.663	0.397	0.442	0.630
TOC	-0.211	-0.008	0.713	0.189	0.147	-0.496	0.492	0.532	0.342	0.343	-0.260	0.011	-0.273	0.184	0.321	0.789
SS	-0.760	0.646	0.727	0.529	0.856	0.509	0.906	0.282	-0.092	-0.326	-0.865	0.489	-0.929	0.307	0.786	0.509
T-N	-0.148	0.265	-0.010	0.483	-0.080	0.432	-0.334	0.596	0.705	-0.653	0.489	0.293	0.587	-0.043	-0.772	0.109
T-P	-0.156	-0.007	0.680	0.092	0.709	0.315	0.533	0.458	-0.730	0.228	-0.666	0.262	-0.343	0.455	0.149	0.465
Flow	-	-	0.942	0.142	-	-	0.949	0.045	-	-	-	-	-	-	0.750	-0.602

COD, TN, TP, TOC, and SS) for five years from 2012 to 2015 have been collected and used. First, the land use situation and major changes in water quality according to external factors are introduced based on the previous analysis of the land use status and trend results of the main points (GR1 ~ GR8) of the upstream, midstream, and downstream in Geumho River.

In the PCA ordination, the two main axes account for most of the total variation across all data sets, and most of the first two axes (axis1, axis2) are in common, clearly showing the temporal and spatial distribution characteristics of the water quality variables in all survey sites (Fig. 7, Fig. 8). Table 4 shows the PCA ordination results for the water quality parameters analyzed in the major points of Geumho River. Table 4. Descriptions of the water quality parameters by the PCA ordination analysis of the Geumho River Considering the results, two PCA axes (axis1, axis2) in the GR1 point account for 82.9% of the total variation (axis 1: 66.6%, axis2: 16.3%). The most important parameters in the axis1 are WT (-0.960), DO (0.615), BOD (-0.555), and SS (-0.760), but there is no apparent correlation of environmental factors in the axis2. As this point is

located in the most upstream with the largest forest area in Geumho River, the environmental factors of the SS are clearly observed due to the impact of rainfall in July and August. Choi et al., (2009) reported that the outflow of non-point sources in forest areas, differences in water quality other than SS was insignificant in a study on the characteristics. In the GR2 point, the most close parameters in the axis1 are DO (-0.615), COD (0.666), TOC (0.713), SS (0.727), TP (0.680), and flow rate (0.942), and the major parameters in the axis2 are WT (0.695), BOD (0.588), and TN(0.483). At this point, the TP, which is a source of organic pollutants and nutrients such as COD and TOC, was identified as a major environmental factor along with the SS. In particular, these environmental factors appear to be heavily influenced by physical and hydrologic factors as they appear to be a strong causal relationship with flow rates in July and August. Therefore, it can be interpreted that the non-point source acts as the main source of pollution. In the GR3 point, the PCA axis1 and axis2 describe 79.4% of the total variation (axis1: 49.6%, axis2: 29.8%). The most important parameters in the axis1 are WT (0.714), DO (-0.737), BOD (0.438), EC (-0.566), COD (0.675), SS (0.856),

and TP(0.709), and shows a high correlation with pH (-0.507), TOC (-0.500), and TN (0.432) has verified.

The major correlation parameters in the GR 4 point are WT (0.723), DO (-0.737), EC (-0.754), COD (0.657), SS (0.906), TP (0.533), and flow rate(0.949), and the major parameters in the axis2 are BOD (0.835), TOC (0.532), and TN (0.596). Also, COD and TP are also considered as important environment parameters in this point, and this point shows the same trend as the GR2 point with a high correlation together with high flows in July and August. The parameters of BOD and TN become major environment parameters during the dry season, January-March. This is likely to be the result of point sources such as sewage treatment plants. In the GR5 point, the PCA axis1 and axis2 represent 76.3% of the total vaiation (axis1: 56.2%, axis2: 20.1%). The highly correlated parameters in the axis1 are DO (-0.677), BOD (-0.490), SS (0.915), WT (0.705), and EC(-0.730), and the major parameters in the axis2 are TN (0.607) and TP (0.343). In the GR6 point, the PCA axis1 and axis2 shows 80.9% of the total variation (axis1: 59.4%, axis2: 21.5%). The highly correlated parameters in the axis1 are WT (-0.842), DO (0.630), EC (0.535), BOD (-0.476), COD (-0.636), SS (-0.865), TN (0.489), and TP (-0.666), and there are no significant water quality parameters in the axis2. An interest point at this point is that environmental parameters such as BOD, COD, SS, TN, and TP are emerged as key parameters. Although the timing of each item's impact varies, increases in the concentration caused by point and non-point sources are occurring at the same time. In the GR7 point, the PCA axis1 and axis2 describe 75.1% of the total vaiation (axis1: 57.3%, axis2: 17.8%). The highly correlated parameters in the axis1 are WT (-0.754), DO (0.662), EC (0.692), BOD (-0.512), COD (-0.663), SS (-0.929), and TN(0.587), and the major parameter in the axis2 is TP (0.455).

In the GR8 point, the PCA axis1 and axis2

represent 78.2% of the total variation (axis1: 54.9%, axis2: 23.3%). The highly correlated parameters in the axis1 and axis2 are WT (0.810), DO (-0.664), EC (-0.705), SS (0.786), TN (-0.772), and flow rate (0.750) and pH (0.443), BOD (0.563), COD (0.630), TOC (0.789), and TP (0.465) respectively. These results show the water quality of the Gemho River watershed in terms of temporal and spatial characteristics according to seasons and specific points depending on the land use characteristics around it. The upstream area is being affected by non-point sources (TPs) in the downstream where the flow rate increases by rainfall. This means that in the upstream areas of the surrounding watershed, where the arable land is heavily distributed compared to the downstream areas, and the increase in nutrients is caused by the run off of the land during the flood period. Changes in rainfall patterns allow a significant impact on changes in water quality in streams and the introduction of nutrients during the flood season (summer season) where rainfall accelerates eutrophication. Moreover, the surrounding land use characteristics are a different factor that causes changes in the temporal and spatial water quality in given watersheds, which is more different from the downstream area. The watersheds surrounding the mid- and downstream areas of the Geumho River watershed are formed by large urban and industrial zones, and pollutants originating from these regions can continue to affect the water quality of Geumho River throughout the year. The PCA ordination shows that TN, which originated from point sources, is increasing due to the relatively lack of rainfall during the dry season (January-February).

Except for the GR6 point, the non-point source (TP) acts as a direct factor in water quality simultaneously during the flood period (June-August), in addition to the point source (TN). It is considered that this phenomenon is to be a combination of the residential and industrial sources in the surrounding

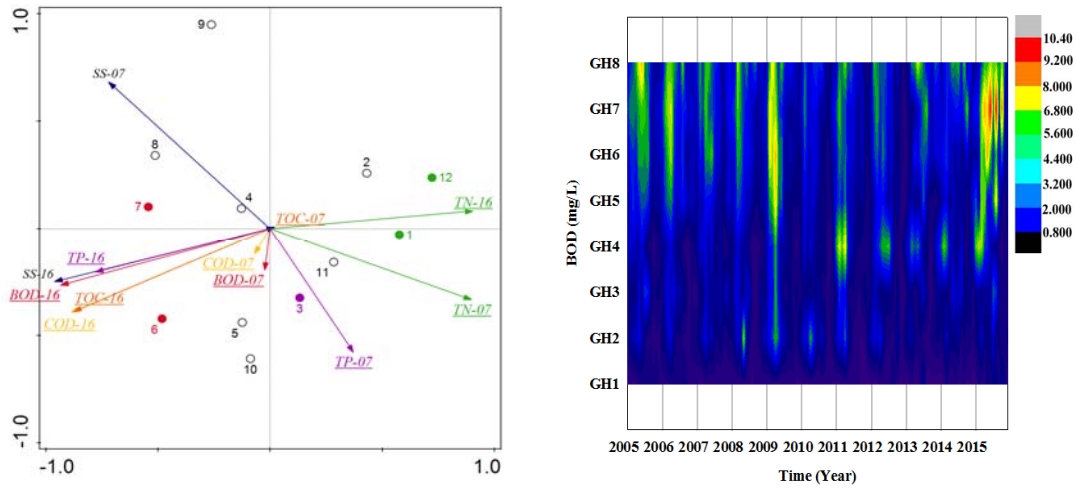


Fig. 9. PCA ordination analysis for the comparison of 2007 and 2016 data, XYZ triplet temporal-spatial contour map, BOD at the GR8 (Geumho River 6) point.

areas and the land-related sources from the upstream. In summarizing the results of the PCA ordination statistics, the main environmental parameters in Geumho River are the order of COD>TOC>TP>TN>BOD, whose origins are largely affected by non-point sources. Here, the point and non-point sources affect the water quality at the same time, and these environmental parameters are thought to be affecting the main stream in the point and non-point sources.

Geumho River is the most important tributary to the water quality of the Nakdong River. In particular, TN and TP, which are originated from the Geumho River watershed as a temporal and spatial manner, are major limiting factors that determine the growth and primary productivity of photosynthesis such as plant plankton in freshwater ecosystems. At the same time, they also act as a major source of pollution in the watershed. Fig. 8 represents an analysis of the variation in pollution by year of water quality parameters at the GR8 (Geumho river 6) point at the end of the Geumho River watershed.

As shown in the biplot results, TN is still affecting the period of the dry season (November-February) in 2016 compared to 2007 and becomes a strong source

at this point. On the other hand, TP represents that patterns of the origin of pollution were changed due to non-point sources in 2016 if it was under the influence of point source as of 2007. It can be interpreted as meaning that the pollution load at the point has decreased as a result of reduction of TP loads. In addition, it is also important to note that the arrows in the same direction, along with the SS and TP, are extended in the same direction and the arrows are passing between June and July. In case of TOC and COD, if the effects were small in 2007, it can be interpreted that the main source is acting as a major pollutant source at this point in 2016 and its origin is coming from a non-point source. In the case of BOD, its impact was more highlighted in 2016 compared to 2007. This is also consistent with the previous trend analysis and results from XYZ triplet content map graphs. In view of these results, the effect on the point source has been reduced due to a reduction in the BOD load on the point source. However, it can be seen that changes in the pattern of the sources show that BOD loads are occurring at the point source and the concentration is also higher than in 2007. Previously, in the results of the PCA ordination of the

main parameters, it shows that BOD and COD can be interpreted as the effects of non-point sources caused by rainfall rather than point sources. Thus, it is considered that the urban non-point sources should be managed together with point sources.

4. Conclusion

In this study, the following conclusions were obtained by analyzing trends in water quality and changes in the characteristics of temporal and spatial water quality based on the data of the eight main streams of Geumho River.

1. In the results of the investigation of changes in long-term water quality characteristics through a temporal and spatial trend analysis based on the observations of BOD, COD, TN, and TP items of Geumho River over the past 10 years, the BOD concentration has been gradually improved through applying the total water quality pollution, Stage 1 and Stage 2, and recently the increasing trend of concentration again has been clearly observed in the downstream areas of Geumho River. It is analyzed that the COD concentration is damaged throughout the water system regardless of the water quality improvement project. Also, the TN concentration has been significantly increasing in the midstream areas of Geumho River since 2013. In the case of the TP concentration, it was clearly observed that the concentration was decreasing since 2012 after applying the total water quality pollution, Stage 2. It is believed to be due to the full-scale operation of the sewage and waste treatment facilities completed during this period.

2. The PCA ordination results show that TN, which originated from point sources, is increasing in the dry season (December-February) in Geumho River from upstream to downstream where there is less rainfall, TP in the upstream is affected by non-point sources in the summer season with

increased flows caused by rainfall in the downstream, and as down the downstream, the origin of the sources such as BOD, COD, and TOC is clearly changed because of appearing non-point sources. In addition, accurate diagnosis of temporal and spatial situations between water quality variables was possible, and it is expected to be highly utilized as a method of assessing water environmental pollution among variables.

3. It is considered that the statistical approach in connection with the water measuring network with different viewpoints is applicable in assessing the effects of water quality improvement on implementing the water quality policy. Thus, the results in this study will provide important information for efficient water quality managements in Geumho River in the future.

Acknowledgements

This work was supported by a grant from the National Institute of Environment Research (NIER), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIER-2018-03-03-002).

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