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Effects of Wastewater Treatment Plants (WWTPs) on Downstream Water Quality and Their Comparisons with Upstream Water Quality in Major Korean Watersheds

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The purpose of the study was to evaluate spatial and temporal effects of wastewater treatment plants (WWTPs) on the water quality of downstreams (Tan Stream, TS; Daemyeong Stream, DS; Gwangju Stream, GS, and Kap Stream, KS) located in four major watersheds along with impact analysis of nutrient enrichments on the WWTPs during 2004∼2008. In the four streams, seasonal means of BOD, COD, TN, and TP were significantly ($p < 0.01$) greater in the downstreams (D_s) than the upstreams (U_s). The removal effect of nutrients (nitrogen, and phosphorus) from the WWTPs was much less than the BOD, indicating a greater nutrient impact on the downstreams. Seasonal dilution of organic matter, based on BOD, during the summer monsoon of July∼September was most pronounced in the downstreams of all four watersheds. However, mean TN in the downstreams during the monsoon varied little in all four streams. Regression analysis of TN in the downstreams against TN from the WWTPs showed that in the TS, and DS regression slopes in the upstreams were similar to the slopes of downstream but there was a significant difference in the GS ($p < 0.001$) and KS ($p < 0.01$). Tan-Stream WWTP showed low removal efficiency of BOD and COD concentrations, compared to the nutrients, whereas, two WWTPs of Gwangju and Kap Stream had low removal effects in TN and TP. Regression analysis of TN and BOD in the downstreams showed that they was closely related ($p < 0.01$) with stream water volume only in the GS. Our data analysis suggests that greater treatment efficiencies of phosphorus and nitrogen from the WWTPs may improve the downstream water quality.

Key words : wastewater treatment plant, downstream, water quality, nitrogen, phosphorus

INTRODUCTION

Rapid urbanization, dense population, and industrialization caused water contamination and eutrophication in aquatic ecosystems of urban streams and rivers, resulting in exceeding of self-purification capacity of streams and rivers (Eom *et al.*, 2004; Kim *et al.*, 2005). One of the most important factors in the pollution is closely associated with effluent water from wastewater treatment plants (WWTPs) near the stream and urban stream pollution is directly influenced by the point source of WWTPs (An *et al.*, 2007; Kim *et al.*, 2008). Such evidence is shown in previous stream studies in Han-River (Lee and Byun, 2001), Keum-River (Bae *et al.*, 2007), Nakdong-River (Lee *et al.*, 2008c), and Yongsan-River (Choe and Lee, 2005) watersheds. In these streams and rivers, organic matters and nutrients like phosphorus and nitrogen inflowing to the lotic environments from the WWTPs caused nutrient enrichments,

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low dissolved oxygen, high ionic concentrations, and hazard chemicals (Kim *et al*., 2005; Bae and An, 2006; Bae *et al*., 2007; Lee *et al*., 2008d), resulting in frequent algal blooms, decreases of species diversity (fish, macroinvertebrate) and habitat degradations (Kim *et al*., 2008; Kim *et al*., 2009). In general, the WWTPs in the urban region collect sewage through the pipe from the households, purify it, and then discharge the effluents to the downstream. For this reason, the WWTPs effectively cut down pollutant loadings, but continuous large amounts of effluents evidently resulted in sediment pollutions and fish kills attributed to increased inputs of nutrients and organic pollutants (Choe and Lee, 2005).

The types of sewage treatments in wastewater treatment plants (WWTPs) influenced degree of nutrient pollution near the downstreams. The WWTPs have different sewage treatments systems depending on the regions (watersheds) and the facility supported by the government. The WWTPs influencing Tan-Stream has sewage-treat system by Standard Activated Sludge Process (SASP), which has low treatment efficiency at removing phosphorus and nitrogen. Seobu WWTPs, which is located in Nakdong-River watershed (Daemyoung Stream), Daegu city, has a system of anaerobic/anoxic and oxidation (A^2/O), which manages phosphorus and nitrogen well at the same time. In the mean time, Gwangju WWTPs influencing Gwangju Stream and Daejeon WWTP influencing Kap-Stream handle sewage by Nitrogen & Phosphorus Removal Process (NPR). Recent studies (MEK, 2007b) pointed out that 46 sites of total WWTPs in Korea exceeded their capacity of the sewage treatments and that the effluents from the WWTPs of Gwangju (BOD: 16.5 mg L^{-1}) and Daejeon (BOD: 10.3 mg L^{-1}) exceeded annual water quality values.

Korea has set maximum permissible values for effluents of WWTPs since 2008 that BOD is below than 20 mg L^{-1} in the normal site. Compare with normal site, in the specific site BOD is below than 10 mg L^{-1}. In comparison, Germany applies permissible values for effluents of WWTPs differently depending WWTPs' scale. Small scale WWTPs have higher values (BOD: 40 mg L^{-1}) than large WWTPs (BOD: 15 mg L^{-1}). Also, United States sets permissible values for effluents of WWTPs that BOD_5 is below than 30 mg L^{-1}, but each state has different values with site, processing technique (MEK, 2002). Such differences in the regulatory criteria resulted in the variation of downstream water quality. In Korea, Lee (2008) showed that influx volume from the WWTPs is potentially associated with the downstream water quality. Also, Huh *et al*. (2005) showed that Geann Stream WWTPs, one of the Han River watersheds, deteriorated the dowstream of Han River, and Wonju WWTPs increased downstream phosphorus of Seom River. Also, Choe and Lee (2005) suggested that when the discharge of the stream water (Seobang Stream, Gwangju) was reduced 5%, BOD loading was decreased by 2.8%.

In spite of these researches, little is known about how the effluents from the WWTPs influence the downstream water quality. The WWTPs which is a point-source of nutrients, is influx site of pollutant into the stream river, and it is easier to control than non-point pollution source (Kwak *et al*., 2008; Lee *et al*., 2008b; Park *et al*., 2008). In this study, we evaluated the spatial and temporal variations of TN, TP, BOD, and COD in the effluents of four WWTPs (Tan-Stream WWTP, Seobu WWTP, Gwangju WWTP and Daejeon WWTP) influencing the downstream water quality, and compared the effects of upstreams versus downstreams along with impact analysis of effluents from the WWTPs.

MATERIALS AND METHODS

1. Sampling sites and periods

Our preliminary results of the study sites showed that there were 38 sites of wastewater treatment plants (WWTPs) in the major cities in Korea. The WWTPs which do not discharge their effluents into the stream were excluded for the analysis, and then sites were divided distinctly into downstream versus upstream locations from the WWTPs. Based on these results, sampling sites (name of WWTPs, stream name) were selected are as follows: Tan-Stream WWTP of Tan-Stream (TS, Han-River watershed), Seobu WWTP of Daemyeong-Stream (DS, Nakdong-River watershed), Gwangju WWTP of Gwangju-Stream (GS, Youngsan-River watershed), and Daejeon WWTP of Kap-Stream (KS, Geum-River watershed) in four major Korean watersheds (Fig. 1). Also, upstream and downstream was defined on the basis of each WWTPs site. Tan-Stream WWTP's up and downstream was located on Tan-Stream 3, 4. Seobu WWTP's up and downstream was located on Dal-

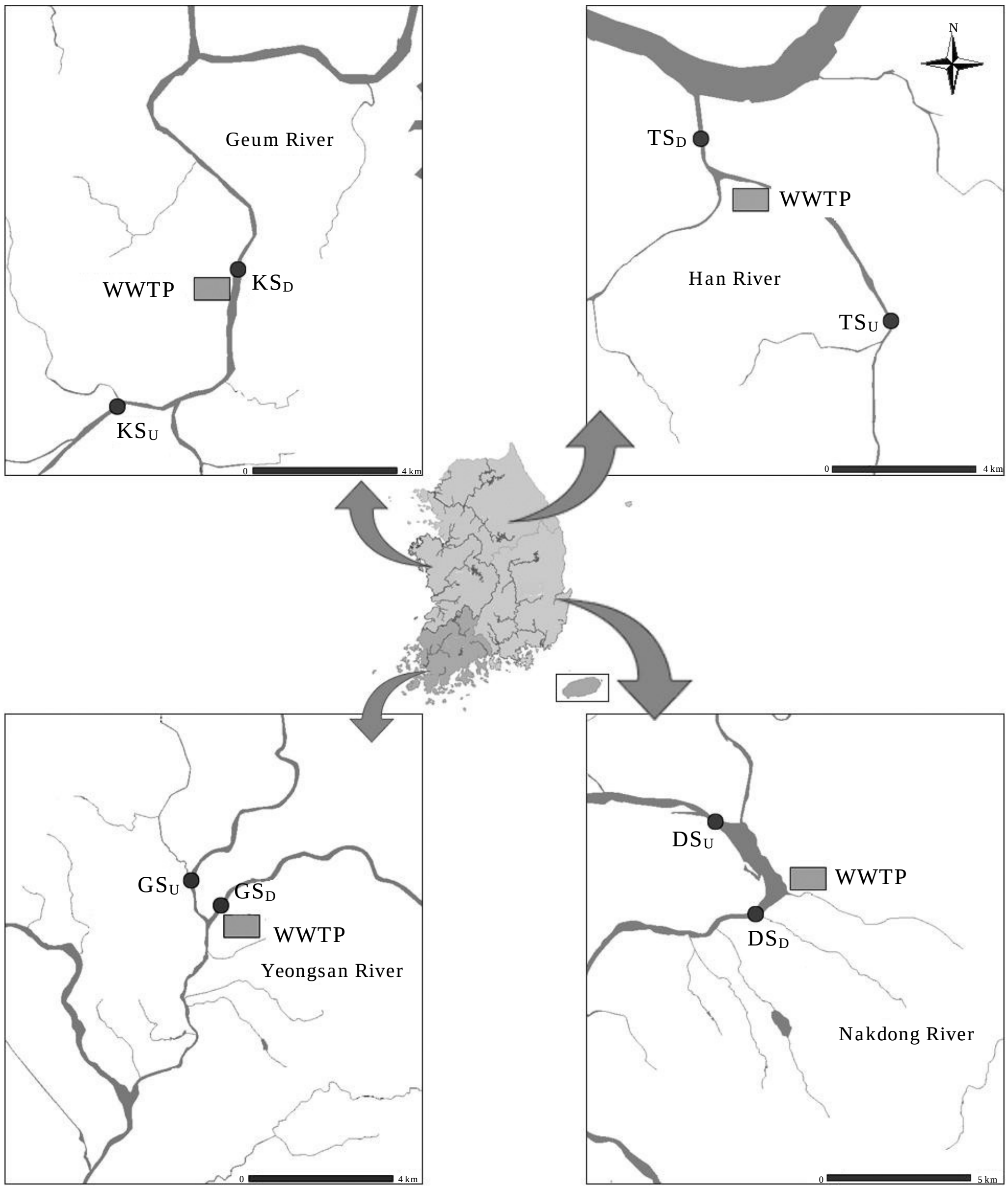

Fig. 1. Sampling sites in four streams, influenced by wastewater treatment plants (WWTPs) within four Korean major watersheds. The sampling sites are as follows: Daejeon WWTP of Kap-Stream (K_U, K_D, Geum-River watershed), Tan-Stream WWTP of Tan-Stream (T_U, T_D, Han-River watershed), Gwangju WWTP of Gwangju-Stream (G_U, G_D, Youngsan-River watershed), and Seobu WWTP of Daemyeong-Stream (D_U, D_D, Nakdong-River watershed).

seong, Hwawonnaru. Gwangju WWTP was located on Gwangju 1, Gwangju industrial complex 1. Daejeon WWTP's up and downstream was located on Kap-Stream 3, 4. Each of them is located in the upstream and downstream of Tan-Stream (TS_U, TS_D), upstream and downstream of Daemyeong-Stream (DS_U, DS_D), upstream and downstream of Gwangju-Stream (GS_U, GS_D), upstream and downstream of Kap-Stream (KS_U, KS_D). The sites are as follows:

TS: Tan-Stream, Irwon-dong, Gangnam-gu, Seoul
TS_U: Tan-Stream 3, TS_D: Tan-Stream 4

DS: Daemyeong-Stream, Daecheon-dong, Dalseo-gu, Daegu
DS_U: Dalseong, DS_D: Hwawonnaru

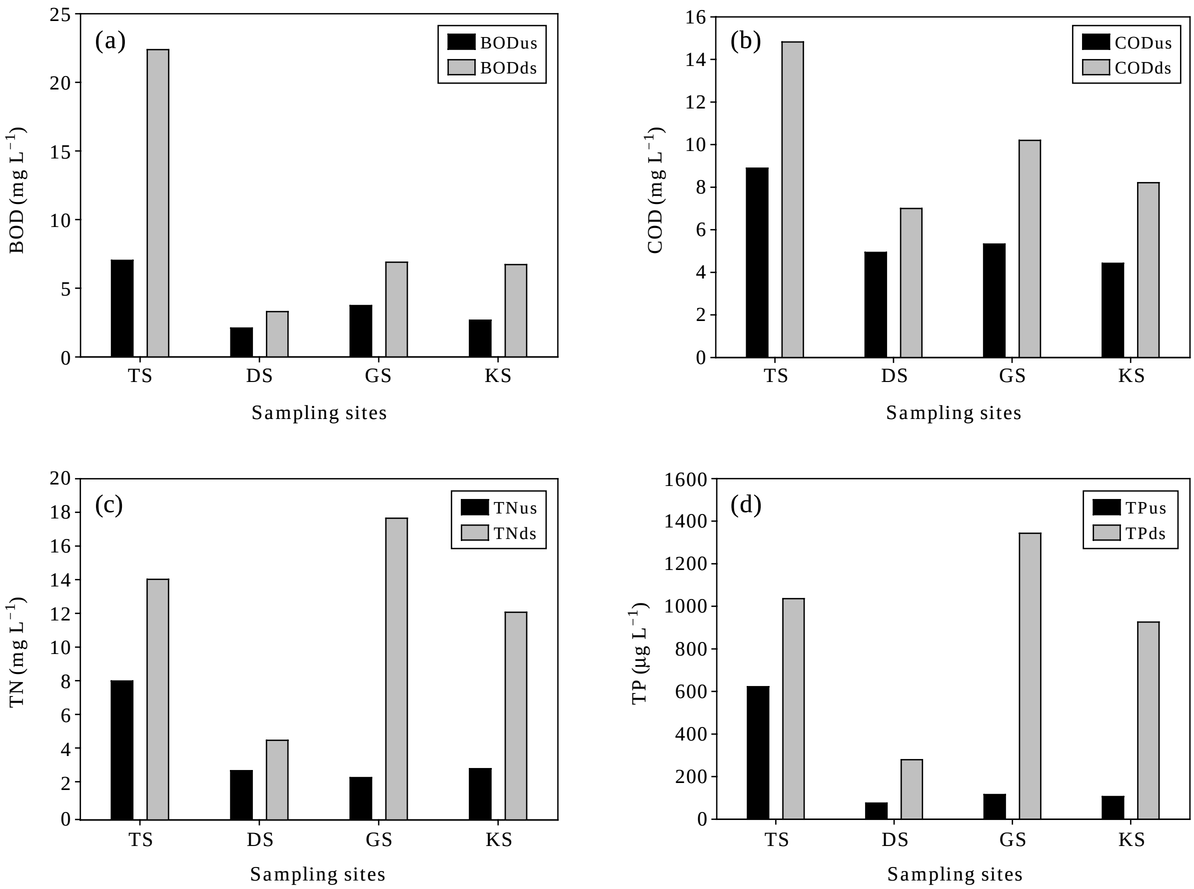

Fig. 2. Comparisons of biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) in the four streams of Tan Stream (TS), Daemyeong Stream (DS), Gwangju Stream (GS), and Kap Stream (KS).

GS: Gwangju Stream, Chipyeong-dong, Seo-gu, Gwangju

GS_U: Gwangju 1, GS_D: Gwangju industrial complex 1

KS: Kap-Stream, Wonchon-dong, Yuseong-gu, Daejeon

KS_U: Kap-Stream 3, KS_D: Kap-Stream 4

Water quality at the stream was compared with water quality of the effluents from the WWTPs along with stream water volume and precipitation data. To investigate seasonal trends, 3 periods of premonsoon (pre, April～June), monsoon (mon, July～September), and postmonsoon (pos, October～December) were compared in 2007.

2. Methods

Water quality data, obtained from the Ministry of Environment, Korea (MEK, 2007a) were analyzed and the dataset during 2004～2008's data (http://water.nier.go.kr/weis) were used for the analysis. The data of precipitation (rainfall) and stream water volume was obtained from regional weather repots station (http://daejeon.kma.go.kr) and national environmental research institute (http://smat.nier.go.kr) to compare them with stream water quality data and data from the effluents of wastewater treatment plants (WWTPs). Using the dataset, we conducted correlation analysis and regression analysis using SPSS software package. In this study, we determined the significance in 95% confidence interval (p=0.05).

RESULTS AND DISCUSSION

1. Organic matter inputs and nurient enrichments in the downstreams

Water quality, based on organic matter and

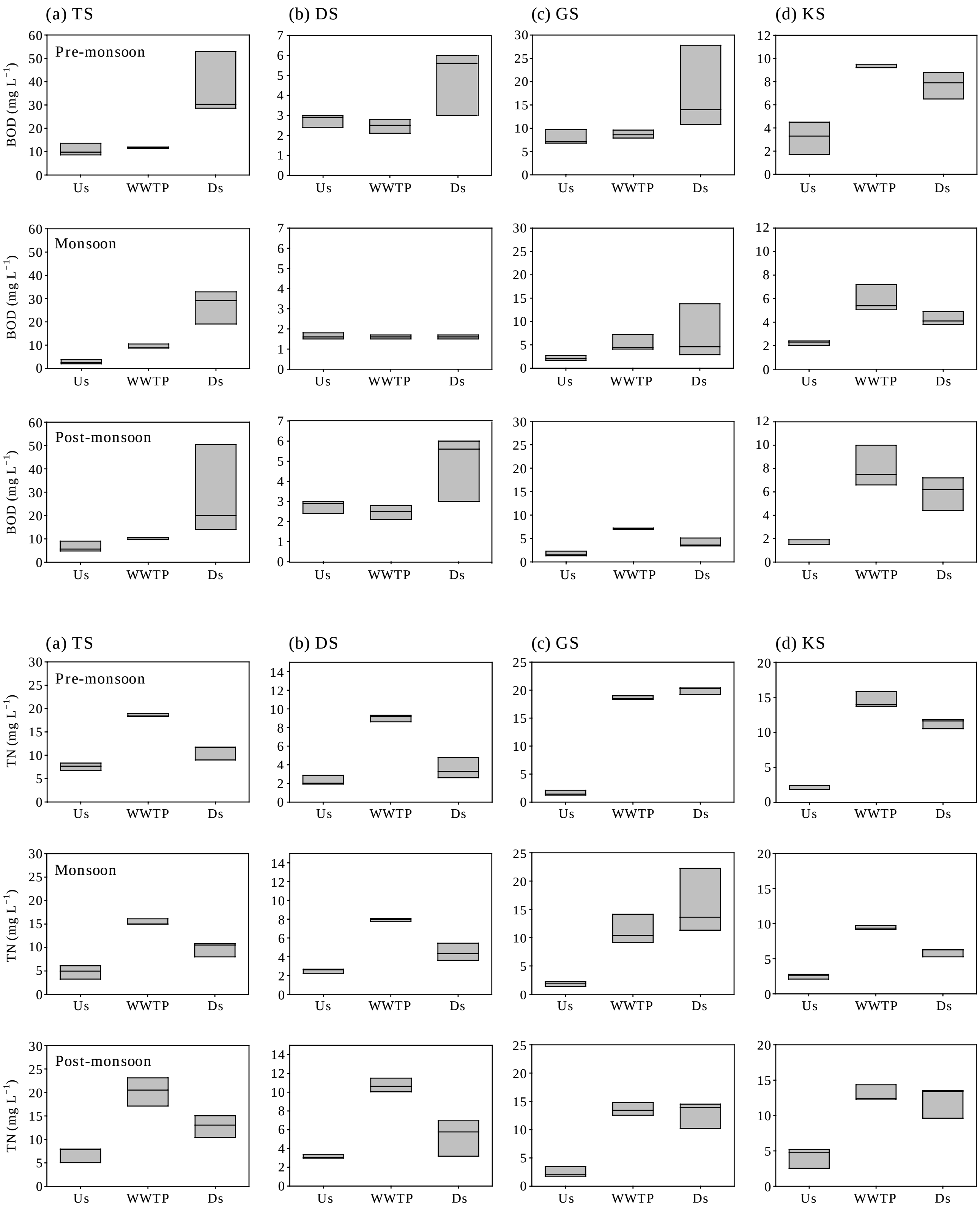

Fig. 3. Seasonal (Pre=premonsoon, Mon=monsoon, and Pos=postmonsoon) BOD, TN, and TP concentrations in the upstreams (Us), downstreams (Ds), and wastewater treatment plants (WWTPs) in 2007. The stream names are as follows: Tan Stream (TS), Daemyeong Stream (DS), Gwangju Stream (GS), and Kap Stream (KS).

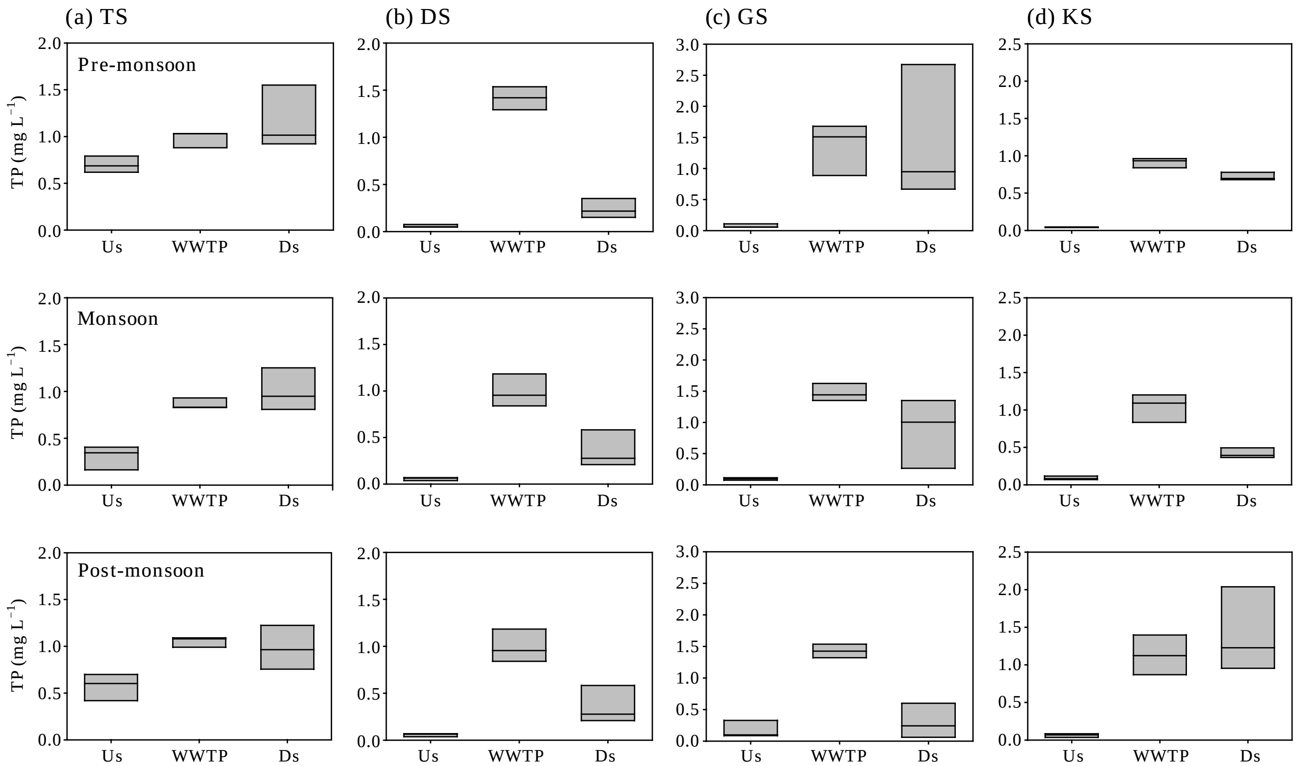

Fig. 3. Continued.

nutrients concentrations, varied largely between the upstream and downstream, influenced by wastewater treatment plants (WWTPs) depending on the location of the watershed. In the four streams of Tan Stream (TS), Daemyeong Stream (DS), Gwangju Stream (GS), and Kap Stream (KS), seasonal means of biological oxygen demand (BOD) were significantly ($p < 0.01$) greater in the downstreams (D_s) than the upstreams (U_s). BOD in the upstream of four watersheds averaged 3.88 mg L^{-1} while BOD in the downstreams averaged 9.76 mg L^{-1} (Fig. 2a) indicating that the discharging effect of effluents from the WWTPs was evident. The largest difference of BOD between the D_s and U_s occurred in the stream of TS; Mean BOD in the stream of U_s was 7.0 mg L^{-1}, but the value increased up to 22.1 mg L^{-1} (Fig. 2a), resulting in $>$3-fold difference of BOD in the downstream. Thus, the water quality, based on the BOD, in the downstream was judged as a "very bad condition" (or VI rank) based on the criteria of stream water quality, the Ministry of Environment, Korea (MEK, 2003). In contrast, BOD values in the remaining downstreams of DS, GS, and KS were lower than 2-fold, compared to the upstream BODs. (Fig. 2a). Therefore, the removal efficiency of organic matter from the WWTPs may be lower in the TS than in any other locations (DS, GS, and KS). Also, organic matter pollutions, based on chemical oxygen demand (COD), showed a similar patterns with BODs in the four streams (Fig. 2b).

As shown in Fig. 2, the removal effect of nutrients (nitrogen and phosphorus) from the WWTPs was much less than the BOD. Concentrations of total nitrogen (TN) were $<$4 mg L^{-1} in the upstreams of DS, GS, and KS, whereas TN was 8.14 mg L^{-1} in the upstream of TS (Fig. 2c). The data of nitrogen indicates that the water quality was worse in the upstream of TS than any other upstreams. However, after the effluent discharge from the WWTPs, TN was increased up to 15.2 mg L^{-1} in the GS and 9.7 mg L^{-1} in the KS (Fig. 2c), resulting in 7 times and 4 times greater in the downstreams, respectively. This result indicates that the removal efficiency of nitrogen from the WWTPs may be low, especially in GS and KS and the difference of TN between the upstreams and downstreams were most pronounced in the streams of GS and KS. Compared to the BOD in

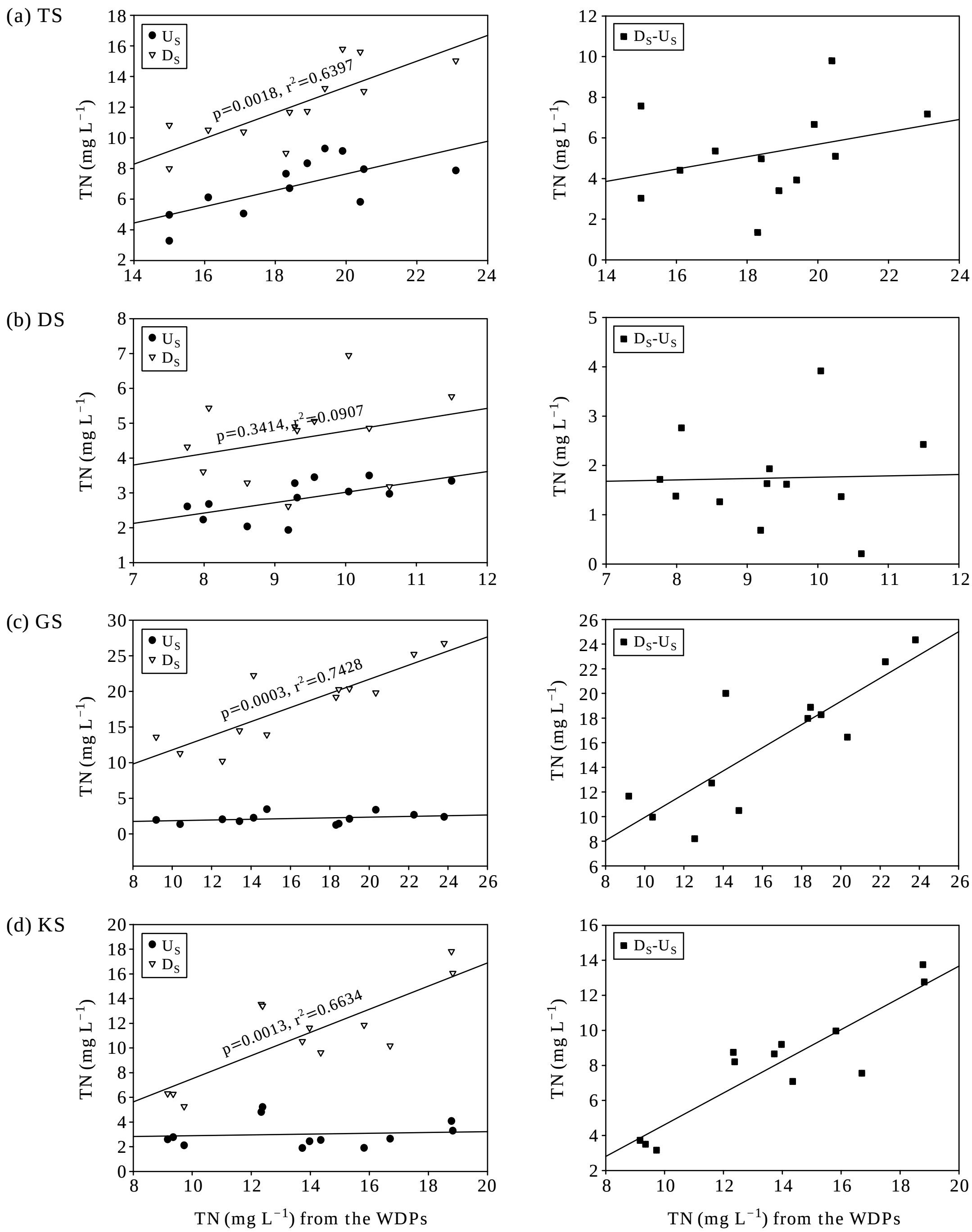

Fig. 4. Relations of stream water TN to the TN from the wastewater treatment plants (WWTPs) in the four streams of Tan Stream (TS), Daemyeong Stream (DS), Gwangju Stream (GS), and Kap Stream (KS).

the streams, the mean removal efficiency of N from the WWTPs was much lower than the removal of BOD. Our data suggest that removal efficiency of nitrogen from the WWTPs should be improved for the stream conservations.

Similarly, total phosphorus (TP) in the upstreams of four watersheds averaged 230 μg L^{-1} while TP in the downstreams averaged 893 μg L^{-1} (Fig. 2d) indicating that the discharging effect of phosphorus from the WWTPs was evident. The largest difference of TP between the Ds and Us occurred in the streams of GS and KS; In the downstreams

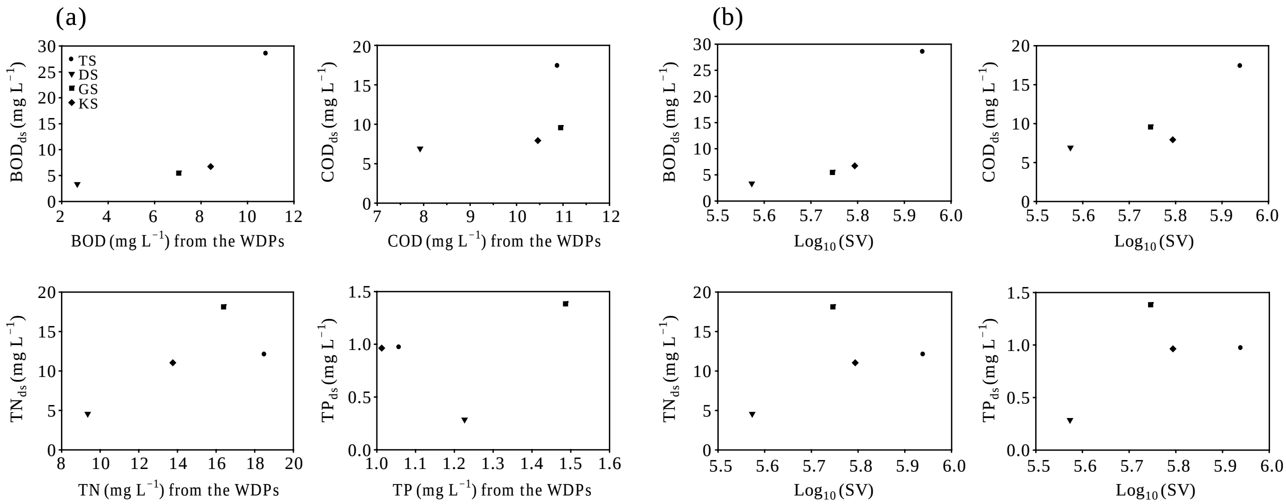

Fig. 5. (a) Relations of water quality (BOD, COD, TN, TP) in the downstreams to water quality (BOD, COD, TN, TP) of WWTPs and stream water volume (SV).

of GS and KS, mean TP was increased by 7-fold and 4-fold, respectively (Fig. 2d). Data of nitrogen and phosphorus in the downstreams suggest that nutrient enrichment is much higher than the organic input and the N and P effluents from the WWTPs in the GS and KS was most pronounced in this study.

2. Seasonal effects of BOD, COD, and nutrients by effluents of WWTPs

Seasonal dilution means stream river usually contains abundant stream river volume in summer than other seasons because of much precipitation (Lee *et al.*, 2008a). Seasonal dilution which is caused by much precipitation of organic matter, based on BOD, during the summer monsoon of July～September was most pronounced in the downstreams of all four watersheds. Mean BOD in the effluents from wastewater treatment plant (WWTPs) was 8.04 mg L^{-1}, 7.04 mg L^{-1} and 6.92 mg L^{-1}, respectively (Fig. 3) in the premonsoon (P_r), monsoon (M_o), and postmonsoon (P_o), indicating almost same concentrations regardless of the season. In the downstream of TS, maximum BOD in the M_o was 32.9 mg L^{-1}, which is 2-fold lower than the BOD values of the P_r and P_o (Fig. 3). Thus, BOD in the downstream was judged as "very bad condition (VI rank)" of criteria of MEK regardless of the season. Severe pollution by high BOD in the downstream may be a results of long-term accumulations of organic matters, even if the current BOD level of the effluents was 11.7 mg L^{-1} and was not so much different from the upstream in the premonsoon (10.7 mg L^{-1}). Such phenomenon were also found in the upstream during the monsoon, indicating that organic matter in the downstream is largely diluted by the rain water, which results in water quality improvement. But there was still nearly 2～3 fold differences of BOD between the upstream and downstream during the three seasons (Fig. 3a of BOD). In the mean time, mean BOD values in the stream of TS were nearly same regardless of the season, indicating a large dilution of BOD by the rain or upstream waters. However, as the precipitation decreased, BOD increased to previous level of 5.6 mg L^{-1} (Fig. 3).

Similar dilutions of BOD by the monsoon rain were shown in the downstreams of GS and Ks. However, mean TN in the downstreams during the monsoon varied little in the all four streams; In the downstream of TS, mean TN was 11.74 and 15.03 mg L^{-1} in the premonsoon and postmonsoon, respectively, while in the downstream of DS, TN was 5.44 and 6.94 mg L^{-1} in the premonsoon and postmonsoon. Also, there were no significant ($p > 0.05$) differences of TN between premonsoon and the monsoon in the downstreams of GS and KS. These results in the four downstreams influenced by the WWTPs suggest that nitrogen contents may not have a large seasonal dilution of downstream water by summer monsoon. The dynamics of N seemed like a different pattern, com-

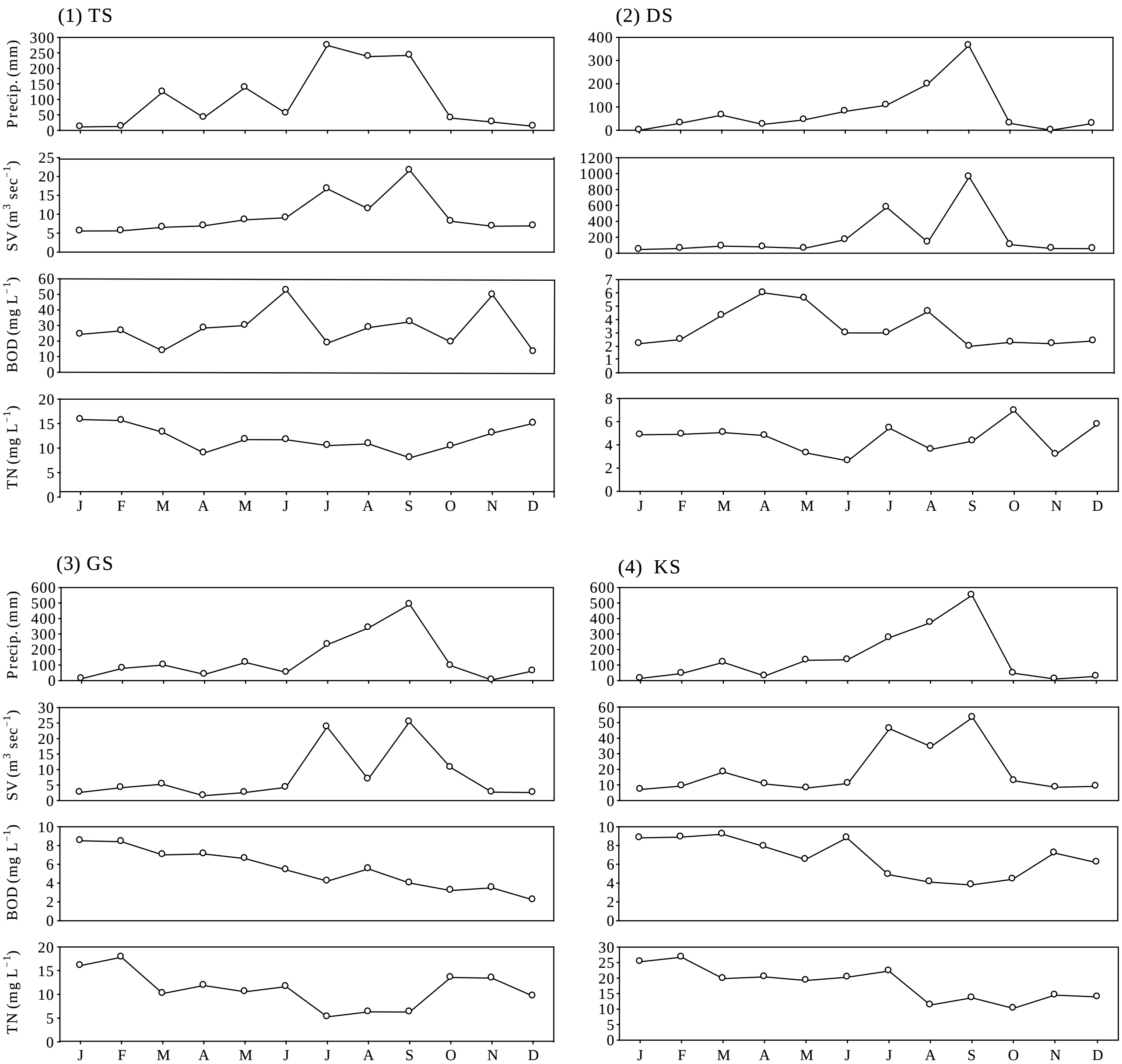

Fig. 6. Monthly variations of precipitation (Precipi.), stream water volume (SV), downstream BOD and TN in the four streams of Tan Stream (TS), Daemyeong Stream (DS), Gwangju Stream (GS), and Kap Stream (KS).

pared to variables of BOD, COD and total phosphorus.

3. Relations of downstream TN to effluent's TN from WWTPs

Regression analysis of TN in the downstreams against the TN from the WWTPs showed that in the TS, DS streams, regression slopes in the upstreams were similar slopes to the downstream's; The slope in the TS was 0.5342 and 0.8399 in the upstream versus downstream, respectively and the slope in the DS were 0.2982 and 0.3255 in the upstream versus downstream, respectively. However, the slope between the upstream and downstream was significantly different in the GS ($p < 0.001$) and KS ($p < 0.01$). The data indicate that the upstream nitrogen in the GS and KS was mainly influenced by effluents from the wastewater treatment plants, but not by the nitrogen input from the upstreams, and that in other streams of TS, DS, the nitrogen in the downstreams is influenced by both of N from the WWTPs and N from the upstreams. Under this circumstance, nitrogen should be controlled by decreases of N from the upstreams as well as the decreases of nitrogen from the WWTPs.

Influences of WWTPs effluents in the downstream with all sampling sites indicate that TS is the most influenced site in BOD value (Fig. 5a). The relation between WWTPs effluents and stream river volume (SV) of all sampling site (Fig. 5b) shows that TS has the most abundant SV, but pollutant level doesn't follow it. It is considered that other factors have more effect than SV's effects.

4. Seasonal influence of precipitation and stream discharge on the water quality

According to analysis of seasonal organic matter and nitrogen dynamics in the streams, rainfall (precipitation) within the watershed influenced directly stream discharge, even if the absolute values in the stream inflow varied depending on the size of streams (Fig. 6). Especially, in July, there is rapid change in precipitation, stream river volume, BOD and TN in the four watersheds. Precipitation of TS in June is 54.5 mm and that in July is 274.1 mm. And BOD of TS in June is 52.9 mm and that in July is 19.1 mm. SV and TN is showed a similar patterns with precipitation and BODs in the four streams.

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LITERLATURE CITED

An, K.G., K.I. Kim and J.H. Kim. 2007. Biological water quality assessments in wastewater-impacted and non-impacted streams. *Korean J. Limnol.* **40** (1): 82-92.

Bae, D.Y. and K.G. An. 2006. Stream ecosystem assessments, based on a biological multimetric parameter model and water chemistry analysis. *Korean J. Limnol.* **39**(2): 198-208.

Bae, D.Y., E.C. Yang, S.H. Jung, J.H. Lee and K.G. An. 2007. Nutrients and chlorophyll dynamics along the longitudinal gradients of Daechung Reservoir. *Korean J. Limnol.* **40**(2): 285-293.

Choe, J.W. and Y.H. Lee. 2005. Influence of Gwangju stream on the waste water disposal plants influx water quality. 2005 Collaboration autumn scientific anouncement p. 111-121.

Eom, M.C., K.Y. Lee, G.H. Jo and J.W. Lim. 2004. Characteristics of pollutant runoff from the Saemangeum Basin. *KCID J.* **11**(1): 77-87.

Huh, I.R., J.Y. Choi, Y.J. Kim and U.H. Jeong. 2005. Effect of municipal sewage treatment plant on water quality in western kangwon area. *Kor. J. Env. Hlth.* **31**(4): 235-240.

Kim, H.M., J.H. Lee and K.G. An. 2008. Water quality and ecosystem health assessments in urban stream ecosystems. *Korean J. Environ. Biol.* **26**(4): 311-321.

Kim, Y.C., D.R. Lee and G.S. Hwang. 2005. Determination of representative long-term water quality parameters of the streams in estuarine lake. *Environmental Engineering Research* **27**(3): 262-272.

Kim, Y.P., E.H. Lee and K.G. An. 2009. Ecological health assessment of Dongjin river based on chemical measurement and fish assemblage analysis. *Korean J. Limnol.* **42**(2): 183-191.

Kwak, D.H., S.J. Yoo, J.H. Kim, I.H. Lim, J.Y. Kwon and P.G. Chung. 2008. Characteristics of non-point pollutant discharge from upper watershed of Seomjin Dam during rainy season. *J. of Kor. Society of Wastewater* **22**(1): 39-48

Lee, C.S. 2008. Influence of the point source inflow on the water quality variation in the downstream of Hyeongsan river. *Journal of the Environmental Sciences* **17**(10): 1075-1080.

Lee, J.K., W.H. Jeong, S.B. Yim and H.D. Jong. 2008a. Variation of quality and quantity of river basin by the distribution of wastewater treatment plants. Collaboration spring scientific anouncement 381-382.

Lee, J.Y., S.H. Jang and J.S. Park. 2008b. Analyzing runoff pollutant roading characteristics of non-point source during rainfall in urban area-focussing of Pohang region. *J. of Kor. Society of Water Science and Technology* **16**(1): 35-44.

Lee, K.J., K.S. Kee, T.H. Park and J.S. Kim. 2008c. A study on monitoring method of ecological restoration land and unused land management for improvement of water quality, Nakdong-river. *Korean J. Environ. Ecol.* **2008**(1): 110-112.

Lee, S.C., J.H. Han and K.G. An. 2008d. Functional modifications of Daechung Reservoir eutrophication by upper dam construction. *Korean J. Limnol.* **41**(3): 348-359.

Lee, T.G. and H.S. Byun. 2001. The Management for the water quality of Jung-rang River. *J. of Kor. Technological Society of Water and Waste Water*

Treatment **9**(1): 45-52.
Ministry of Environment, Korea (MEK). 2002. Development of sewage purifying process system & characteristic analaysis in the inside and outside of the country.
Ministry of Environment, Korea (MEK). 2003. Regional effluents water quality of wastewater disposal plants.
Ministry of Environment, Korea (MEK). 2007a. Sewage statistics. 11-1480000-000159-10.
Ministry of Environment, Korea (MEK). 2007b. Analysis of wastewater disposal plants operation management in 2006.
Park, J.D., J.H. Park, D.H. Rhew and D.I. Jeong. 2008. Estimation of nonpoint discharge coefficient for the management of total maximum daily load. *J. of Kor. Society on Water Quality* **24**(4): 452-457.

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