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The effect of Combined Sewer Overflows on river's water quality

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Abstract. The effect of Combined Sewer Overflow on the river system was investigated throughout three preliminary field tests and three main ones. As a result of the study, Combined Sewer Overflow did not affect water qualities on the main stream since the concentration of the main stream did not significantly changed during rainfall events although the water quality of tributaries has rapidly deteriorated due to the influence of the Combined Sewer Overflow during rainfall events. The main cause of the result is that the flow rate of the tributaries is considerably lower than that of the main stream, so that the tributaries with deteriorated water quality during rainfall events did not significantly affect the quality of the actual main stream. Therefore, the water quality of the Kumho River is more affected by the wastewater treatment facilities that discharges water continuously to the main stream than pollutants from non-point pollution sources during rainfall events. As a result, managements for discharges from wastewater treatment facilities should be strengthened in order to improve the water quality of the river.

Keywords: Combined Sewer Overflow; rainfall event; water quality; wastewater treatment facility

1. Introduction

Water quality managements are the main issue in worldwide as water pollutions are getting worse because of urbanization and industrialization. In this respect, it is very important to intercept pollutants before they reach to the water bodies in order to properly manage the water quality of water systems. Dealing with pollutants from non-point pollution sources is relatively difficult compared to that from point pollution sources because it is not possible to accurately identify pollution sources. Therefore, non-point pollution sources have been widely studied to ensure proper managements for water quality. Among those studies, stromwater managements are the majority topic since stormwater is the medium that transports pollutants from non-point sources to water bodies (Bae 2007, Noble *et al*. 2003, Whitlock *et al*. 2002, Yang and Bae 2012).

Stromwater drainage systems are crucial to the management of river's water quality. The Combined Sewer Systems are structures that transport stormwater as well as sewage. Generally, combined sewer systems have regulators, installed in the downstream or the main line sewer pipe and regulators control water flows during rainfall events to bypass the water treatment facilities when flows are exceeding the capacity of the secondary pipe as well as the treatment facilities. This effluent from the combined sewer system during rainfall events is referred to as the Combined Sewer Overflows (CSOs). CSOs are recognized as a major contributor of water pollutions since water flows, which bypassed the facilities, contain significant amount of contaminants from non-point pollution sources (Lee 2003, Seo *et al*. 2005, Rizzo et. al. 2018, Snodgrass *et al*. 2018). The water quality, therefore, cannot be maintained properly if CSOs flow into water bodies such as rivers or lakes. Bacteria, nutritional salts, solids, BODs, heavy metals, and other toxic substances are typical contaminants resulting from the influx of CSO (Lim *et al*. 2013, Tchobanoglous *et al*. 2003).

The amount of pollutants in CSOs significantly vary depending on the number of days during dry period prior to rainfall events, intensity and duration of precipitation, development status of the area, land use patterns, cleanliness of the city area and etc. (Kim and Ko 2003). The concentration of pollutants in initial runoff during the rainfall events is much higher than that of discharges from wastewater treatment facilities during the dry season because the initial runoff contains accumulated pollutants on the surface and in the sewer pipe during the dry season. In this study, the effect of CSOs on the river's water quality was investigated, focusing on the Kumho River, known as the most polluted river in Korea.

2. Materials and methods

2.1 Study area

The Kumho River is located at the Southeastern part of Korea and runs from City of Pohang to Deagu Metropolitan City, total length 118 km. It has 23 branches and its watershed covers 2,110 km2 of area (Korea Ministry of Environment Daegu Branch 2000, RIMGIS 2017). Until the 1970s, the river had abundant flow rates and its ecosystem was well preserved. The river, however, became the most polluted river in Korea - its BOD level at the end of river (Kumho 6 at Figure 1) was 191 mg/L in 1983 - as flow rates were decreased because many dams were constructed in the

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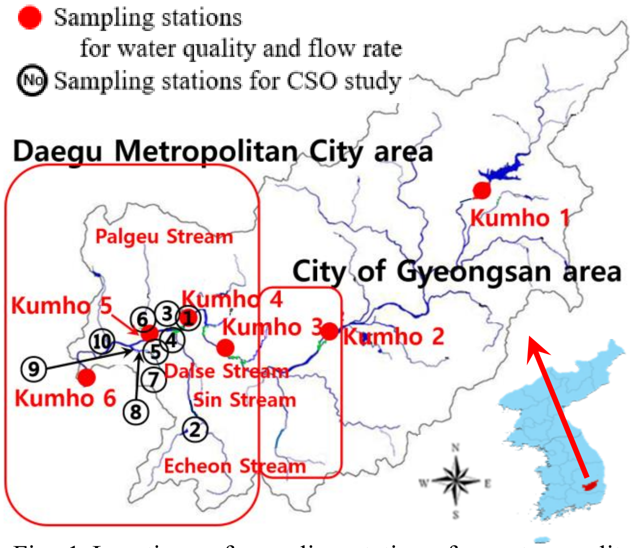

Fig. 1 Locations of sampling stations for water quality, flow rate, and CSO

tributaries. In addition, pollutant inflows rapidly increased due to accelerations of urbanization for adjacent cities, such as Daegu Metropolitan City and City of Gyeongsan (Korea Ministry of Environment Daegu Branch 2005).

The river's water quality, however, has dramatically improved - its annual average BOD reached at 3.8 mg/L at Kumho 6 in 2017 - because Korean Government and Daegu Metropolitan City put lots of investments for managing the Kumho River's water quality such as constructing 13 wastewater treatment facilities in the Kumho River watershed (Korea Ministry of Environment Daegu Branch 2005, WIS 2017). Scientific and systematic plans needed to manage the river's water quality properly as the development pressure in the Kumho River watershed continues to rise. Intensive management plans, therefore, needed for nonpoint pollution sources as well as point ones to improve the Kumho River's water quality.

2.2 Sampling and analysis

Figure 1 shows locations of sampling stations for water quality and flow rate as well as sampling stations for CSO study. Water quality and flow rate data were measured at Kumho 1 ~ Kumho 6 and CSO study samples were collected at 10 sampling points, ① ~ ⑩ in Figure 1, focused on the locations of wastewater treatment facilities since the preliminary study showed that water qualities around wastewater treatment facilities rapidly changed during rainfall events. In addition, several studies reported that the main contamination sources of rivers are effluents of wastewater treatment facilities, CSO as well as rainfall runoff from agricultural areas or wildlife habitats (Donovan *et al*. 2008, Kistemann *et al*. 2012, Ottoson *et al*. 2006, Tondera *et al*. 2016).

Figure 2 shows the schematic map of sampling stations for CSO study. Three times preliminary tests for CSO study were carried out for three rainfall events from April 2013 to May 2013 to decide proper sampling points as well as

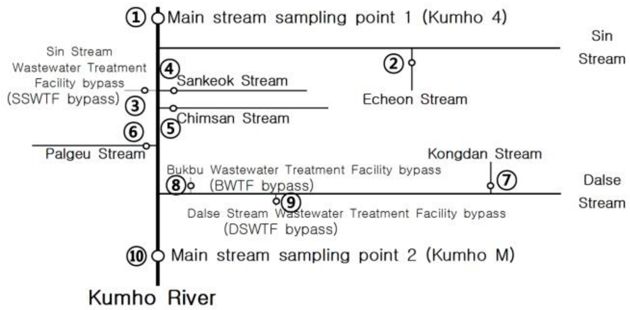

Fig. 2 Schematic view of locations for sampling stations of CSO study

sampling periods and then three main tests for CSO study were followed for another three rainfall events from July 2013 to September 2013. The preliminary field test had nine sampling stations and collected samples for every 1 hour from the beginning of rainfall events for 10 hours (data not shown). As results of the preliminary tests, 10 sampling stations including two points in the main stream were selected. Samples for all stations except two points at mainstream were taken every 10 minute for the first one hour of rainfall event and then every 30 minutes for the following two hours since the results of preliminary tests showed that concentrations were rapidly changed during the first one hour of rainfall events and not significantly varied thereafter. Samples at mainstream were collected every 30 minutes from the beginning of the first overflow at any point until one hour after overflows at all sampling stations stopped to consider the travel time of the river. Samples were transported to the lab after they were taken and BOD, COD, SS, T-N, T-P, TOC were measured by following Korean Standard Method for water quality (MOE 2013).

3. Results and discussion

3.1 Water quality and flow rate

Figure 3 shows changes of water quality and flow rate for each station (Kumho 1 ~ Kumho 6) of the Kumho River. Water qualities between Kumho 3 and Kumho 4 showed dramatic decrease as discharges from wastewater treatment facilities and pollutants from tributaries are flowing into the main stream. Wastewater treatment plants (WWTP) in Daegu Metropolitan City, especially Ansim WWTP, Sincheon WWTP and Dalsecheon WWTP, greatly affected on the downstream of Kumho River's water quality. BOD concentrations were fluctuated in a wide range at all sampling stations while changes of COD concentrations in every station showed similar patterns except Kumho 3 during October. SS concentrations for the first samples at all sampling points except Kumho 1 were extremely high compared to other samples through the year. The reason for those high SS concentrations is the first rainfall event of the year after a long term dry period as well as it was heavy (50.1 mm of total precipitation). Changes of T-N and T-P concentrations at all sites except those at Kumho 1 were fluctuated similar to those of flow rate, but changes of T-P concentrations for Kumho 2,3,5 and 6 from Aug. to Oct. showed opposite patterns to changes of flow rates. TOC concentrations at Kumho 1 showed similar levels to those at other sampling stations unlikely concentrations of other factors at Kumho 1 were lower than those at other sampling points.

The reason might be the upper stream of Kumho River has high concentrations of non-degradable substances. Flow rates for Kumho River were increased as the river runs to downstream, but the interesting fact is that flow rates are suddenly enlarged at the station of Kumho 4 from August to October since flow rates were controlled by the rubber beam located between Kumho 4 and Kumho 5. The river flows, therefore, are dependent on operating the rubber beam rather than the natural inflow from the branches.

3.2 CSO study

Ten sampling points including two main stream stations were selected for the main CSO study and figure 4 shows those sampling stations during rainfall events. Among 10 sampling stations, five points are close to the industrial complex, SSWTF bypass, DSWTF bypass, BWTF bypass, Kongdan stream, and Sankeok stream.

Figure 5 shows the changes of BOD concentration for the CSO study. The starting times and periods of overflow for each sampling point were different since the surface conditions of each stations were varied. The highest peaks and rapid changes of BOD concentrations at most stations were shown within one hour after overflows were started except Chimsan stream sampling station at the first rainfall and Sankeok Stream sampling station at the second rainfall. BOD concentrations at the Kongdan Stream station were extremely high for the first and the third rainfall events while that at the BWTF showed the highest peak for the second rainfall event. Kongdan station and BWTF station are located at the Bukbu industrial complex, so CSO from those stations might be affected by the run-off from the industrial complex. In addition, the possible reason for extraordinary high concentrations for Kongdan stream station is the underground retention tank.

The underground retention tank is installed in front of the Kongdan stream station and its capacity is 30,000 m3, so contaminants concentrations in overflow from the underground retention tank are normally enormously high since they are accumulated before overflowing. The retention tanks, therefore, may be the cause of serious deterioration of river's water quality if they are not properly designed. BOD concentrations at Chimsan stream station with the first rainfall event and Sankeok stream station with the first and second rainfall events showed the highest peaks at two hours after the overflow started and then immediately decreased unlike the most other sites showed the highest peaks at the early of overflow. Chimsan and Sankeok stream station are located at the end of residential area and the area may the cause of late overflow since the area has dense drainage systems.

Figure 6 shows the changes of COD concentration for the study. Patterns of changes for COD concentrations are similar to those for BOD concentration, but COD concentration at SSWTP bypass station with the second rainfall event showed higher comparing to BOD concentrations at the same stations with same rainfall event. Figure 7 shows the changes of SS concentration for the study. SS concentrations at the beginning of overflows showed extremely high since particulate pollutants would be the major CSO components as Xu *et al*. reported (2018). SS concentrations, however, with the first rainfall event were relatively higher than those with later two rainfall events except Kongdan stream station sample for the third rainfall event. The reason for the differences among rainfall events might be the total amount of the first rainfall event was almost doubled compared to those of other two precipitations. The underground retention tank may be the cause of high SS concentrations at Kongdan stream station. The result showed that the SS concentration is the one which is mostly affected by rainfall events.

Figure 8 shows the changes of T-N concentration for the study. T-N concentrations at Kongdan stream station appeared similar levels with that at other stations unlikely concentrations for other factors at Kongdan stream station were much higher than those at other stations. High T-N concentrations at BWTF station may be caused by inflow from the closed industrial complex, Dye industrial complex while those at SSWTF,Sankeok Stream, and Chimsan Stream stations may have affected by domestic sewage.

Figure 9 shows the changes of T-P concentration for the study. The concentrations of T-P at the main stream sampling point 1 (Kumho 4, upper stream) were higher than those at the main stream sampling point 2 (Kumho M, downstream) after 22:30 for the first rainfall event unlikely concentrations of other factors at downstream were higher than those at upper stream except few samples for BOD. For the second and the third rainfall events, differences of T-P concentration between the upper stream and the downstream of the main stream were not significant. Main sources of T-P are point pollution sources such as domestic sewage, livestock farm wastewater as well as nonpoint pollution sources such as agricultural land, forest area, and urban area. The probable reasons, therefore, for the higher or similar levels of T-P concentrations at the upper station than those at lower station might be the locations for wastewater treatment facilities and the effect of upper city, City of Gyeongsan. Four wastewater treatment facilities are located at upper areas than the Kumho 4, main stream sampling point 1, and the most parts of City of Gyeongsan are the agricultural lands.

Figure 10 shows the changes of TOC concentration for the study. TOC is an index indicating the total amount of organic carbon. Wastewater treatment facilities in Korea have focused on BOD removal oriented operations, so that BOD concentrations in the waterbodies dramatically decreased. Concentrations for organic carbon, however, are stagnating or increasing due to the lack of measures to reduce organic substances because of BOD removal oriented operations. (MOE 2008 NIER 2009). Therefore, TOC concentrations in this study tended to be high in the vicinity of the industrial complex - SSWTF bypass, DSWTF bypass, BWTF bypass, Kongdan stream, and Sankeok stream.

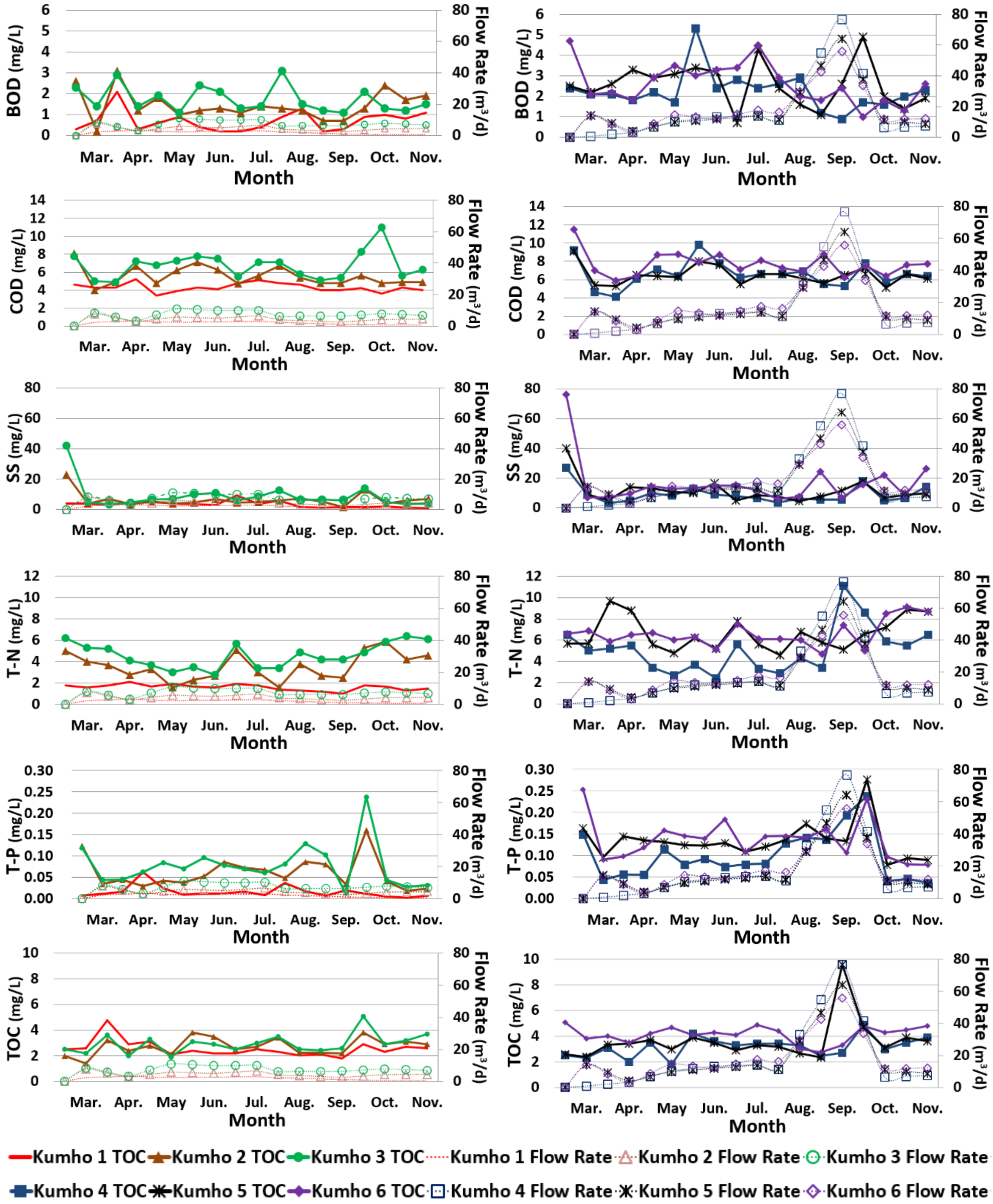

Fig. 3 Water quality and flow rate at Kumho 1 to Kumho 6

Overall, Concentrations for water quality factors in most sampling stations dramatically increased within an hour after the overflow started, but concentrations rapidly dropped down within two hours after the overflow started. The facts show that the high levels of concentrations for water quality factors caused by CSO would not last more than two hours. Concentrations, however, of water quality factors in some sites tended to re-increase. This tendency was mostly observed in wastewater treatment facility bypass samples and it seems to be related to facilities' operation mode, which were arbitrarily controlling the discharge amount of bypass during rainfall events. Overflows from Kongdan stream and DSWTF bypass were started 1 to 2 hours later than those from other points and durations of these sites were shorter than those of other points. The different sites seems to be affected by the difference of the land use/land cover in each area and intervals between rainfalls. Overflows were stopped in most stations after 2 hours of overflows and the water quality of Kumho River was not affected by CSO anymore.

Fig. 4 Sampling stations for CSO study

The highest and the lowest concentrations of water quality factors for the annual water quality monitoring (AWQM) study and concentrations of water quality factors for CSO study were compared and showed in Figure 11 to give the better understand how the overflow influences the concentration changes of main stream. The black dashed lines in the graph indicate the highest concentration of each factor for the AWQM study and the blue dotted lines the lowest.

In the case of first rainfall event, most water quality concentrations, especially from upper main stream sampling during overflows were above the highest concentrations for the AWQM study while some of water quality from lower main stream samples were lower or similar to the highest concentrations for the AWQM study. For second and third rainfall events, concentrations of water quality factors for most samples from both upper and lower main stream during overflow did not exceed the highest concentrations for the AWQM study.

In spite of various changing patterns for water quality factors during overflows, changes of T-N concentrations from both upper and lower main stream samples during overflow for all rainfall events were below the highest concentrations for the AWQM study.

In addition, concentrations of water quality factors from both upper and lower main stream samples show similar levels, but concentrations for SS at the downstream were significantly higher than those at the upstream for all rainfall events. It is considered that this was influenced not only by the inflow of the turbid water from nonpoint

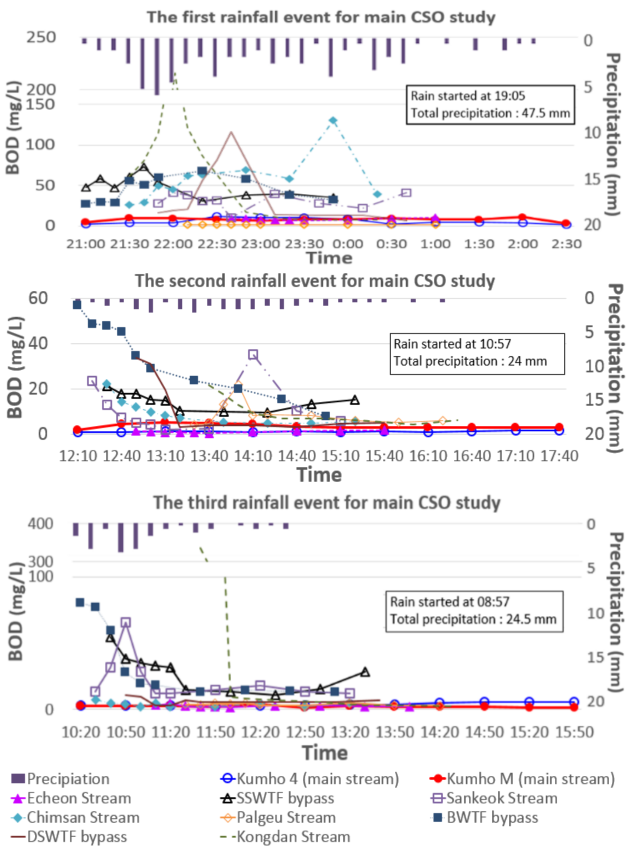

Fig. 5 BOD changes for main CSO study

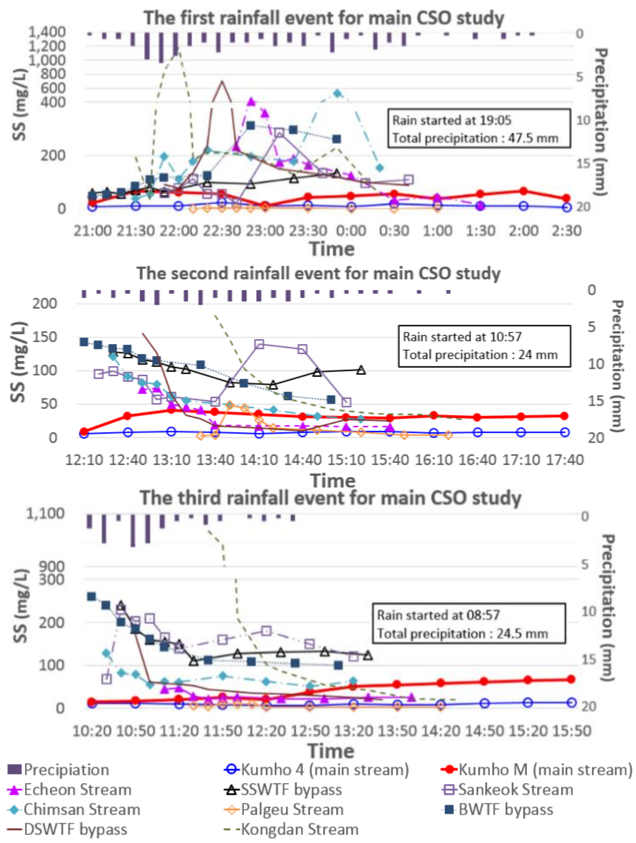

Fig. 7 SS changes for main CSO study

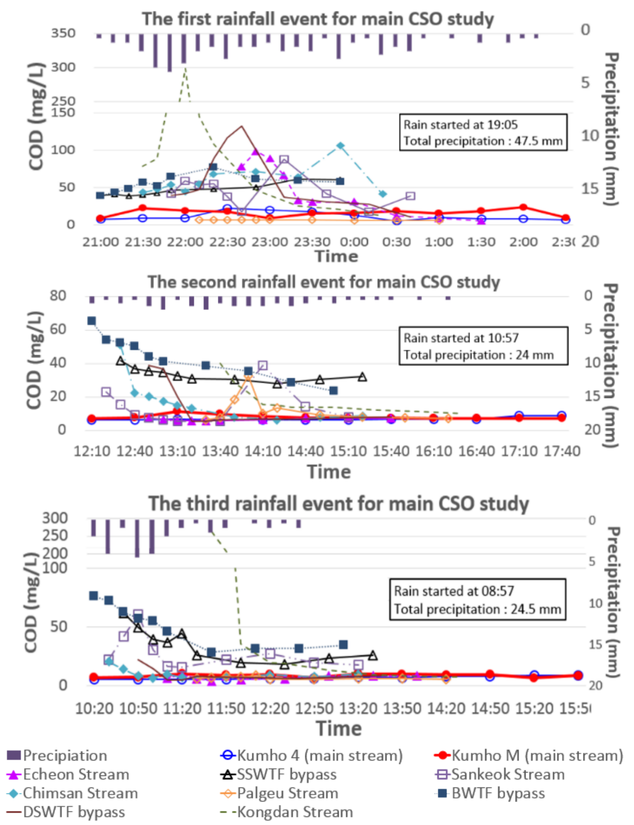

Fig. 6 COD changes for main CSO study

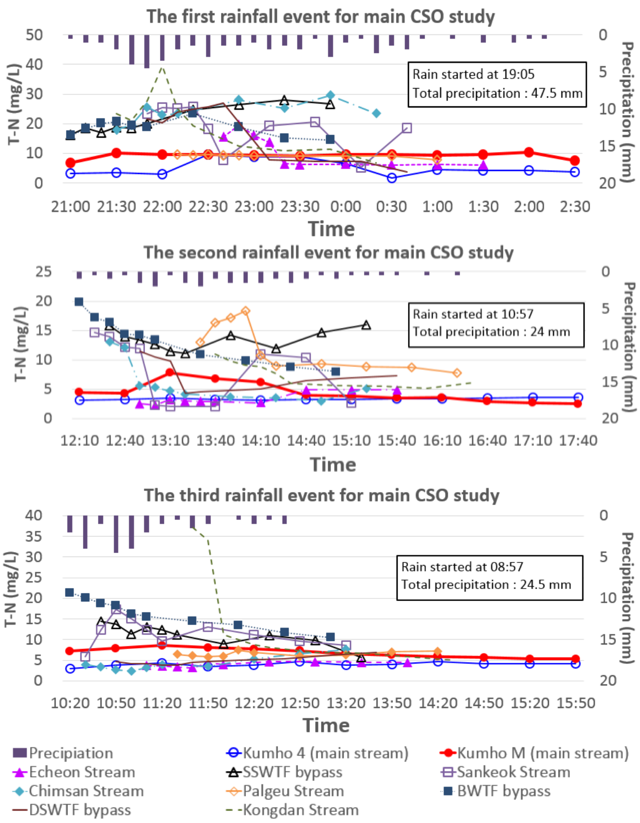

Fig. 8 T-N changes for main CSO study

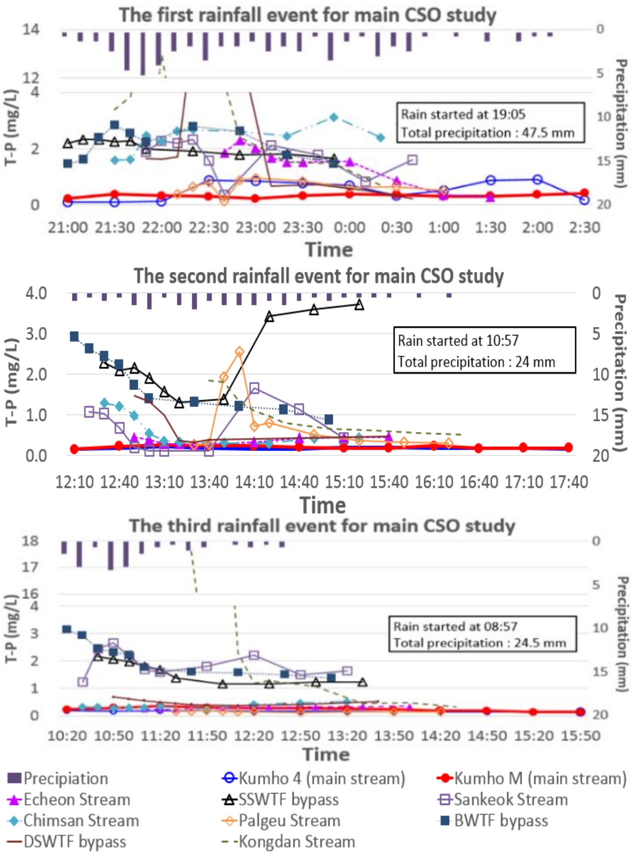

Fig. 9 T-P changes for main CSO study

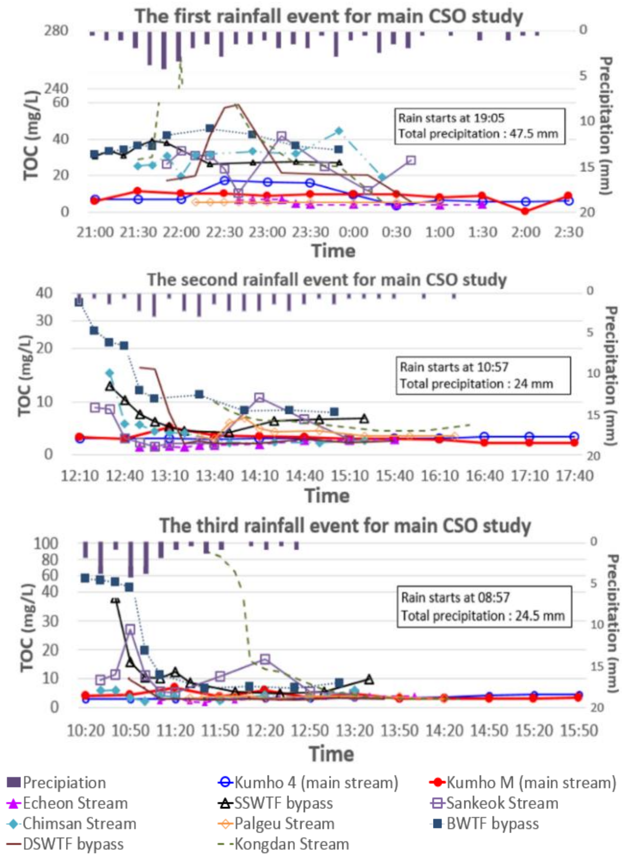

Fig. 10 TOC changes for main CSO study

sources caused by CSO but also by the sediment re-suspension due to rainfall events. As a result, CSO may not be the main reason for decreasing Kumho River's water quality since concentrations of Kumho River's water qualities during CSO were not exceeded the highest concentrations of each water quality factor from the AWQM study.

4. Conclusions

In this study, CSO events were investigated to figure out the effect of CSOs on river's water quality. Water quality and flow rate of Kumho River were monitored to check the status of the river; 18 times sampling for water quality and nine times for flow rate during nine months. As a result of the water quality monitoring, Kumho River's water quality were steeply decreasing along with the inflow of tributaries' flow as well as effluents from the wastewater treatment facilities in City of Gyeongsan and Daegu Metropolitan City. The flow rate of Kumho River was greatly influenced by the operation of artificial rubber beam located at Kumho 4 and Kumho 5. Therefore, rubber beam and wastewater treatment facilities should be carefully operated for proper management of flow rate and water quality at downstream of the Kumho River. For example, the operation system for the rubber beam should be systematized based on scientific investigations for changes of water quality and flow rate depending on operations of the rubber beam.

As results of CSO study, the overflow was highly dependent on the amount of precipitation and rainfall patterns, but the common point of each CSO event was that the concentrations for water quality factors during overflow rapidly increased within 1 hour after the rainfall started and then concentrations for those were dramatically decreased or overflows were even stopped 2 hours after the rainfall started. In addition, concentrations for water quality factors in main stream during overflows in most cases of CSO study did not exceed the highest concentrations of those from the annual water quality monitoring study. Two things are obvious from results of CSO study. 1. the initial response for CSO would be the most important issue during whole rainfall events; Watershed managements for non-point sources at upper stream area should be strengthened to reduce the levels of pollutants in initial overflows. Furthermore, constructing retention lakes for initial overflows from first one or two hours of rainfall events may be a good method to respond early overflow which has high concentrations of contaminants. 2. CSOs, however, might not be the main cause of decreasing the Kumho River's water quality since the amounts and periods of overflows were not significant as well as the concentrations of water quality factors in most case did not exceed the highest concentrations of those from annual water quality monitoring study.

The main reason for decreasing Kumho River's water quality might be the discharges from wastewater treatment

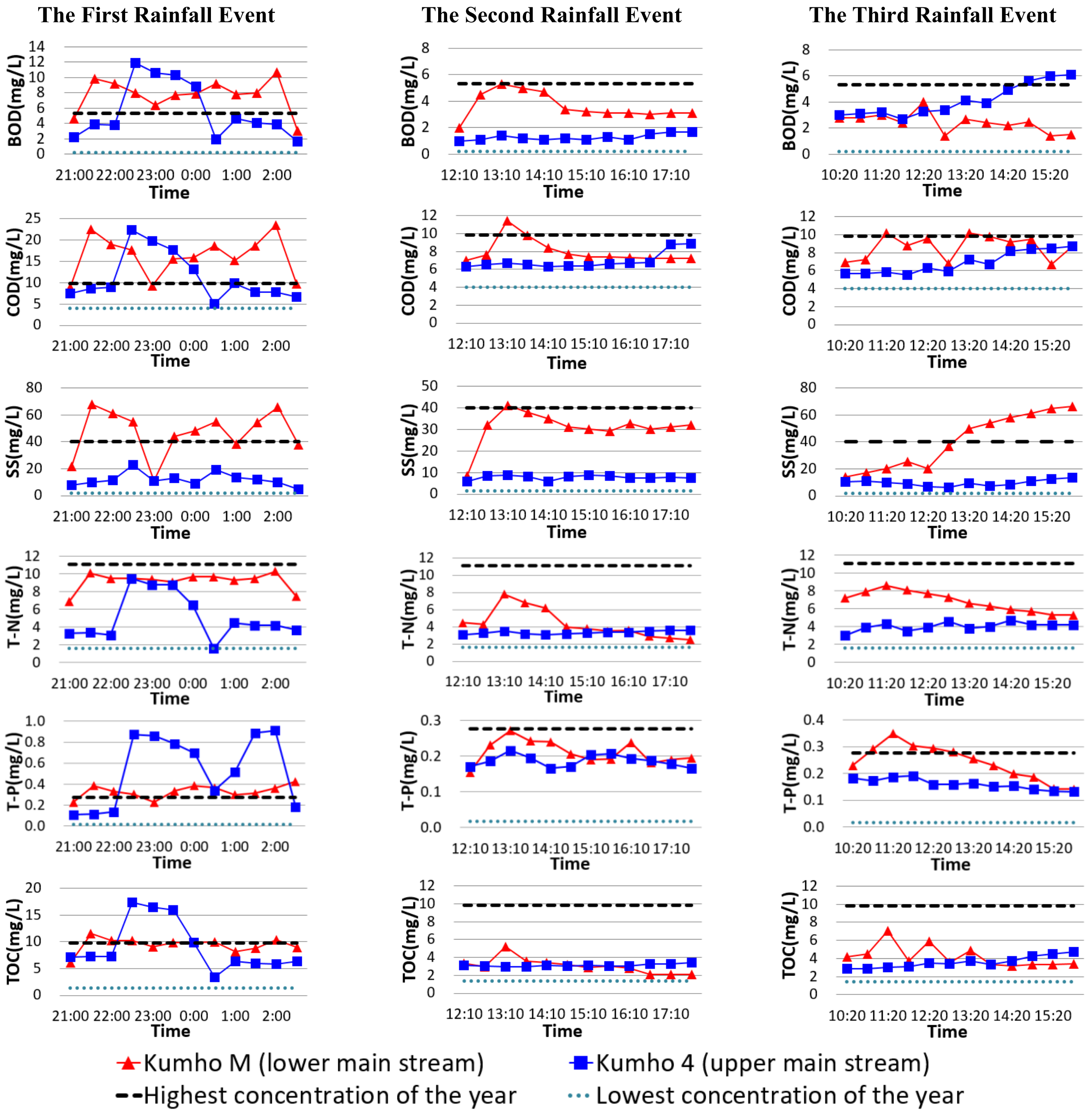

Fig. 11 Water quality concentrations at main stream during CSO and the highest and the lowest water quality concentrations for annual water quality monitoring

facilities located at City of Gyeongsan and Daegu Metropolitan City since concentrations of water quality factors for discharges from wastewater treatment facilities are much higher than those for the Kumho River. Wastewater treatment facilities should pay more attention to make concentrations of water quality factor for their discharges lower down, so that they operate their facilities to the certain level for not only satisfying the water quality standards but also maintaining concentration levels similar to or lower than that of Kumho River. To make it possible, adopting advanced treatment systems such as membrane process might be a one way to assure maintaining the proper water quality of discharges from facilities.

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