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Effect of Stormwater Runoff on Combined Sewer Overflows in Korea

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Abstract

The Kuem-River, one of the largest rivers in Korea, is the primary water source for more than 4 million people in Kongju city and surrounding area. To study the effect of stormwater runoff to CSOs, twelve monitoring sites were selected in two large cities (City of Kongju and City of Buyeo) near the Kuem-River. Monitoring was performed by collecting grab samples, measuring flow rates during dry and wet seasons during over two rainy seasons. Generally the flow rate of wastewater in combined sewers was rapidly decreased after 23:00 P.M. and gradually increased from 06:30 A.M. in all sites during the dry season. The concentrations of pollutant increase approximately 5 to 7 fold for TSS and 1.5 to 2.5 fold for BOD during the rainy season. Monitoring and statistical analysis show that the groundwater contributes on sewage volume increase (average 25-45% more) during dry periods and the stormwater runoff contributes approximately 51-72% increase during rainy periods. Generally the concentrations of combined sewage were more polluted during the first flush period than after the first flush during a storm event.

key words : Combined sewer overflows; Pollutant loading rates; Kuem-River; Stormwater.

1. Introduction

Combined sewer systems (CSS) in the study areas are designed to collect stormwater runoff, domestic sewage, and industrial wastewater in the same pipe. During the dry season, combined sewer systems transport most of the wastewater to a wastewater treatment plant. However, during periods of heavy rainfall, the sewage volume in a combined sewer pipe can exceed the capacities of the sewer system or treatment plant. For this reason, the combined sewer system is designed to overflow occasionally and discharge excess wastewater directly to the nearby river. The overflows, combined sewer overflows (CSOs), are containing stormwater, untreated municipal and industrial wastewaters. It is a major water pollution concern for the Kuem-River in the study area with non-point sources (Mulliss et al., 1997; Skipworth et al., 2000; Duchesne et al., 2001; Sztruhar et al., 2002).

During the rainfall, at the very beginning, stormwater containing many pollutants, which is defined as the first flush, are usually flowing into the sewer pipes. It causes serious problems to

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quality of combined sewer overflows due to high pollutant concentrations. However, the existence of first flush has been debated and many defining criteria exist. Thornton and Saul (1987) defined the first flush as the initial period of storm flow during a storm event. Geiger (1987) defined a first flush as occurring when the slope of normalized cumulative mass emission plotted versus normalized cumulative volume is greater than 45%. Later investigators have also used this definition (Sansalone et al., 1998). Vorreiter and Hickey (1994) proposed using only the first 25%of runoff volume in defining first flush. Deletic (1998) used standard statistical methods including a multiple regression model, and restricted first flush to the first 20% of runoff. Saget et al. (1995) and Bertrand-Krajewski et al. (1998) defined a first flush as occurring when at least 80% of the pollutant load is emitted in the first 30% of the runoff volume. Recently Kim et al. (2002) proposed the first flush criteria using 30% mass first flush (MFF_{30}) ratios. Another problem on the sewer networks are due to worn-out or broke-down pipes that are the reason of inflow/infiltration of groundwater.

This manuscript summarized the effect of stormwater runoff by comparing monitoring results during rainy and dry seasons in the two large cities near the Kuem-river. Also the effect of inflow/infiltration in the sewer pipes will be discussed on this paper.

2. Methods

2.1 Site descriptions

The Kuem-river starts in South-East Chungnam-Do, Korea and travels to the Yellow sea through Kongju and Buyeo cities. The river directly receives untreated urban stormwater runoff and combined sewer overflows from many nearby cities including those research areas. Two large cities (Kongju and Buyeo) are selected to investigate the effects of stromwater and groundwater on sewer systems. Figure 1 shows the location of the two cities and Table 1 summarizes the details of monitoring sites such as watershed area, population density, surface water use, land use, etc. The watershed areas vary from 3.1 to 122.2 ha and are mostly using as residential or commercial purposes.

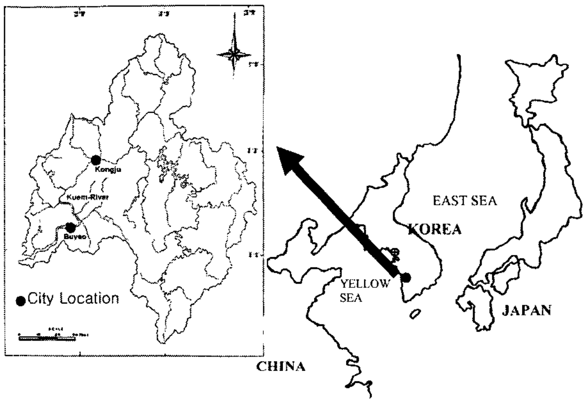


Fig. 1. Study area.

Table 1. The characteristics of monitoring site (Kongju City Statistics, 2002)

Sites and locations		Watershed area (ha)	Population density (capita/ha)	Surface water use (m^3/day)	Land use	Sewer line types
Kongju	S1	78.4	174	3,281.0	Residential	CSS
	S2	2.5	207.2	125.0	Residential	
	S3	17.3	48.2	201.0	Residential/commercial	
	S4	241.6	95	5,516.0	Residential/commercial	
	S5	3.1	198.4	149.0	Residential	
	S6	16.6	148.0	593.0	Residential/commercial	
Buyeo	S7	122.2	68.9	2,098.4	Residential/commercial	
	S8	32.5	61.9	615.3	Residential	
	S9	75.3	90.1	1,410.0	Residential	
	S10	17	151.6	435.5	Residential/commercial	
	S11	5.3	93.9	104.5	Residential/commercial	
	S12	23.9	27.9	94.9	Residential	

2.2 Monitoring and data analysis

Twelve monitoring sites (each city has 6 monitoring sites) were selected from the cities. Monitoring was performed during two years from 2001 to 2002 by collecting grab samples and measuring flow rates for dry and wet seasons during over two years. The rainfall data was gathered from rainfall station of Kongju city provided by Korea Meteorological administration. A large suite of water quality parameters was measured, including oxygen demand parameters, metals, nutrients and ions. In order to define the effects of stormwater and groundwater to combined sewer systems, theoretical water and mass balances were used for each site.

3. Results

3.1 Weather information and runoff coefficients

Average monthly temperature and rainfall in Kongju and Buyeo areas are shown on Figure 2. Because of Monsoon weather in Korea, the rainy season starts in March and ends in November. Usually the monthly mean temperature increases up to 24°C during summer and falls -2°C in winter. Average yearly rainfall is recorded on 1,354 mm in Kongju and 1,334 mm in Buyeo. During monitoring periods, runoff coefficients are generally ranged from 0.2 to 0.8 for all sites. It has wide ranges because of different rainfall intensity, storm duration and antecedent dry day periods.

Considering the first flush effect during the storm events on combined sewer systems, monitoring were performed and analyzed the relationship between water quality and quantity. For first flush criteria, the 30% mass first flush are applied at sampling program because it can show more reasonable relationship between pollutant mass and water volume (Kim et al, 2002).

3.2 Polluto- and load-graphs

Figure 3(a) shows polluto- and load-graphs at site S5 on Oct. 04, 2001. The flow rate was rapidly decreased after 23:00 P.M. and gradually increased from 06:30 A.M., which tendency can be seen on all of sites. However, it is difficult to find the relationship between pollutant concentrations and flow rate because the pollutant concentration in a sewer pipe is very dependent on time. Figure 3(b) is pollutant loading rates during a storm event. It is very dependant on the flow rate because the pollutant mass is obtained by multiplying a concentration with a flow rate. Therefore, the mass loading can be predicted with some affecting parameters in the future research.

3.3 Statistical analysis for concentrations during dry and rainy periods

Statistical summaries of concentrations during dry and rainy periods are shown on Figure 4. The notched box plots shows minimum, median, maximum, standard deviations, upper/lower 95% confidence intervals and outliers for each parameter. In Kongju areas, the concentration ranges of 95% confidence intervals during dry periods are

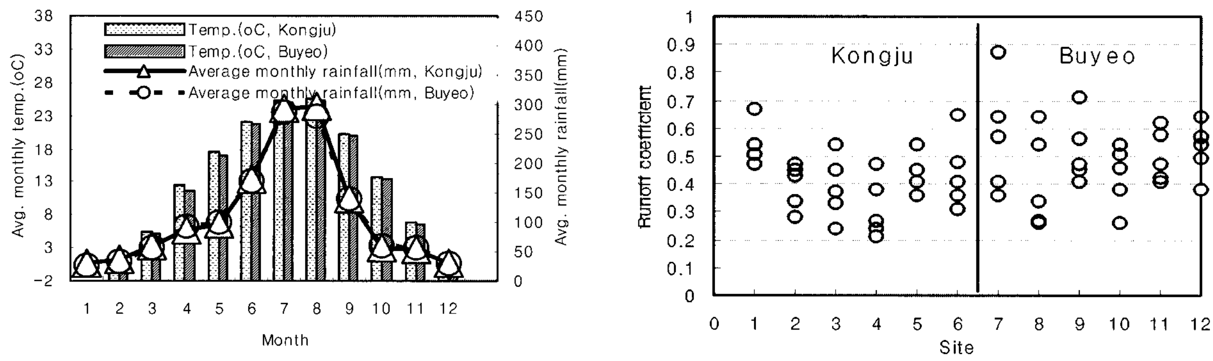
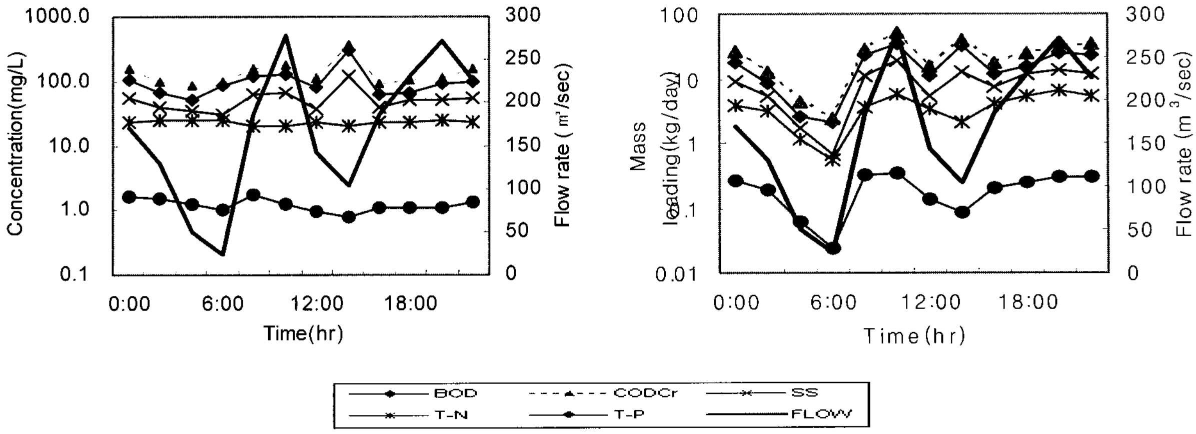
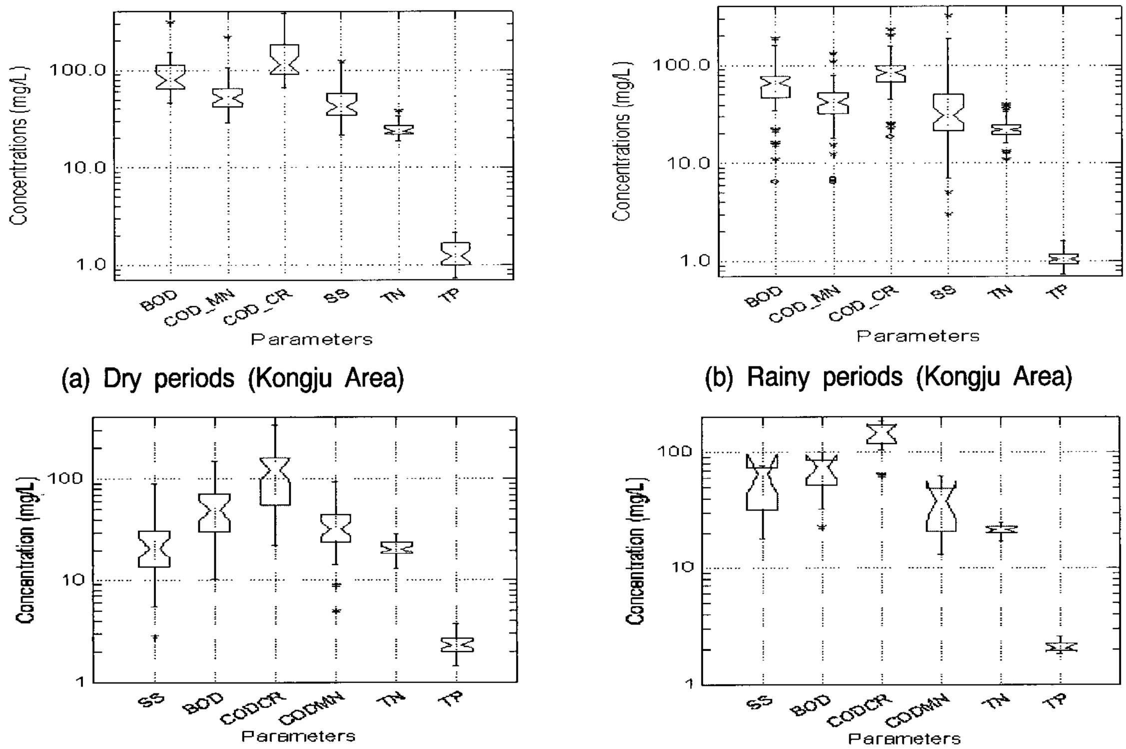


Fig. 2. Weather information and runoff coefficient during monitoring periods.



(a) concentrations (b) mass loadings

Fig. 3. Polluto-graph(a) and load-graph(b) during a storm period at S5(Oct. 04, 2001).



(a) Dry periods (Kongju Area) (b) Rainy periods (Kongju Area)

(c) Dry periods (Buyeo Area) (d) Rainy periods (Buyeo Area)

Fig. 4. Statistical summaries for concentrations during rainy and dry periods.

65-115 mg/L for BOD, 92-195 mg/L for COD_{Cr}, 39-60 mg/L for suspended solids, 22-27 mg/L for TN and 1.0-1.64 mg/L for TP. However it is decreased during rainy periods because of dilution effect from stormwater. The concentration ranges are decreased to 47-85 mg/L for BOD, 72-105 mg/L for COD_{Cr}, 23-55 mg/L for suspended solids, 20-25 mg/L for TN and 0.08-1.20 mg/L for TP during rainy periods, respectively. Most of water quality parameters show slightly higher concentrations during dry days than that of rainy days. In Buyeo areas, the 95% confidence concentration during rainy days ranges 35-100 mg/L for SS, 50-98 mg/L for BOD, 110-170 for COD_{Cr}, 18-24 mg/L for TN and 1.91-2.35 mg/L for TP. The ranges during dry periods are decreased to 15-30 mg/L for SS, 30-70 mg/L for BOD and 25-150 for COD_{Cr}. However TN and TP did not show the decreasing tendency, which ranges 16-27 mg/L for TN and 2.0-2.75 mg/L for TP. The results show that the combined sewage concentrations during rainy periods in Buyeo areas are highly affected from highly polluted storm runoff compared to Kongju area, respectively.

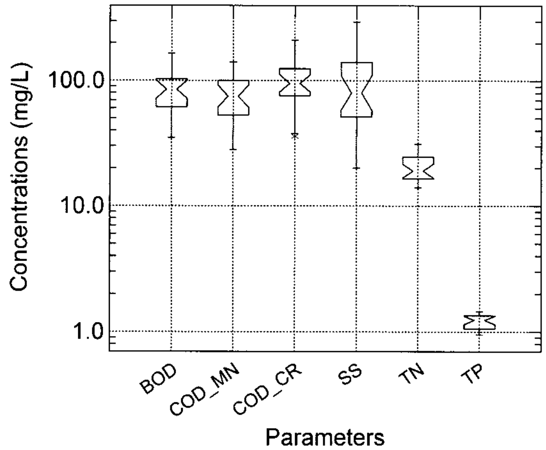


Fig. 5. Statistical summary for concentrations during first flush periods of storm events.

In order to investigate in detail the stormwater effect on combined sewage concentrations, first flush study is carried out. Figure 5 shows the box plots of statistical summaries for concentrations during first flush periods of storm events. These plots clearly show that there are large differences between minimum and maximum concentrations. These differences are assumed to be partially due to variations in rainfall intensity and antecedent dry periods. When it is compared to the concentrations of Figure 4, we can fine the values of suspended solids are higher in first flush. It means that during first flush periods large amount of sediments and inorganic màterials are flowing in the combined sewer pipes. The pollutants are originated from streets, construction sites, residential houses, etc. Also it means that initial storm runoff highly polluted are flowing in sewer pipe and increasing the sewage concentrations during a storm event.

3.4 Variations of flow rate and BOD mass in sewer pipes

Inflow rate (quantity) and BOD inflow ratio (quality or pollutant mass)to the sewer pipe for all sites are summarized on Table 2. The flow rate increased average 25.4-45.0% during dry days, which was originated from groundwater inflow to pipes. During rainy periods the flow rate was more increased because of direct flowing of the stromwater. BOD mass loadings are 2 fold larger during rainy days than that of dry days. It means that the first flush added more pollutants to the sewer during a storm. However, we expected an important thing, which is that the groundwater near sewer pipes is very highly polluted and the ground level is very high. The sewer pipes in research

Table 2. Variations of flow rate and BOD mass

Sites	Inflow rate ratio (%)		BOD inflow ratio (%)	
	No rainfall	Rainfall	No rainfall	Rainfall
S1	13.2−35.4	30.0−62.4	14.6−25.4	45.1−58.9
S2	24.1−41.2	35.4−64.7	10.5−18.7	62.4−75.6
S3	26.8−62.4	45.2−85.4	17.1−22.3	45.8−62.5
S4	11.0−51.5	41.3−74.8	8.2−12.7	36.7−45.3
S5	23.4−45.8	36.8−75.4	7.0−25.9	15.8−26.8
S6	25.7−35.1	56.7−84.7	23.5−42.5	51.2−74.8
S7	32.4−48.7	67.8−75.8	31.4−39.7	35.2−41.8
S8	64.2−80.0	85.4−90.0	21.4−28.7	32.4−52.6
S9	34.1−52.9	56.4−74.9	25.6−32.1	42.5−56.3
S10	13.4−25.1	42.7−68.4	28.4−36.4	36.4−47.1
S11	14.8−29.4	42.6−86.4	9.7−18.6	22.4−36.5
S12	21.5−32.5	75.8−88.7	24.5−32.8	32.1−48.9
Average	25.4−45.0	51.3−77.6	21.0−28.0	38.2−52.3

areas are worn-out or broken-down for a long time, so that large amount of pollutant exists in soil near the pipes. Therefore, in these research areas the combined sewer pipes should be re-constructed or repaired to protect the qualities of groundwater and nearby surface water.

4. Conclusions

Combined sewer systems in Korea transport municipal and industrial wastewaters, stormwater and groundwater to a treatment plant. It affects very serious problems for nearby receiving water bodies and for wastewater treatment process operations. Also the unstable or worn-out sewer networks have another problem, which can be the reason of inflow or infiltration of groundwater to the pipe. Therefore this research investigates the effects of stormwater and groundwater to quality and quantity in the sewer pipes. Major findings of this research are:

1) It is impossible to find the relationship between pollutant concentrations and flow rate because the pollutant concentration in a sewer pipe is very dependent on time.
2) During first flush periods, most of water quality parameters show higher concentrations because of the highly polluted first flush effect. After first flush periods, the concentrations on the sewer pipes are decreased due to dilution effect.
3) The flow rate increases by average 25.4-45.0 % during dry days because of groundwater inflow to pipes. During rainy periods the flow rate is more increased because of direct flowing of the highly polluted stromwater runoff. BOD mass loadings are 2 fold larger during rainy days than that of dry days because of the first flush.
4) The sewer pipes in research areas are worn-out or broken-down for a long time, so that large amount of pollutant can be existed on soil near the pipes. Therefore, more research needs on the pipes to determine the status of pipes.

References

Bertrand-Krajewski J., Chebbo G. and Saget A. (1998) Distribution of pollutant mass vs volume in stormwater discharges and the first flush phenomenon. *Wat. Res.*, 32(8), pp. 2341-2356.

Deletic A. (1998) The first flush load of urban surface runoff. *Wat. Res.*, 32(8), pp. 2462-2470.

Duchesne S., Mailhot A., Dequidt E., Villeneuve J.P. (2001) Mathematical modeling of sewers under surcharge for real time control of combined overflows, *Urban Water*, 3, pp. 241-252.

Geiger W. (1987) Flushing effects in combined sewer systems. *Proceedings of the 4th Int. Conf. on Urban Drainage*, Lausanne, Switzerland. pp. 40-46.

Kim L-H, Kayhanian K. and Stenstrom M.K. (2002) Prediction of event mean concentration and first flush effect using mass interpolation washoff model for highway runoff, *Conference proceedings of 6th International Conference on Diffuse Pollution*, September, Amsterdam, The Netherlands. pp. 227-235.

Kongju City Statistics (2002) http://www.gongju.go.kr/03_service/service_02.html.

Mulliss R., Revitt D.M., and Shutes R.B.E. (1997) The impacts of discharges from two combined sewer overflows on the water quality of an urban watercourse, *Water Sci. & Tec.*, 36(8-9), pp. 195-199.

Saget A., Chebbo G. and Bertrand-Krajewski J. (1995) The first flush in sewer system. *Proceeding of the 4th Int. Conf. on Sewer Solids-Characteristics, Movement, Effects and Control,* Dundee, UK. pp. 58-65.

Sansalone J.J., Koran J.M., Smithson J.A. and Buchberger S.G. (1998) Physical characteristics of urban roadway soils transported during rain events, *J. of Environ. Engineering,* 124(5), pp. 427-440.

Skipworth P.J., Tait S.J., Saul A.J. (2000) The first Flush in combined sewers: an investigation of the causes, *Urban Water,* 2, pp. 317-325.

Sztruhar D., Sokac M., Holiencin A., Markovic A.

(2002) Comprehensive assessment of combined sewer overflows in Slovakia, *Urban Water,* 4, pp. 237-243.

Thornton R.C. and Saul A.J. (1987) Temporal variation of pollutants in two combined sewer systems. *Proceedings of the 4th Int. Conf. on Urban Drainage,* Lausanne, Switzerland, pp. 51-52.

Vorreiter L. and Hickey C. (1994) Incidence of the first flush phenomenon in catchments of the Sydney region. *National Conf. Publication-Institution of Engineers,* Australia.3, pp. 359-364.

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