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Characteristics of Non-Point Pollution from Road Surface Runoff

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Abstract

Pollutants from urban pavement consists various kinds of substances which are originated from dry deposition, a grind out tire, corrosive action of rain to pavement and facilities and raw materials of the road etc.. These are major pollutants of urban NPS (Non-point source) during rainfall period. However there is not enough information to control such pollutants for appropriate management of natural water quality. In this study of transportation areas, three monitoring stations were set up at trunk road, urban highway and national road in Gyeongnam province. Runoff flow rate was measured at every 15minutes by automatic flow meters installed at the end of storm sewer pipe within the road catchment area for water quality analysis. Data was collected every 15 minutes for initial two hours of rainfall. Additional samples were collected 1-4 hours interval till the end of rainfall. The monitoring parameters were COD_{Mn}, SS, T-N & T-P and heavy metals. The average EMCs of TSS and COD_{Mn} were 62.0 mg/L and 24.2 mg/L on the city trunk road, which were higher than those of urban highway and national road, indicating higher pollutant loads due to activities in the city downtown area beside the vehicle. On the other hand, the average EMC of T-N and T-P were in the range of 2.67-3.23 mg/L and 0.19-3.21 mg/L for all the sampling sites. Heavy metals from the roads were mainly Fe, Zn, Cu and Mn, showing variable EMCs by the type of road. From the TSS wash-off analysis in terms of FF(first flush) index, first flush phenomenon was clearly observed in the trunk road(FF : 0.89-1.43). However, such mass delivery behavior was not apparently shown in urban highway(FF : 0.90-1.11) and national road(FF : 0.81-1.41).

Key Words : NPS(Non-point source), EMC(Event mean concentration), Runoff flow, Rainfall, Pollutant loads

1. Introduction

Surface water quality management has been implemented mainly by point source control in Korea. However the water quality has not been improved and still deteriorated gradually in some watershed. This could be identified by several reports that show no significant improvement of surface water quality in spite of efforts to reduce pollutant loading from point sources (Park et al., 1998; UN environmental program, 2004). Recently, therefore, Korean government becomes to recognize the importance of non-point source control. And they have launched a long term monitoring project to establish pollution load from various non-point sources. In addition a new concept has also been introduced to consider urban as an area source in terms of non-point pollution. Especially traffic road surface is characterized by the occurrence of a number of pollutants, such as suspended solid, heavy metals, hydrocarbons and nitrogen, which may be originated by wet and dry depositions, grind tire

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debris, corrosive materials of road facilities and exhaust gas from vehicle etc. (USEPA, 1994). There are the great temporal and spatial variability in pollution load from the road surface runoff due to site characteristics and to rainfall pattern (Mangani et al., 2004). Since, again, the phenomenon of pollutant wash off is complex it is required to collect a reliable data set for more detailed interpretation of pollutant migration from the road by storm event (Berretta et al., 2007). This paper focuses on the evaluation of pollution load from various types of urban road, i.e. the roads of urban highway, suburban national road and a city trunk road. And the data were analyzed for best management practice (BMP) of non-point pollution control in urban area.

2. Methods

Three monitoring stations were set up at a city trunk road, an urban highway and a national road in Gyeongnam province as shown in Fig. 1. Runoff flow rate was measured at every 15 minutes by automatic flow meters installed at the end of storm sewer pipe for each road catchment area. Grab sampling was carried out for water quality analysis. Samples were collected every 15 minutes for initial two hours of rainfall. Additional samples were collected 1-4 hours interval till the end of rainfall. The monitoring parameters were COD_{Mn}, TSS, T-N & T-P and heavy metals. The characteristics of rainfall events at the three monitoring sites are summarized in Table 1.

Table 1. Summary of monitoring events in this study

Site	Event no.	Event date	Area (m^2)	ADD (days)	Total rainfall (mm)	Runoff duration (hr)	Avg. rainfall intensity (mm/hr)	Runoff coeff.
Site 1	E-1	2008/04/09	1,240	2	15.5	5.1	3.04	0.20
	E-2	2008/04/16	1,240	7	2.5	2.5	1	0.18
	E-3	2008/05/13	1,240	9	5.5	1.16	4.74	0.10
	E-4	2008/05/19	1,240	5	15.5	1	15.50	0.61
	E-5	2008/05/28	1,240	8	65.5	28	2.34	0.48
	E-6	2008/06/04	1,240	7	13.0	12.45	1.04	0.27
	E-7	2008/06/17	1,240	9	48.5	11.1	4.37	0.16
	E-8	2008/07/02	1,240	3	40.5	6.16	6.57	0.86
	E-9	2008/07/20.	1,240	16	17.5	3.03	5.78	0.67
Site 2	E-1	2007/09/15	1,500	8	51.8	6.50	7.97	0.62
	E-2	2007/10/07	1,500	12	36.9	4.35	8.48	0.59
	E-3	2008/04/09	1,500	2	21.0	8.34	2.52	0.23
	E-4	2008/05/18	1,500	4	11.9	5.55	2.14	0.24
	E-5	2008/06/28	1,500	6	81.5	8.42	9.68	0.09
	E-6	2008/08/22	1,500	5	12.9	1.47	8.78	0.17
	E-7	2008/10/22	1,500	32	28.5	6.56	4.34	0.13
Site 3	E-1	2007/09/15	2,000	8	51.8	7.00	7.4	0.57
	E-2	2007/10/07	2,000	12	36.9	4.35	8.48	0.46
	E-3	2008/04/09	2,000	2	21.0	8.34	2.52	0.18
	E-4	2008/05/18	2,000	4	11.9	5.55	2.14	0.27
	E-5	2008/06/28	2,000	6	81.5	8.42	9.68	0.10
	E-6	2008/08/22	2,000	5	12.9	1.47	8.78	0.20
	E-7	2008/10/22	2,000	32	28.5	6.46	4.41	0.10

Site 1: City trunk road, Site 2: Urban highway, Site 3: National road

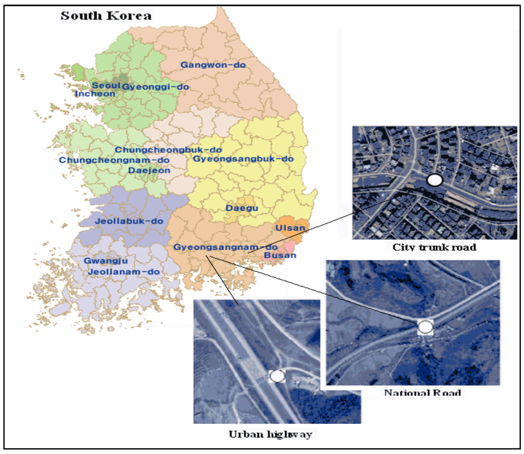


Fig. 1. Monitoring stations for traffic roads.

3. Results and Discussion

3.1. EMC analysis for each type of road runoff

Generally the overall runoff quality associated with each rainfall event is expressed as event mean concentration(EMC) which is calculated by integrating the product of runoff rate and concentration of substances. The EMC could be used for determining the mass loading to receiving waters. The definition of the EMC is expressed as following equation.

$$EMC = \frac{M}{V} = \frac{\int_0^T q(t)c(t)dt}{\int_0^T q(t)dt}$$

Table 2 is the EMC values for each water quality parameter. The runoff coefficients of the three roads were quite different and were influenced by the rainfall intensity. They were 0.1-0.86 for city trunk road, 0.1-0.57 for urban highway and 0.09-0.62 for national road. The event mean concentration(EMC) of each road was also significantly variable by antecedent dry days, first flush rainfall intensity and rainfall duration time. As shown in the table, the mean EMC values of TSS and COD_{Mn} were 62.0 mg/L and 24.2 mg/L in the city trunk road, which are higher than the other two sampling sites. However these values are relatively low compared to previous research results reported for urban highway, which was in 45.5-125.8 mg/L and 52.0-95.5 mg/L for TSS and COD_{Mn} at 95% confidence interval (Kim et al., 2007). Since the runoff concentration is varied in a large range even a single land use it is difficult to predict EMC accurately. The lower EMC values could also be influenced by type of road, rainfall intensity and runoff flow rate (Lee et al., 2008). The mean EMC of T-N and T-P were in the range of 2.67-3.23 mg/L and 0.19-3.21 mg/L for all the sampling sites, which are similar to other research results. Fig. 2 shows the statistical EMC ranges of the pollutants elements for each road. Heavy metals detected in this study were iron, zinc, copper and manganese. Iron was the most abundant element measured in this study. The mean

Table 2. Event mean concentration observed at the monitoring sites

Item	City trunk road (Rainfall discharge rate : 0.09-0.62)		Urban highway (Rainfall discharge rate : (0.1-0.86)		National road (Rainfall discharge rate : 0.1-0.57)	
	Mean(mg/L)	SD	Mean(mg/L)	SD	Mean(mg/L)	SD
TSS	62.0	64.36	33.51	35.92	37.34	43.07
CODMn	24.2	3.2	23.07	28.25	10.44	11.39
T-N	2.67	0.18	2.97	2.34	3.23	0.12
T-P	3.21	0.076	0.19	0.29	2.62	0.14
Fe	0.14	0.213	0.19	0.318	0.09	0.092
Zn	0.045	0.026	0.03	0.034	0.12	0.221
Cu	0.024	0.024	0.02	0.019	0.034	0.039
Mn	0.021	0.036	0.01	0.027	0.013	0.028

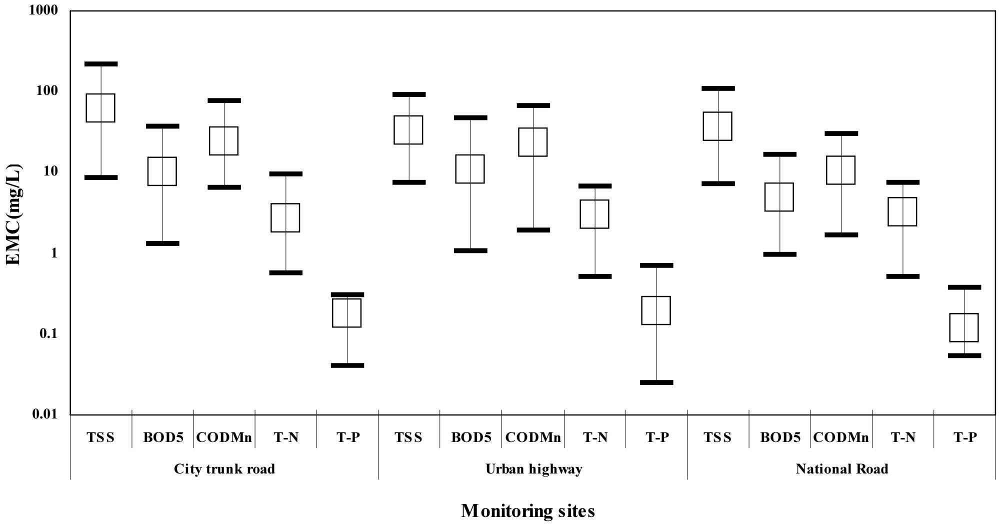


Fig. 2. Statistical EMC ranges for each pollutant parameter.

EMCs of iron were 0.19mg/L for urban highway and 0.14 mg/L for city trunk road, which are slightly higher than the results (around 0.1 mg/L) by other reports (Giovanna et al., 2004; Kim et al., 2007). The origin of iron may be vehicle metal corrosion and tires wear mainly. The second abundant element was zinc followed by copper and manganese. While zinc was most abundant element for national road, of which EMC was 0.12 mg/L, followed by iron, copper and manganese.

3.2. Pollutants wash-off analysis from the urban roads

Pollutant mass transport associated with storm runoff is a dynamic process affected by several factors including hydrologic parameters, catchment characteristics and the nature of pollutants(Berretta et al., 2007). The elaboration of experimental data generally reveals a remarkable occurrence of the first flush for TSS (Berretta et al., 2007). Fig. 3 to Fig. 5 show the hydro- and polluto-graph of TSS for the three types urban roads. The measured TSS concentration is high at initial rainfall and sharply decrease after 1hour period followed by another increase at peak flow as shown in the figures. This is a typical pollutants wash off pattern for impervious pavement road. The higher initial concentration of TSS maybe caused by the anticedent dry days (ADD) and/or higher traffic density in the city trunk road. It is obvious from the hydro- and polluto-graph that pollutant wash off is accomplished at initial run off. Kim et al. (2007) has explained the first flush phenomenon as dynamic EMC which is rapidly declined within the early 20-50 minutes of runoff duration. Thus long term monitoring is necessarily required on this first flush runoff of pollutants.

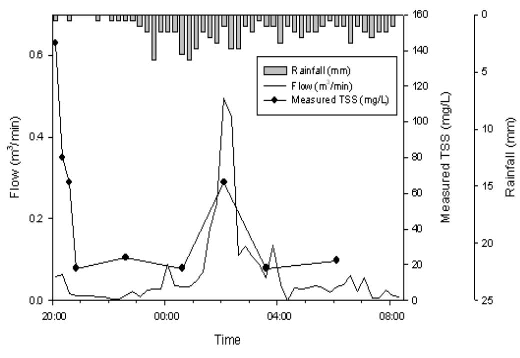


Fig. 3. Hydro and polluto-graph for TSS measured concentrations at city trunk road.

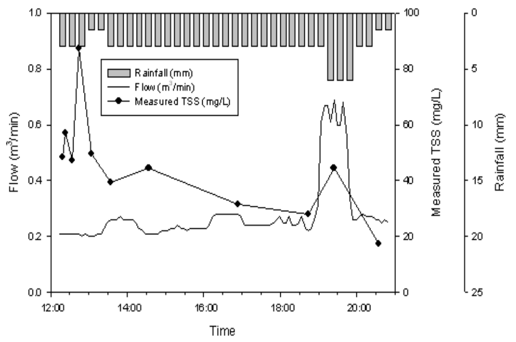


Fig. 4. Hydro and polluto-graph for TSS measured concentrations at urban highway.

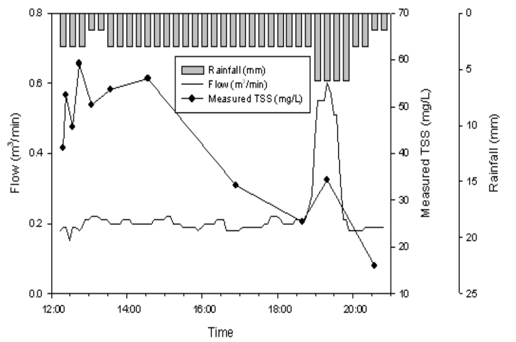


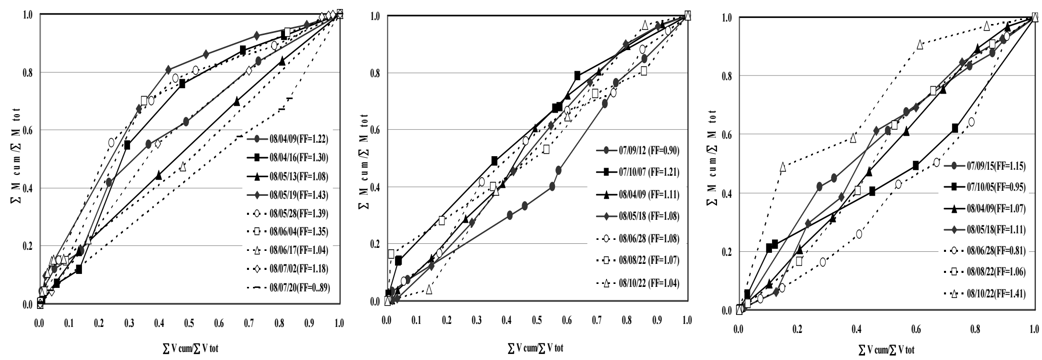
Fig. 5. Hydro- and polluto-graphs for TSS measured concentrations at national road.

Generally rainfall runoff events can be classified in two different pollutant mass delivery behaviors: mass-limited and flow limited events (Sansalone and Cristina, 2004). Mass-limited events are characterized by high runoff volumes and disproportionately high delivery of mass in the early rainfall events, on the contrary flow-limited events are characterized by low runoff volumes and a more proportionate mass delivery with respect to the runoff hydrograph across the event (Sansalone et al., 1998; Cristina and Sansalone, 2003).

In order to investigate the mass delivery behavior, the wash-off process could be analyzed using the dimensionless *M(V)* representation, which reports the cumulative fraction of total pollutant mass *M* versus the cumulative fraction of total runoff volume *V*. This allows comparing the evolution of pollutant loads from different rainfall events (Berretta et al., 2007). A quantitative measure of the first flush phenomenon is provided through the first flush index FF which is defined as following equation.

$$FF_{index} = \frac{\left(\sum_{i=1}^{N} (\bar{V}_i - \bar{V}_{i-1})(\bar{M}_i - \bar{M}_{i-1}) / 2\right)}{1/2}$$

Where *Vi* and *Mi* are the cumulative fraction of runoff volume and TSS mass respectively, N is the



a) City trunk road b) Urban highway c) National road

Fig. 6. *M(V)* curves for TSS corresponding to the mass-limited events by type of road. (The first flush index, FF is indicated in brackets.)

total number of measurements. So the FF index could be calculated as the ratio between the areas subtended by the *M(V)* curve and by the bisector in the same graph. The first flush occurs when FF is greater than 1 ($0 \leq FF \leq 2$). Fig. 6 illustrates the *M(V)* curves corresponding to the rainfall runoff events characterized by a mass limited behavior and the calculated FF index for the three urban roadways. In case of city trunk road, six over nine events confirm such mass delivery behavior for TSS. While two and three over seven events confirm mass delivery behavior for urban highway and national road, respectively. The mass-limited events were not clearly exhibited in the monitoring sites of urban highway and national road which is quite different first frush phenomenon of city trunk road. This may be caused by the monitoring site characteristics and/or the limited data set for the analysis.

4. Conclusion

From the investigation of surface run off characteristics from three types of urban roadways, followings could be concluded. The mean EMC values of TSS and COD_{Mn} were 62.0 mg/L and 24.2 mg/L in the city trunk road, which are higher than those of urban highway and national road. It could be evaluated that the higher pollution load was due to complicated activity in the city down town area beside the vehicle transportation. On the other hand, the mean EMC of T-N and T-P were in the range of 2.67-3.23 mg/L and 0.19-3.21 mg/L for all the sampling sites. Heavy metals from the roads were mainly Fe, Zn, Cu and Mn of which the EMC were variable by the type of road. From the TSS wash-off analysis in terms of FF index, first flush phenomenon was clearly observed in the city trunk road. However such mass delivery behavior was not apparently shown in urban highway and national road.

Acknowledgement

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