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도시화된 토지이용에서 유출되는 강우유출수의 유출특성분석

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Characteristics of stormwater runoff from urbanized areas

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요약 : 도시화된 토지이용은 불투수율이 높고 강우시 다량의 비점오염물질이 유출되어 지표수 및 지하수에 영향을 끼친다. 이러한 포장지역의 비점오염물질로 인한 수질오염을 저감하기 위하여 환경부는 수질오염총량제도 및 개발사업에 대한 비점오염 저감시설 설치신고 제도를 도입하여 운영 중에 있다. 그러나 비점오염저감시설의 규모 및 저감기능 설계를 위해서는 유출특성 분석이 필요하나 현재 기초자료가 부족하여 원단위 산정 등의 애로점으로 남아있다. 따라서 본 연구에서는 원단위 산정 및 저감시설의 규모산정에 필요한 강우유출수 특성과 EMC를 제시하고자 한다. 모니터링은 도로 및 주차장에서 3년간 총 30개의 강우사상에 대하여 수행되었다. 초기강우 유출현상은 강우 시작 후 30분 동안 매우 분명하게 나타났으며, 유출수의 농도에 영향을 미치는 인자는 강우량, 유역면적, 토지이용, 지리 및 지형적 특성으로 분석되었다. 본 연구결과는 향후 포장지역의 원단위 산정 및 저감시설 설계시 기초자료로써 활용가능할 것으로 판단된다.

핵심용어 : 비점오염원, 유량가중평균농도, 주차장, 초기강우, 포장지역

Abstract : Stormwater runoff affects the quality of surface water and groundwater due to the nonpoint sources (NPSs) of pollutants that it carries during storm events. Typically, urbanized areas experience high pollutant mass emission because of paved roads and other areas which are all highly impervious. For this reason, proper identification of the levels of pollutants from the watershed area is important to pass the Ministry of Environment of the Republic of Korea’s water quality standards in rivers and streams. This research was conducted in order to determine and quantify the different constituents present in stormwater runoff generated from highly impervious areas in Cheonan City, Korea. Also, the average event mean concentration (EMC) of stormwater runoff from paved areas was compared with EMCs of other countries to determine the possible causes of its occurrence. In addition, the occurrence of first flush phenomenon was studied in order to find the first flush criteria to be used on the design of best management practices. The results show the pollutant concentration of stormwater runoff was higher than other countries due its landuse and relatively small size of catchment area.During the first 30 minutes of the rainfall events, occurrence of first flush phenomenon was highly evident. Several factors affected the pollutant concentrations in the stormwater such as landuse type, geographic and topographic characteristics,catchment area and amount of rainfall. This research can provide guidance in achieving an effective NPS pollution management applicable to highly urbanized areas in the future.

Keywords : Event mean concentration, First flush, Nonpoint source pollution, Paved areas, Stormwater runoff

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1. Introduction

Stormwater runoff affects the quality of surface water and groundwater due to the nonpoint sources (NPS) of pollutants that it carries during storm events. Today, the disruption of the natural hydrologic cycle is associated with urbanization. Urbanization, a result of global change, is the physical growth of urban areas. Typically, urbanized areas experience high pollutant mass emission due to its paved roads and other areas which are all highly impervious. Transportation related land uses such as highways, roads, parking lots and bridges were identified to have contributed to NPS pollution (Maniquiz, 2010a). NPS pollution that includes constituents such as particulates, organics, nutrients and heavy metals was being carried by sediments from these areas. Urbanization also results to the alteration of stream flow and watershed hydrology, reduction of ground water recharge and the increase of stream sedimentation and water acidity.

Discharging the stormwater runoff containing high pollutant concentrations could impose negative impacts to the aqua-ecosystem. For this reason, proper identification of the levels of pollutants from the watershed area is important to pass the Ministry of Environment (MOE) of the Republic of Korea's water quality standards in rivers and streams. Although point source pollution has been greatly reduced and regulated to preserve the quality of surface waters, nonpoint source pollution from various areas, such as urban runoff, still is detrimental to receiving waters when left untreated (Kim et. al., 2007a; Kim et. al., 2006). In response to the increasing risk posted by the effects of NPS to the surface water bodies in Korea, 'Comprehensive measures for Non-point Source pollution Management' was established in March 2004. In addition, MOE is pursuing the implementation and compliance with total maximum daily loads for watershed for watershed protection (Jung et. al., 2008).

This research was conducted to determine and quantify the different constituents present in stormwater runoff generated from highly impervious land in Cheonan City, Korea. Furthermore, the occurrence of first flush phenomenon was also investigated in this study. The collected data can be used in devising an effective management strategy to reduce NPS pollution in the future. Lastly, this study analyzed the average event mean concentration (EMC) and compared it with similar studies in other countries to determine the possible causes of its occurrence.

2. Materials and Methods

2.1 Site description

The three sites (two parking lots and road) selected for this study were located at Kongju National University (KNU), Cheonan city, Chungcheong Province, South Korea. On an average, the city annually receives rainfall amounting to 1236 mm. Fig. 1 shows the map of KNU with the specific locations of the areas studied. The catchment areas for the parking lot 1, parking lot 2 and road were 450, 880 and 520 m^2, respectively. All three sites were paved with asphalt and 100% impervious.

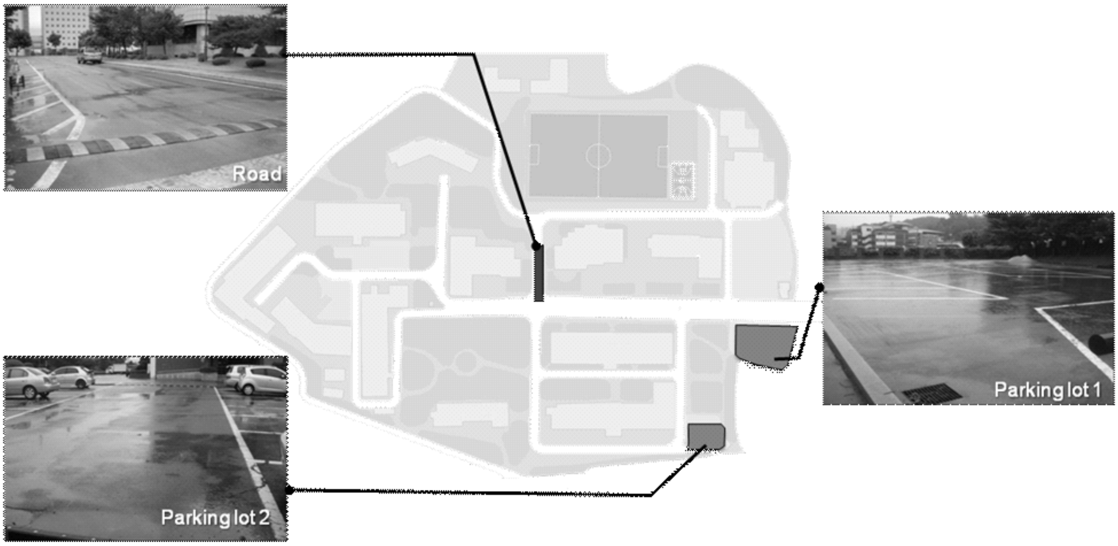


Figure 1. Site locations

2.2 Monitoring, data collection and analyses

Monitoring of storm events were conducted from May 2009 to November 2011 in the three selected sites for this study. Both water quality and quantity were gathered from a total of 30 storm events. Following the typical sampling scheme in Korea, six grab samples were collected during the first hour of the storm event (Maniquiz et. al., 2010b). The first grab sample was collected as the runoff started, followed by the grab sample collection after 5, 10, 15, 30 and 60 minutes, respectively. After the first hour, one grab sample was collected for each succeeding hour. In addition to the grab samples collected for chemical analyses, continuous flow measurements were also performed and recorded using a 5 minute interval. Standard method for testing the typical water constituents was used to identify the particulate, organics, nutrients and soluble metal in the runoff samples collected (Greenberg et al, 1992).

The effects of stormwater runoff were evaluated with the use of event mean concentration (EMC). The EMC represents a flow weighted average concentration computed by dividing the total pollutant mass by the total runoff volume for event duration (Kim et. al., 2004). The results of water quality were statistically analyzed using SYSTAT 12 package software including analysis of Pearson correlation which was performed to investigate relationship between typical water constituents, rainfall variables and the relationship of the two. The correlations were tested at 95% confidence level which signifies that *p* value was less than 0.05.

3. Results and Discussion:

3.1. Rainfall variables and event mean concentrations

The statistical summary of monitored storm events was summarized in Table 1. The monitored storm events range from 1 to 29 mm which produced 0.03 to 12.78 m^3 volume of runoff. The antecedent dry days (ADD) varied from 0.6 to 34.2 days. The rainfall durations measured were from 0.98 to 6.75 hrs while the runoff durations varied from 0.25 to 6.0 hrs. ADD and average rainfall intensity showed significant correlation with TP and Cr, respectively ($p<0.05$). On the other hand, turbidity was significantly correlated with rainfall duration, runoff duration, runoff volume and rainfall volume with p value less than 0.05. These rainfall variables affect the EMC due to the dilution effect that these bring during a storm event (Kim et. al., 2007c). The ratio of rainfall and runoff volume for the different sites monitored in which the runoff coefficient may be derived is presented in Fig. 2. The road has a mean ± SD runoff coefficient of 0.55 ± 0.28 while the parking lot has a mean ± SD runoff coefficient of 0.32 ± 0.28. Road has relatively greater runoff coefficient due to slope of the catchment area greater than 3% compared to the slope of the parking lots which were between 1% to 2% only. The overall mean± SD runoff coefficient of the paved areas monitored was 0.46 ± 0.29.

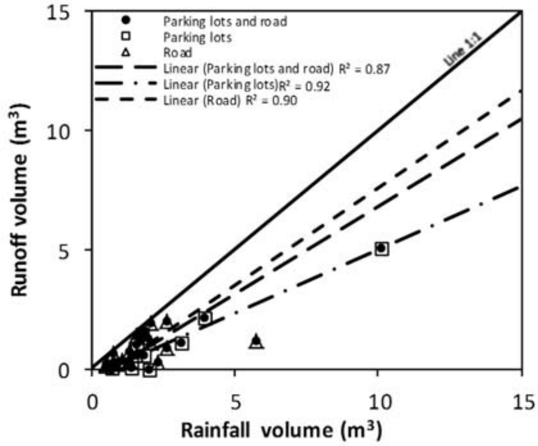
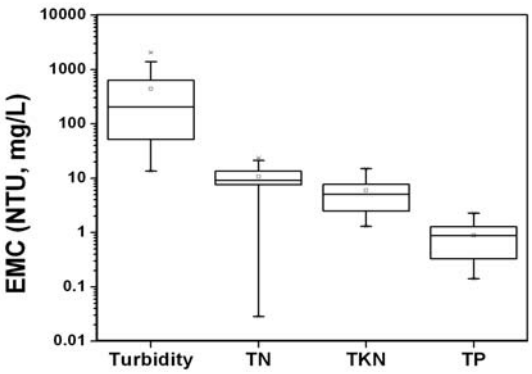


Figure 2. Linear plot of the ratio of rainfall and runoff volume for the different sites monitored.

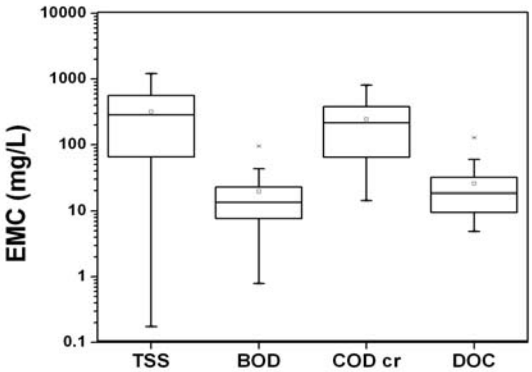
Table 1 Summary of storm events data from the sites monitored

	Unit	Minimum	Maximum	Median	Mean	SE	SD
ADD	day	0.2	34.2	4.6	7.547	1.536	8.413
Rainfall Depth	mm	1	29	3.5	6.05	1.271	6.96
Rainfall Duration	hr	0.5	6.75	2.835	2.781	0.268	1.465
Runoff Duration	hr	0.25	6	1.665	1.856	0.246	1.347
Time Before Runoff	hr	0	2.87	0.69	0.99	0.166	0.907
Runoff Volume	m^3	0.007	18.54	0.99	2.556	0.836	4.58
Rainfall Volume	m^3	0.52	15.08	1.81	3.108	0.64	3.508
Rainfall intensity	mm/hr	0.375	12.162	1.5	2.626	0.557	3.053

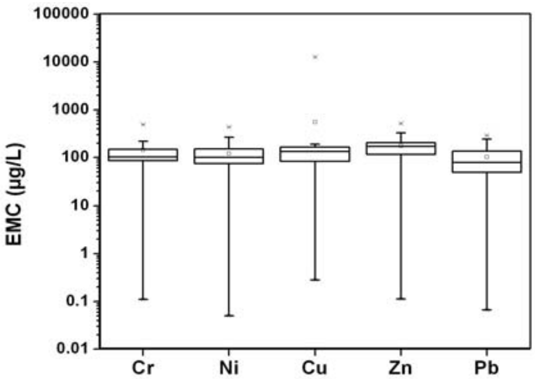
The box plots of the typical storm water runoff constituents from road and parking lots are displayed in Fig. 3. Road produced greater value of mean ± SD EMC for TSS, BOD, COD_{Cr}, DOC, TN , TKN and TP amounting to 445.8 ± 313, 26.7 ± 23, 312.7 ± 186, 34.4 ± 27, 12.1 ± 5.8, 6.6 ± 3 and 1.1 ± 0.5 mg/L, respectively than the mean ± SD EMC produced by the parking lot amounting to 119.1 ± 144, 10.3 ± 9, 136.7 ± 218, 12.1 ± 9, 8.5 ± 5, 4.8 ± 4 and 0.6 ± 0.5, respectively. On the other hand, the soluble metal mean concentrations derived from parking lots were greater compared to the soluble metal mean concentrations of road due to the longer exposure of the parking lots to the transportation vehicles carrying heavy metal constituents. This affected the overall mean EMC of all the paved areas studied. The median EMC of all the constituents were less than the mean EMC. This signified that most of the concentrations in the stormwater runoff were low. Also, high variability in EMC was associated with rainfall variables such as rainfall depth, rainfall duration, runoff volume, runoff durations and ADD. In addition, the activity in the sites monitored such as traffic should be considered as a factor affecting the variability of EMC.



(a) Water physical properties and nutrients



(b) Particulate and organics EMC



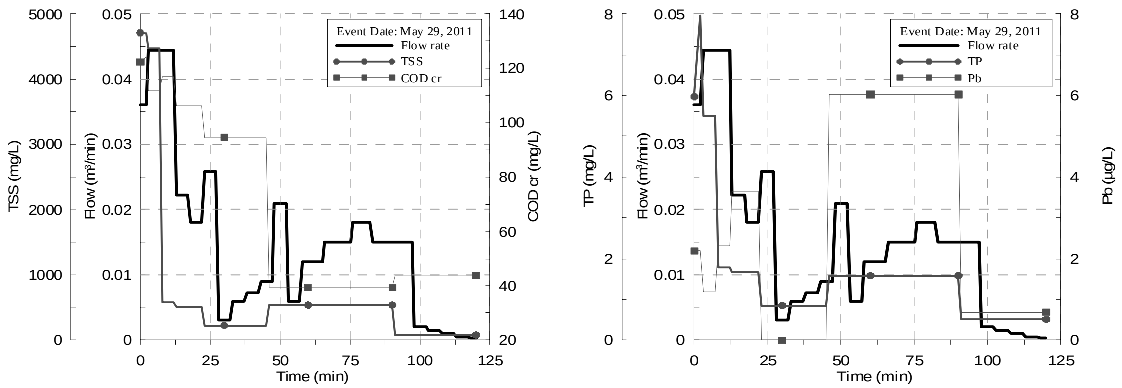
(c) Soluble heavy metals

Figure 3. Box plots of the pollutant EMC

Table 2 Pearson correlation matrix for the stormwater constituents

	Turbidity	TSS	BOD	COD_{Cr}	DOC	TN	TKN	TP	Cr	Ni	Cu	Zn	Pb
Turbidity	1												
TSS	0.68*	1											
BOD	0.764	0.734	1										
COD_{Cr}	0.128	-	0.559	1									
DOC	0.615	0.873	0.64	-	1								
TN	0.329	0.459	0.629	0.485	0.547	1							
TKN	0.404	0.422	0.658	0.523	0.452	0.911	1						
TP	0.491	0.341	0.536	0.165	0.443	0.318	0.256	1					
Cr	-**	-	0.079	0.65	-	0.084	0.203	-	1				
Ni	-	-	0.08	0.637	-	0.077	0.2	-	0.994	1			
Cu	-	-	0.093	0.674	-	0.156	0.248	-	0.965	0.966	1		
Zn	-	-	0.07	0.638	-	0.077	0.207	-	0.894	0.882	0.86	1	
Pb	-	-	-	0.282	-	-	-	-	0.835	0.827	0.739	0.821	1

* Bold values have p value less than 0.05
** Negative values were not shown



(a) TSS and COD_{Cr} (b) TN and soluble Pb

Figure 4. Hydro-polluto graphs

Table 2 exhibits the Pearson correlation matrix for the stormwater runoff. Organics including BOD, COD_{Cr} and DOC showed significant correlation to most of the stormwater constituents. BOD showed significant correlation to nutrients comprising of TN, TKN and TP with p values of 0.002, 0.001 and 0.012, respectively. Similarly, COD_{Cr} was significantly correlated with soluble metals excluding Pb ($p<0.05$). TSS was significantly correlated with Turbidity, BOD, DOC and TN with p value less than

0.05. These findings signify that the particulates or solids have significant effect with regards to pollutant generation in the stormwater runoff. Usually, these solids or particulates were transported by air, transportation vehicles and humans. During storm events, these particulates were washed off in the impervious surfaces causing the storm water runoff to be polluted. However, Only TN and TKN were found to be significantly correlated to each other ($P<0.001$) in nutrients. Lastly, all soluble metals exhibits significant correlation to each other with p value less than 0.001. The generation of these metals was frequently associated with emerging impervious spaces in highly urbanized areas. Therefore, TSS, COD_{Cr}, and TN removal should be considered in choosing a proper best management practice which could be used to control the emerging quantity of NPS.

3.2. First flush investigation

First flush is a phenomenon in which the pollutant concentration of stormwater runoff generated was substantially higher compared to the runoff generated at the latter period of the storm event (Lee et. al., 2002; Kim et. al., 2007b). Fig. 4 demonstrates the hydro-

Table 3. Average concentration of typical constituents in stormwater runoff studies in Korea and other countries.

Country		Germany	Macau, China	Italy	USA	South Korea	
Reference		Gobel et al., 2007	Huang et al., 2007	Gnecco et al., 2005	Brezonik and Stadelmann, 2002	This study	
Land use and surface characteristic		Garden, grassed area and cultivated land (unpaved)	Residential and commercial spaces (paved)	Roof and road (paved)	Residential, commercial, industrial and grasslands (paved and unpaved)	Parking lots (paved)	Road (paved)
Catchment Area (ha)		-	14	0.28	6.9-215	0.133	0.052
Average Annual Rainfall (mm)		837	2,120	1,323	788	1,352	1,352
Parameter	Unit	Mean Concentrations					
TSS	mg/L	12	318.6	140	184	119.1	425.1
BOD	mg/L	2	-	-	-	10.3	25.9
COD	mg/L	19	201.4	129	169	136.7	222.3
Cu	μg/L	11	4.9	19	-	1224.5	132.4
Zn	μg/L	80	3.2	81	-	213.3	145.9
Pb	μg/L	9	55	13	60	116.4	77.0

observable especially during the first 30 minutes of the rainfall duration. As the storm polluto-graphs of the storm event monitored in the road during the February 27, 2011. TSS, COD_{Cr}, TP and soluble Pb were used as representative constituents of the particulate, organics, nutrients and heavy metals. Pollutant concentration was not dependent on the volume of stormwater runoff. On the other hand, first flush phenomenon was progressed, the concentration of the stormwater constituents was decreasing or sometimes inconsistently changing. Similar trend was observed in other storm events monitored. Therefore, first flush phenomenon should be considered in identifying the BMP that should be used to control the NPS pollutants present in the stormwater runoff.

3.3. Comparison with other studies

The mean concentration of selected constituents with the corresponding site characteristics for five different studies was provided in Table 3. It was observed that the pollutant concentration of stormwater runoff in this study was higher than other countries due to the land use and relatively small size of catchment area. The site monitored in Germany exhibited low pollutant concentration due to the surface characteristic of the site being unpaved with low annual precipitation. On the other hand, USA, Italy and China exhibited high TSS and COD concentration while low heavy metal concentration comparable to the monitored site in this study. Based on the water quality standards ofthe Republic of Korea, the BOD levels of the 4 major watershed/rivers should be reduced to 0.20 to 0.65 mg/L (MOE, 2004) to secure and preserve the aquatic ecosystem. The standard was only 1 to 3 % of the measured BOD concentration in the monitored sites in KNU. Therefore, it was observed that the catchment area, land use and surface characteristics were directly affecting the stormwater pollutant generation. Paved areas generated greater concentration of pollutant compared to unpaved or pervious areas. On the other hand, the effect of annual rainfall to pollutant generation was still variable and needs further investigation.

4. Conclusion

Non-point source pollutants were usually transported by storm water runoff especially in highly urbanized areas. A total of 30 storm events were monitored to determine the factors affecting the pollutant generation in stormwater runoff from May 2009 to November 2011. The pollutant concentration of stormwater runoff generated from paved areas varies depending on several rainfall variables such as rainfall depth, rainfall duration, runoff volume, runoff durations and ADD. Slope of the catchment affects the runoff coefficient. Due to the surface imperviousness of the site studied, generation of TSS and organics which was significantly correlated to most of the pollutants found in stormwater runoff was apparent. Soluble heavy metals were also observed to be significantly correlated to each other. TSS, COD_{Cr}, and TN removal should be considered in choosing a proper best management practice which could be used to control the emerging quantity of NPS since these constituents were found to be significantly correlated with other stormwater constituents. In addition to the rainfall variables, other factors such as land use, geographic and topographic characteristics, catchment area and amount of rainfall affects the stormwater pollutant concentration. Lastly, the occurrence of first flush phenomenon should also be considered in devising an effective management strategy in treating NPS pollution. Therefore, in devising an effective and appropriate management strategy to control NPS pollution, the factors and phenomenon identified in this study should be incorporated. In the future, this study can aid in the advancement of NPS control in Korea.

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