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Characteristics of stormwater runoff from junkyard

Je Chan Jeon[a], Koo Ho Kwon[a], Yong Jun Jung[b], Min-Ji Kang[c], Kyung Sok Min[a,*]

[a]*Department of Environmental Engineering, Kyungpook National University, Daegu 702-710, South Korea, Korea, email: ksmin@knu.ac.kr (K.S. Min)*
[b]*Department of Environmental Engineering, Catholic University of Pusan, Pusan 609-817, South Korea*
[c]*Water Environmental Research Department, National Institute of Environmental Research, Incheon 404-708, Republic of Korea*

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ABSTRACT

Many countries including Korea and the USA have carried out many studies on point pollution sources to preserve rivers and lakes over the past 30 years. According to the Ministry of the Environment, Korea, the pollutant loading rate caused by non-point pollutant sources at the major four rivers of Korea comprise of 22–40% of the total pollutant loading rate. The Ministry of the Environment, Korea, predicted that in 2020, non-point pollutant sources should comprise up to 62.5% of the river pollutant loading. For the stable management of non-point pollutant sources, a study of basic data, such as concentration range and run-off pattern of pollutants discharged with land use patterns is very important. This study examined the characteristics of pollutants during rainfall events at the zones for recyclable material separation. The biochemical oxygen demand and chemical oxygen demand (CODcr) concentrations in three rainfall events ranged from 27.4 to 72 mg/L and 66.8 to 168.8 mg/L, respectively. The total suspended solids concentration ranged broadly from 30.1 to 690 mg/L. The first flush effect was strongly shown. The total nitrogen and total phosphorus concentration ranged from 1.2 to 19.8 mg/L and 5.2 to 10.0 mg/L, respectively. The concentrations of pollutants from the zone for recyclable material separation were higher than those of the pollutants in the run-off generated from residential and commercial districts, roads, and parking areas. In addition, there was no correlation between the pollutant concentration and rainfall intensity. These results will be used as basic data for measuring the removal of non-point pollutants.

Keywords: Precipitation; Stormwater; Run-off; Non-point pollutant; Correlation of pollutant; The zone for recyclable materials separation

1. Introduction

Over the past 30 years, many countries including Korea and the USA have carried out many research projects on point pollution sources to preserve the water qualities of rivers and lakes [1]. Recently, sewage and wastewater treatment technologies were developed rapidly with the development of biological removal processes and advanced treatment processes. Therefore, the pollution ratio caused from a point source, such as sewer treatment plants, decreased

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*Corresponding author.

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dramatically. Although the water quality of public water bodies has been improved due to the better treated wastewater with an improvement in the wastewater treatment plant, the water quality of public water bodies is no longer decreasing after reaching a certain value. Based on a literature review on the quality of public water bodies over the last decade, the US EPA concluded that non-point pollutant sources comprise a large proportion of water pollution [2]. Non-point source pollutants enter waterways as stormwater run-off from diffuse, distributed sources across the landscape [3]. The reason that non-point pollutants in rivers takes up high ratio of water pollution is that land use modifications associated with urbanization includes the removal of vegetation and replacement of pervious areas with impervious surfaces which result in changes in the characteristics of the surface run-off hydrograph [4]. And pollution from diffuse sources such as stormwater run-off is more difficult to monitor and control [5].

According to the Ministry of the Environment, Korea, the pollutant loading rate caused by non-point pollutant sources at the major four rivers of Korea comprise 22–40% of the total pollutant loading rate. The Ministry of the Environment, Korea, predicted that in 2020, non-point pollutant source should make up approximately 62.5% of the river pollutants loading [6]. And it is widely reported that the urban run-off has been one of the main reasons which cause significant damage to the aquatic environment [7–9]. Because of these study results, non-point pollutants caused by various land use patterns have become an object of concern around the globe, and studies of non-point pollutant sources are ongoing [10]. Many studies on the run-off characteristics of pollutants during rainfall, which is a part of research on non-point pollutant source, have been examining industrial complexes, residential areas, construction sites, loading, rice paddies, parking lots, rural areas, and combined sewer overflow, etc. [11–18].

These studies have examined the type and concentration range of pollutants, calculation of the event mean concentration (EMC), run-off trend regarding a stormwater run-off and correlation evaluation between the pollutants and rainfall intensity or antecedent dry days (ADD). Therefore, many studies on planning, construction, and treatment efficiency of non-point pollutants treatment facilities have been reported. Kim et al. compared the pollutant removal characteristics according to the media types using perlite and macromolecule synthesis media [19]. Lee et al. evaluated a suitable determination method for objectively calculating the removal efficiency of pollutants into inflow and outflow from non-point pollutants removal facilities [20]. Meanwhile, Chol et al. examined the intercepting volume of combined sewer overflow during rainfall [21].

Many studies at institutional aspects on non-point pollutants sources have been performed. The Gyeonggi Research Institute in Korea carried out a study on the establishment of effective non-point pollutants source management plans for the introduction of the total maximum daily load (TMDL) [22]. The Korea Rural Community Corporation developed a technical model for the non-point pollutants source management of rural area and suggested management methods [23].

For the stable management of non-point pollutants sources, a study of basic data, such as the concentration range and run-off pattern of pollutants discharged with the land use patterns is very important [24]. The basic data helps to better understand the run-off characteristics of non-point pollutants sources generated during rainfall and enables the design of a proper non-point pollutants removal facility. To determine the unit loads, the generated pollutants can play a large role in accomplishing policies, such as the TMDL. As mentioned above, many studies have estimated the unit loads and run-off trend including the loads, commercial complexes, industrial complex, residential, forest and field, etc. Nevertheless, the run-off characteristics at the zone for recyclable materials separation have received less attention. To examine the run-off characteristics of the target area during rainfall, this study selected the zone for recyclable materials separation, which can release a high pollutant concentration from the cumulated waste. These results can be used as basic data for establishing non-point removal measures.

2. Materials and methods

2.1. Site characteristic and monitoring method

The target area of this study selected the zone for recyclable material separation located in Si-Heung city, South Korea. This zone for recyclable materials separation is the area to gather waste that has been emitted by approximately 535,000 local residents, and separate them for recycling. Because a range of wastes, such as garbage, fluorescent light, plastic goods, and paper, are collected in this zone every day, many types of pollutants including organic matter, nutrient, and heavy metals have been accumulated. The target area of this study was approximately 27,086 m^2 of the catchment area, and the surface of the catchment area is composed of impervious ingredients. To gather stormwater run-off to a specific point, pipes to gather at the edge of the catchment area were installed. Therefore, all of the stormwater run-off generated during rainfall was gathered to the point shown in Fig. 1. Sampling was conducted at this point. The sites were equipped with a recording flow meter and rainfall gauge. Portable flow rate equipment was used to measure the run-off flow rate.

To examine the first flush effect, the run-off characteristics of non-point pollutants sources commonly observed in urban areas, the sampling interval was conducted with a short time interval during the initial rainfall. That is, during a storm event, six samples were collected during the first one-hour with a time interval of 5, 5, 10, 10, 15, and 15 min. Additional samples were then collected through the appropriate time intervals until the end of the run-off. Water quality parameters, such as the total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) were analyzed at the laboratory in accordance to the standard procedure established in KOREA.

2.2. Study contents

To analyze precipitation pattern at the study site, the data for monthly precipitation from 2001 to 2010 collected by the local weather center was used in this study. The run-off data were collected a total of three times during 2010–2011. This study analyzed the run-off trend and concentration range of pollutants using the data collected through monitoring, and the calculated EMC. The EMC is acknowledged as the most appropriate method for estimating the pollutant concentration in stormwater run-off and is used widely [25].

The EMC obtained by considering the data of discharge flow and water quality data is given by the following equation:

$$\mathrm{EMC}\,(\mathrm{mg/L}) = \sum_{t=1}^{t=T} C(t)\cdot q_{run}(t) \Big/ \sum_{t=1}^{t=T} q_{run}(t) \tag{1}$$

where $C(t)$ and $QTRu(t)$ are the pollutant concentration and run-off flow rate discharged at time t.

The EMC calculated per event is more useful than the normal concentration because of the calculated concentration of pollutants in terms of the run-off flow rate during the rainfall event [26]. The EMC obtained in this study was compared with the EMC of pollutants obtained from stormwater run-off generated in land use types, such as residential areas, commercial areas, industrial areas, roads, and parking lots during rainfall. The analysis of the different pollutants EMC according to land use patterns can be utilized in the design of non-point pollutant removal facilities. To identify the correlation between the pollutant run-off concentration and rainfall intensity or ADD, correlation analysis was performed using the data

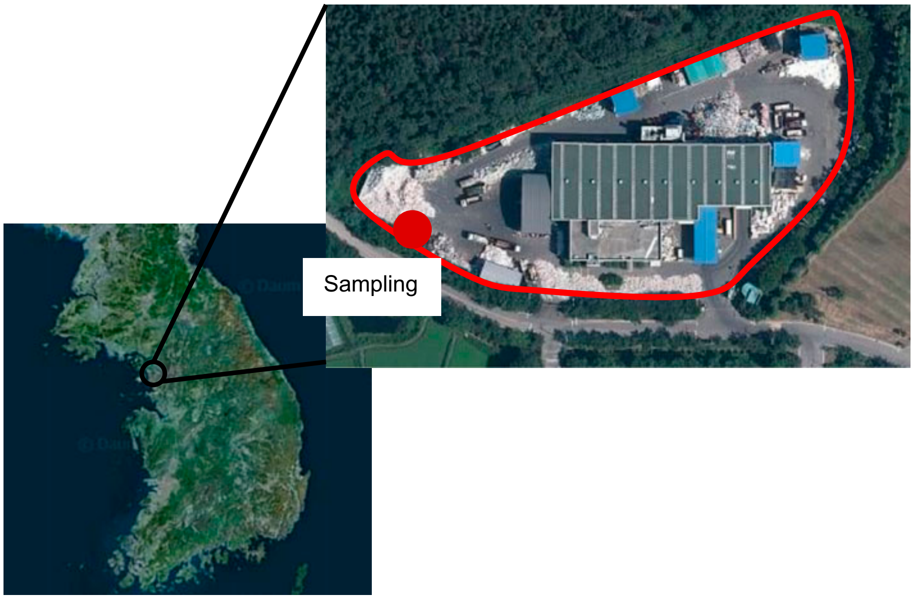

Fig. 1. Map of the study area.

obtained by monitoring the zone for recyclable materials separation.

3. Results and discussion

3.1. Analysis of rainfall

Fig. 2 shows the precipitation trend at the catchment area. The data for the monthly precipitation from 2001 to 2010 collected by a local weather center was used in this study. As shown in the precipitation trends over a decade, the rainfall reaches a maximum between July and August due to the rainy season in Korea. In contrast, the precipitation in winter is very light. As shown Table 1, the annual rainfall has increased consistently from 2007 to 2010, but the precipitation trend from 2001 to 2006 did not show a pattern. The maximum annual precipitation over a decade was 1777 mm in 2010, whereas the minimum annual precipitation was 1033 mm in 2002.

Table 2 lists the events including the total rainfall, rainfall duration, ADD, and average rainfall intensity. The event rainfall varied from 4.3 to 19 mm and ADD from 4 to 19 days. In addition, the average rainfall intensity ranged from 0.46 to 1.55 mm/h.

3.2. Organic matters

Fig. 3 shows the concentration trend of BOD and CODcr in stormwater run-off at each event. The BOD and COD concentrations showed a similar run-off trend. The first flash effect is a common phenomenon that is shown at the stormwater run-off. In the case of E-I and III, the run-off concentration of organic matter increased as rainfall intensity became strong in the latter stages of rainfall. In addition, the higher run-off concentration of organics with the strong rainfall intensity is due to the rainfall washing off the organic waste matters by passing through inside the loaded waste. The BOD concentrations ranged from 27.4 to 67.2 mg/L, and the CODcr concentrations ranged from 66.8 to 158.2 mg/L at E-I. In addition, the BOD and CODcr concentrations ranged from 40.8 to 68.5 mg/L and from 82 to 168.8 mg/L at E-II, respectively. At E-III, the BOD and CODcr concentrations ranged from 32.7 to 72 mg/L, and from 82.9 to 158 mg/L. The BOD concentration at E-I, II, and III ranged from 27.4 to 72 mg/L and showed a similar concentration range in each event. The CODcr concentration at E-I, II, and III ranged from 66.8 to 168.8 mg/L, which were slightly higher than BOD concentration.

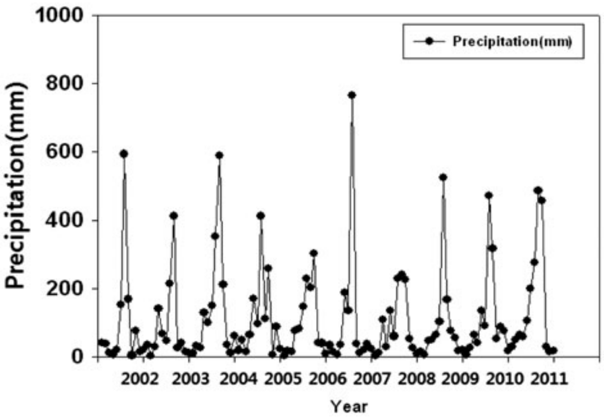

Fig. 2. Profiles of the monthly precipitation (2001–2010).

3.3. Particle material

The run-off trend of TSS, which is the particulate material at E-I, II, and III, was monitored. The first flash effect of TSS was observed clearly (see Fig. 4). In particular, the first run-off concentration of E-II was 690 mg/L. This appears to have a high correlation with the ADD. In general, the increase in ADD causes the accumulation of pollutants on an impermeability layer, and accumulated pollutants are washed off with the first run-off. Therefore, the first stormwater run-off with a long ADD was found to show a high EMC [21]. The TSS run-off concentrations at E-I, II, and III ranged from 30.1 to 240.5 mg/L, 73 to 690 mg/L, and 48 to 112.4 mg/L, respectively. The TSS of E-II showed a very wide concentration range than E-I or III. The rainfall intensity in the mid-to-late rainfall in E-I increased to more than 2 mm/hr, and the TSS run-off concentration also increased again similar to the first run-off. After the first flash effect ended at E-II and III, the pollutant concentrations in run-off were consistently low.

3.4. Nutrients

Fig. 5 shows the nutrients run-off concentration trend on each event. The TN concentrations range in the stormwater run-off at E-I ranged from 8.8 to 19.3 mg/L and the TP concentration ranged from 7.3 to 9.0 mg/L. The TN and TP concentrations at E-II ranged from 9.4 to 19.8 mg/L and 7.1 to 10.0 mg/L. In addition, the TN and TP concentrations at E-III ranged from 1.2 to 3.9 mg/L and from 5.2 to 8.8 mg/L, respectively. The mean TN run-off concentration at E-I was similar to E-II (E-I was 14.3 mg/L and E-II was 13.6 mg/L). On the other hand, the mean TN run-off concentration at E-III was 2.7 mg/L, which is a much lower concentration than that at E-I and II. Further

Table 1
Annual rainfall trend

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Precipitation (mm)	1,145	1,033	1,702	1,307	1,155	1,300	1,120	1,137	1,382	1,777

Table 2
Event table for monitoring

Date (dd/mm/yy)	Event	ADD (d)	Total rainfall (mm)	Rainfall duration (h)	Avg. rainfall intensity (mm/h)
02.10.2010	E-1	4	19	12.22	1.55
20.3.2011	E-Ⅱ	19	5.7	7.73	0.74
22.6.2011	E-Ⅲ	9	4.3	9.3	0.46

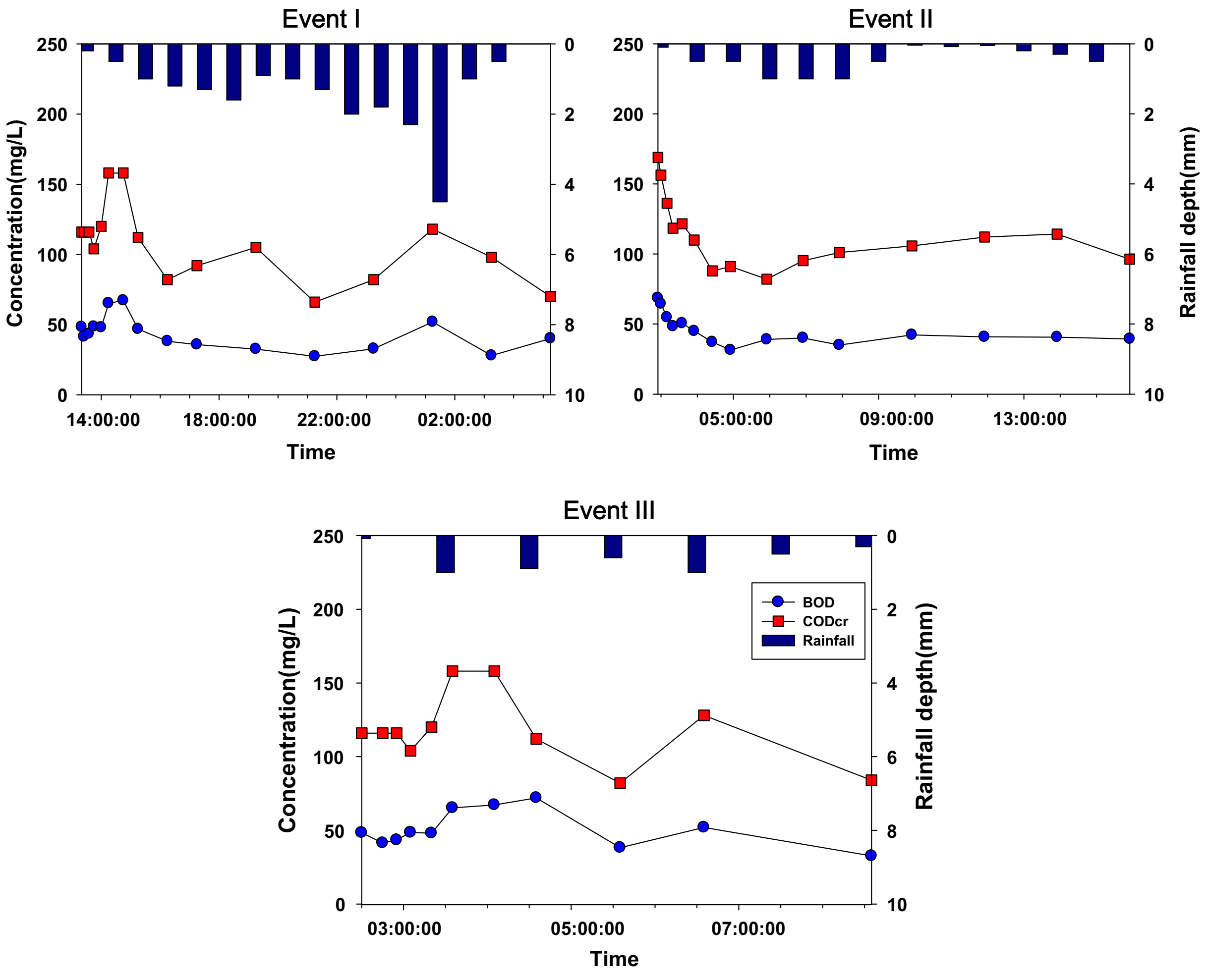

Fig. 3. BOD and COD concentrations.

research will be needed to explain the very low TN run-off concentration in E-III. The mean TP run-off concentration at E-I, II, and III showed similar run-off concentrations (7.7, 7.9, and 7/1 mg/L, respectively).

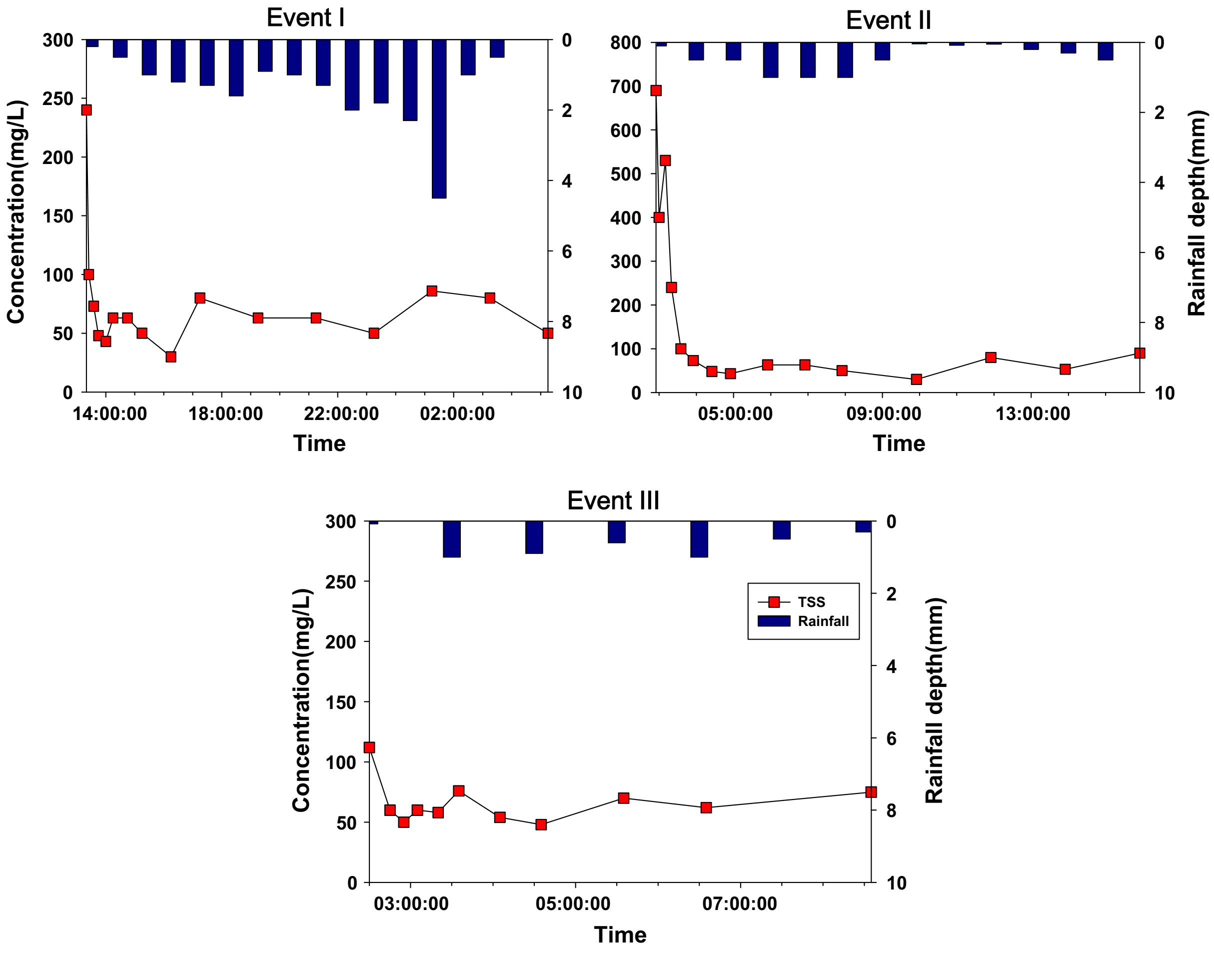

Fig. 4. TSS concentration.

3.5. EMC and the comparison with other land use types

Table 3 lists the EMC of the pollutants in each event. As a result, the average EMC of BOD and COD in the run-off ranged from 38.0 to 45.0 mg/L and 94.3 to 113.7 mg/L, respectively. In addition, the TSS, TN, and TP were in the range, 57.7–75.9, 2.6–14.5, and 7.2–7.5 mg/L, respectively. A large difference in the EMC values among the pollutants at E-I, II, and III is not observed, except for TN. The mean EMC of the pollutants at E-I, II, and III were as follows: 44.1 BOD mg/L, 106.7 COD mg/L, 66.5 TSS mg/L, 10.7 TN mg/L, and 7.4 TP mg/L.

A comparison of the gap between the EMC and mean concentration obtained using the formula to calculate the general average showed that a large gap could be generated in the overall water quality parameters from the organic matter to heavy metals [27,28]. Because of these gaps, a large error can be generated when calculating the volume of a non-point pollutants removal facility. To design the facilities to treat non-point pollutant designs, it is important to examine the EMC according to the land use types [29].

These results could not be compared with the concentration of run-off generated from other catchment areas because there are no reports of the run-off concentration of pollutants at a catchment area with a similar land use type. Therefore, the EMC of the pollutants in this study was compared with the stormwater run-off generated from urban areas including residential areas, commercial areas, loads, and parking lots [30]. The concentration of pollutants from the zone for recyclable material separation had higher concentrations than pollutant concentration in run-off from areas with other types of land use. The mean EMC range of the BOD in the run-off from other areas ranged from 5.3 to 12.3 mg/L, whereas the zone for recyclable materials separation was 44.1 mg/L. That is, the zone for recyclable material separation showed approximately three times higher concentrations than the other areas. The CODcr and TN concentrations in

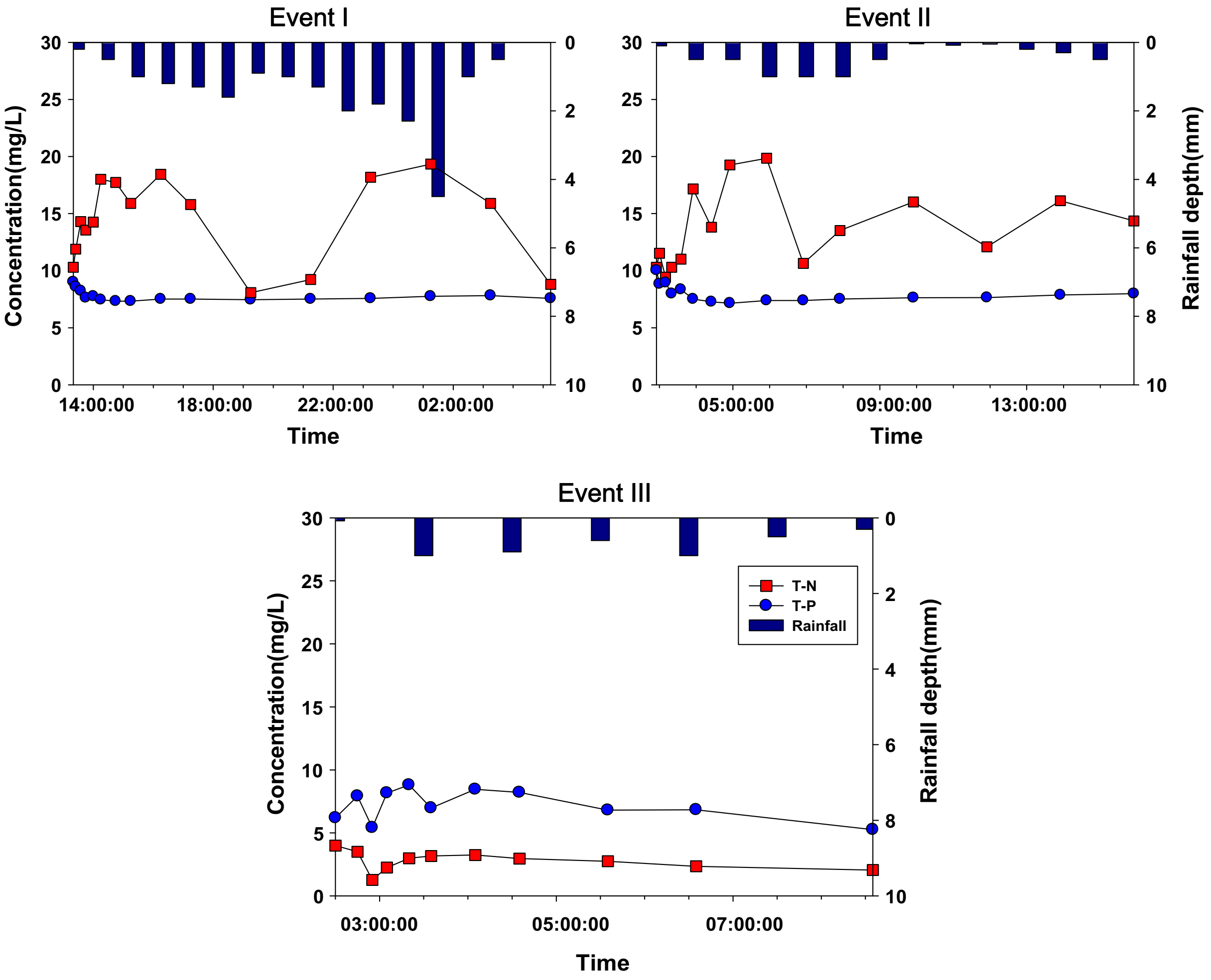

Fig. 5. TN and TP concentrations.

Table 3
EMC on each event (unit: mg/L)

Event	BOD	CODcr	TSS	TN	TP
I	38.0	94.3	57.8	15.2	7.5
II	43.8	112.0	66.1	2.6	7.2
III	45.0	113.7	75.9	14.5	7.6
Avg.	44.1	106.7	66.5	10.7	7.4

the run-off from other catchment areas ranged from 38.5 to 67.7 mg/L and 3.39 to 9.63 mg/L. In comparison, the CODcr and TN concentrations generated from the target area in this study showed higher concentrations (CODcr, 106.7 mg/L and TN, 10.7 mg/L). In the case of TP, the concentration gap between the target area of this study and other land use types was stronger than the BOD, COD, and TN concentrations. The reason for the high concentration of water quality parameters in the zone for recyclable material separation is likely to be due to organics and nutrients generated from a range of waste materials being discharged due to a run-off during rainfall event. On the other hand, the EMC of TSS in the zone for recyclable material separation, which showed similar values to the industrial complex, was lower than the EMC in roads, whereas it was higher than in residential and commercial districts and parking areas.

3.6. Correlation analysis

Correlation analysis was performed using SPSS (Ver.17.0) to verify the correlation between the pollutant run-off trend and ADD or rainfall intensity. Correlation analysis was conducted by analyzing the correlation coefficient and *p*-value at each water quality parameter and ADD or rainfall intensity. A p value < 0.01 was considered significant.

Table 4
EMC according to the land use type (unit: mg/L)

Land use type	BOD	CODcr	SS	TN	TP
A sorter for recyclable materials	44.1	106.7	67.0	10.3	7.3
Residential area	9.0	38.5	32.5	5.0	0.24
Commercial area	8.1	57.9	52.5	9.62	0.39
A manufacturing area	12.3	61.3	67.6	7.35	0.40
Load	12.1	67.7	126.6	7.56	0.48
Parking lot	5.3	48.0	22.7	3.39	0.09

Table 5
Correlation analysis of pollutants and rainfall intensity

Parameter	Correlation coefficients	BOD	CODcr	TSS	TN	TP	Rainfall intensity
BOD	Pearson's correlation coefficients	1	.865**	.401**	−.221	.373*	−.057
	p-value	–	.000	.009	.166	.016	.723
CODcr	Pearson's correlation coefficients	.865**	1	.487**	−.161	.392*	−.172
	p-value	.000	–	.001	.316	.011	.282
TSS	Pearson's correlation coefficients	.401**	.487**	1	−.065	.581**	−.225
	p-value	.009	.001	–	.685	.000	.158
TN	Pearson's correlation coefficients	−.221	−.161	−.065	1	.161	.235
	p-value	.166	.316	.685	–	.315	.139
TP	Pearson's correlation coefficients	.373*	.392*	.581**	.161	1	−.066
	p-value	.016	.011	.000	.315	–	.680
Rainfall intensity	Pearson's correlation coefficients	−.057	−.172	−.225	.235	−.066	1
	p-value	.723	.282	.158	.139	.680	–

According to the analysis, this study did not obtain reliable results for the correlation between the ADD and contaminants with only scant events. Correlation analysis of the rainfall intensity and pollutant effluent concentration showed no significant interrelationship**.** In contrast, BOD and CODcr among pollutants showed a strong ($r^2 = 0.8$) but the correlation coefficient between TSS and COD was weak ($r^2 = 0.4$).

4. Conclusions

1. (1) Rainfall in the 10 years from 2001 to 2010 showed a regular pattern, ranging from 1,033 to 1,777 mm.
2. (2) Stormwater run-off generated from the zone for recyclable materials separation showed the first flash effect. In particular, it was clearly observed on TSS concentration. The increase in ADD increased the TSS concentration discharged from the catchment area.
3. (3) In the three stormwater events, the pollutants' concentration ranged from 27.4 to 72 BOD mg/L, 66.8 to 168.8 CODcr mg/L, 30.1 to 690 TSS mg/L, 2.6 to 15.2 TN mg/L, and 7.2 to 7.5 TP mg/L, respectively. TSS had a high concentration compared to other parameters.
4. (4) The pollutant concentrations generated from the zone for recyclable materials separation were higher than those of the run-off from the residential areas, commercial areas, and parking areas. In particular, the result was clear with the TP concentration.

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