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ORIGINAL ARTICLE

Event Mean Concentrations (EMCs) and First Flush Characteristics of Runoff from a Public Park in Korea

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Abstract Characteristics of non-point source (NPS) pollution runoff from a public park in Gwangju, Korea were investigated. Results exhibited the highest pollutant concentrations at the start of the rainfall events due to their build-up and wash off processes. The average event mean concentrations (EMCs) were 27.8, 7.2, 56.3, 7.5, and 0.84 mg/L (range: 4.2-54.8 mg/L) for COD, (0.5-20.8 mg/L) for TOC, (22.3-138.4) for SS, (1.4-18.5 mg/L) for T-N, and (0.17-2.02 mg/L) for T-P, respectively. The study site presented a strong first flush effect for most rainfall events. However, no first flush effect was observed in rainfall events with small rainfall factors (e.g. intensity, amount, and runoff depth). On the other hand, the ratios of total pollution loads discharged by the first 20% of runoff volume were 32% for COD, 34% for TOC, 36% for SS, 42% for T-N, and 50% for T-P. Especially, MFF_{20} (mass first flush) values of T-N and T-P were larger than those of other pollutants (COD, TOC, SS), indicating that T-N and T-P are easily transported by stormwater runoff from the public park. First flush management of T-N and T-P, therefore, is required for efficient water quality management of the public park.

Keywords event mean concentration · first flush effect · non-point source · public park

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Introduction

Water quality management has been implemented on point sources such as domestic and industrial wastewater to protect streams and lakes in South Korea. In spite of such efforts, the water quality of streams and lakes has not been improved to a satisfactory level (Chung et al., 1987), which suggests that controlling point source discharge alone does not necessarily ensure the attainment of water quality standards (Kang et al., 2006), and water quality improvement may not be achieved without proper control of nonpoint source (NPS) pollution (Rhee et al., 2012). In the US and Europe, NPS pollution has remained a major challenge for river quality improvement after most of the point source pollutants are removed (Adams and Papa, 2000; Mohaupt et al., 2001; Bouwer, 2002). In particular, NPS such as urban stormwater discharge is a major contributor to the pollution of many receiving waters (Saget et al., 1996; Appel and Hudak, 2001; Brezonik and Stadelmann, 2002; Buffleben et al., 2002). Before any planning is done or any practical steps are taken to control the quality of NPS pollution runoff, it is necessary to first specify the characteristics of NPS pollution runoff (Tabei and Droste, 2004; Huang et al., 2007). To do so, intensive monitoring is necessary, because NPS pollutants are transported in a diffused manner; thus their sources cannot be readily identified (Yusop et al., 2005).

Several monitoring studies (Lee et al., 2002; Lee et al., 2004; Soller et al., 2005; Huang et al., 2007; Lee et al., 2011) have been conducted to characterize the NPS pollution runoff from various pollution source types (e.g. roof, highway, urban watershed, and different land-use type) during rainfall. Ballo et al. (2009) observed characteristics of NPS pollution runoff from four roof types - old concrete, new concrete, old clay, and new clay - in central Shanghai, China, during rain events. The authors reported that high levels of NO^{-}_{3} were observed in runoff from new and old concrete roofs. They and other researchers (Pazwash and Boswell, 1997) reported that the materials used for the roof played an important role in determining the water quality of roof runoff. Lee et al. (2011) investigated characteristics of the event mean concentration (EMC) of runoff during rainfall events on highways in Korea. The authors stated that the peak of the pollutant concentrations in runoff occurred 20 minutes after the first rainfall runoff. Also, many researchers have concluded that the first flush results in a substantial concentration peak at the beginning of storm events, indicating that NPS pollution runoff from urban watersheds is one of the leading causes of degradation in the quality of receiving waters, especially during the first flush (Lee et al., 2002). Thus, controlling the first flush is critical to reduction of urban stormwater pollution (Li et al., 2007). In recent years, studies on characteristics of NPS pollution runoff such as EMC, first flush effect from various types of land use (e.g. detached house, apartment, educational facility, power plant, and other public facilities) have been reported in Korea (Rhee et al., 2012). However, only few studies have been performed on NPS pollution runoff from the public park.

The objectives of the present study are to estimate the event mean concentrations (EMCs) through intensive monitoring and to analyze the first flush effect on pollutant export during rainfall events from a public park in Korea.

Materials and Methods

Site description. This study was performed at a public park in Gwangju, Korea, from 2009 to 2011. The public park with the area of 15,882.78 m^2 is located on the north side of Gwangju, with 36% of the study site paved, which means the site is impermeable, and 64% was grass/park (i.e. permeable layer). The municipal sewer network and rainwater drainage network are separated. Monitoring was conducted on rainwater drainage pipe outlets.

Data collection and sample analyses. Rainfall amounts and durations were obtained using rainfall gauges (Casella Rainfall System, UK). To measure the flow rate of the rainwater drainage conduit, an automated flow meter (Flo-Tote 3, USA) was installed at the outlet of the drainage network. Sampling was conducted at 15-min intervals in the first 120 min of a storm event and then at 60-min intervals for receding flow. The samples were stored in 2-L polyethylene bottles at the sites. They were placed in containers with ice bags and transported to the laboratory for chemical analyses. Concentrations of five constituents - chemical oxygen demand (COD), total nitrogen (T-N), total phosphorus (T-P), suspended solid (SS), and total organic carbon (TOC) - were analyzed according to American public health association methods (2001).

Event mean concentration (EMC) and the concept of first flush. Even though concentrations often vary depending on the varying measures of magnitude during a storm event, a single index known as EMC can be used to characterize runoff constituents (Novotny and Olem, 1994; and Sansalone and Buchberger, 1997). The EMC represents a flow-weighted average concentration computed as the total pollutant mass divided by the total runoff volume for an event of duration, *t* is described by the following equation: (Sanalone et al., 1997; Ballo et al., 2009).

$$\mathrm{EMC} = \frac{\mathrm{M}}{\mathrm{V}} = \frac{\int_0^t Q_t C_t dt}{\int_0^t Q_t dt} \quad (1)$$

where M is the total mass of pollutants over the entire event duration (g); V is the total volume of the flow rate over the entire event duration (m^3); *t* represents time (min); C_t is the pollutant concentration at time t (mg/L); and Q_t is the flow rate at time t (m^3/min). The EMC was computed for the entire runoff duration of each event.

A first flush is defined as the initial stormwater runoff when the concentrations of pollutants are substantially higher than those observed during the later stages of the storm event (Gupta and Saul, 1996). The first flush can be described by Equations (2) and (3) of dimensionless cumulative analysis. When dimensionless cumulative runoff is introduced in one or more storm events, the resultant curve usually presents information on the pollutant export characteristics during storm event (Lee and Bang, 2000).

$$\left[\frac{P_i}{\Sigma P_i}\right] \Big/ \left[\frac{Q_i}{\Sigma Q_i}\right] > 1 : \text{Flushing} \quad (2)$$

$$\left[\frac{P_i}{\Sigma P_i}\right] \Big/ \left[\frac{Q_i}{\Sigma Q_i}\right] < 1 : \text{No flushing} \quad (3)$$

where P_i represents pollutant load export at time i, Q_i represents runoff volume at time i. $\left[\frac{P_i}{\Sigma P_i}\right]$ is the dimensionless cumulative pollutant load ratio and $\left[\frac{Q_i}{\Sigma Q_i}\right]$ is the dimensionless cumulative runoff ratio. A first flush phenomenon occurs when the slope of the normalized cumulative mass emission plotted against normalized cumulative volume is greater than the bisector (Geiger, 1987; Park et al., 2010).

Mass first flush ratio. The magnitude of the first flush can be quantified for each storm and for each water quality parameter using a mass first flush (MFF) ratio (Han et al., 2006; Barco et al., 2008). Park et al. (2010) reported that the MFF can be suggested as a useful index for first flush intensity, because various storms and water quality data can be optimized as indicators by statistical analysis. It can be calculated by following Eq. (4) (Han et al., 2006; Barco et al., 2008).

$$MFF_n = \frac{\dfrac{\int_0^T c(t)q(t)dt}{M}}{\dfrac{\int q(t)dt}{V}} \quad (4)$$

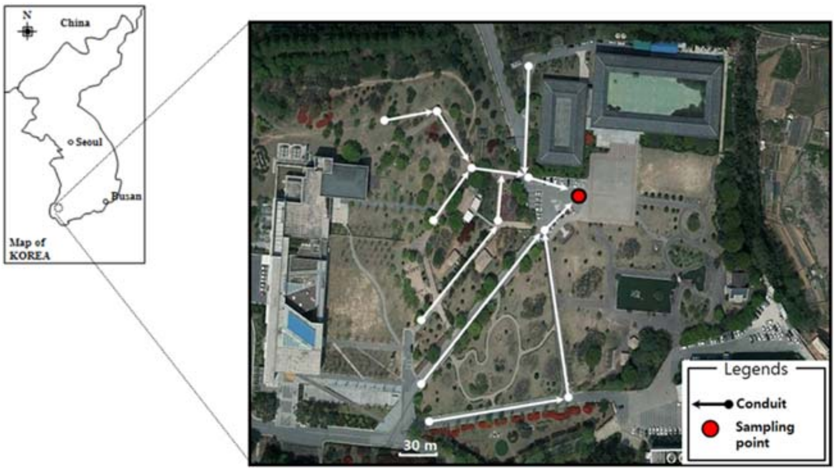

Fig. 1 Location of the study area and sampling site in the public park.

where n is the index or point in the storm, corresponding to the percentage of the runoff, ranging from 0 to 100%. M is the total mass of emitted pollutant, V is the total runoff volume, c(t), and q(t) are the pollutant concentration and runoff volume as function of time. When the value of MFF is equal to or greater than 1, the first flush occurs (Luo et al., 2009). For example, MFF_{20} equals to 2.5 indicates that 50% of the pollutant mass is contained in the first 20% of the runoff volume (Barco et al., 2008).

Results and Discussion

Characteristics of rainfall events from the study site. Total thirteen rainfall events were monitored over the period of 2009 to 2011 and the characteristics of each event are summarized in Table 1. The rainfall depth and average intensity in the study site varied from 5.0 to 191.0 mm and from 0.4 to 11.2 mm/h, respectively.

Concentrations of COD, TOC, SS, T-N, and T-P. The temporal changes in the COD, TOC, SS, T-N, and T-P concentrations and runoff water from the study site are shown in Fig. 2. Concentrations of COD, TOC, SS, T-N, and T-P in all rainfall events showed the highest values at the early stage of surface runoff and then gradually decreased. This phenomenon can be explained by both build-up and wash-off processes (Egodawatta et al., 2009). The descriptive statistics of water quality concentrations measured from the study site are summarized in Table 2. The ranges of concentrations are 2.4-132.2 for COD, 0.2-36.9 for TOC, 5.9-558.0 for SS, 0.7-58.5 mg/L for T-N, and 0.01-8.26 mg/L for T-P. The average concentrations of COD, TOC, SS, T-N, and T-P were 33.9, 9.2, 74.5, 10.6, and 0.71 mg/L, respectively. When the rainfall events occurred, natural organic matter such as soil humus, nitrogen and phosphorus applied in lawn fertilization, and SS caused by soil erosion, which were accumulated in pervious areas,

Table 1 Characteristic of rainfall events in the study site

Events	Date	Rainfall amount (mm)	Average rainfall intensity (mm/h)	ADP (Day)	Runoff depth (mm)	Runoff duration (h)
1	2009/3/22	12.5	4.5	7	4.1	2.8
2	2009/4/20	22.0	3.1	4	7.5	7.0
3	2009/4/24	6.0	3.4	3	1.9	1.8
4	2009/5/16	32.0	6.9	4	14.7	4.7
5	2009/7/28	8.0	0.7	2	2.0	4.7
6	2010/6/26	5.0	0.6	4	0.9	2.3
7	2010/7/11	191.0	11.2	3	143.7	15.8
8	2011/4/21	31.0	2.2	2	15.9	12
9	2011/4/25	14.0	1.0	2	4.5	12
10	2011/4/30	13.0	2.2	3	5.0	3
11	2011/6/10	8.5	0.4	12	2.0	7
12	2011/7/14	15.5	2.2	1	5.2	3
13	2011/11/5	32.5	6.5	1	20.2	4

ADP: Antecedent Dry Period (Day)

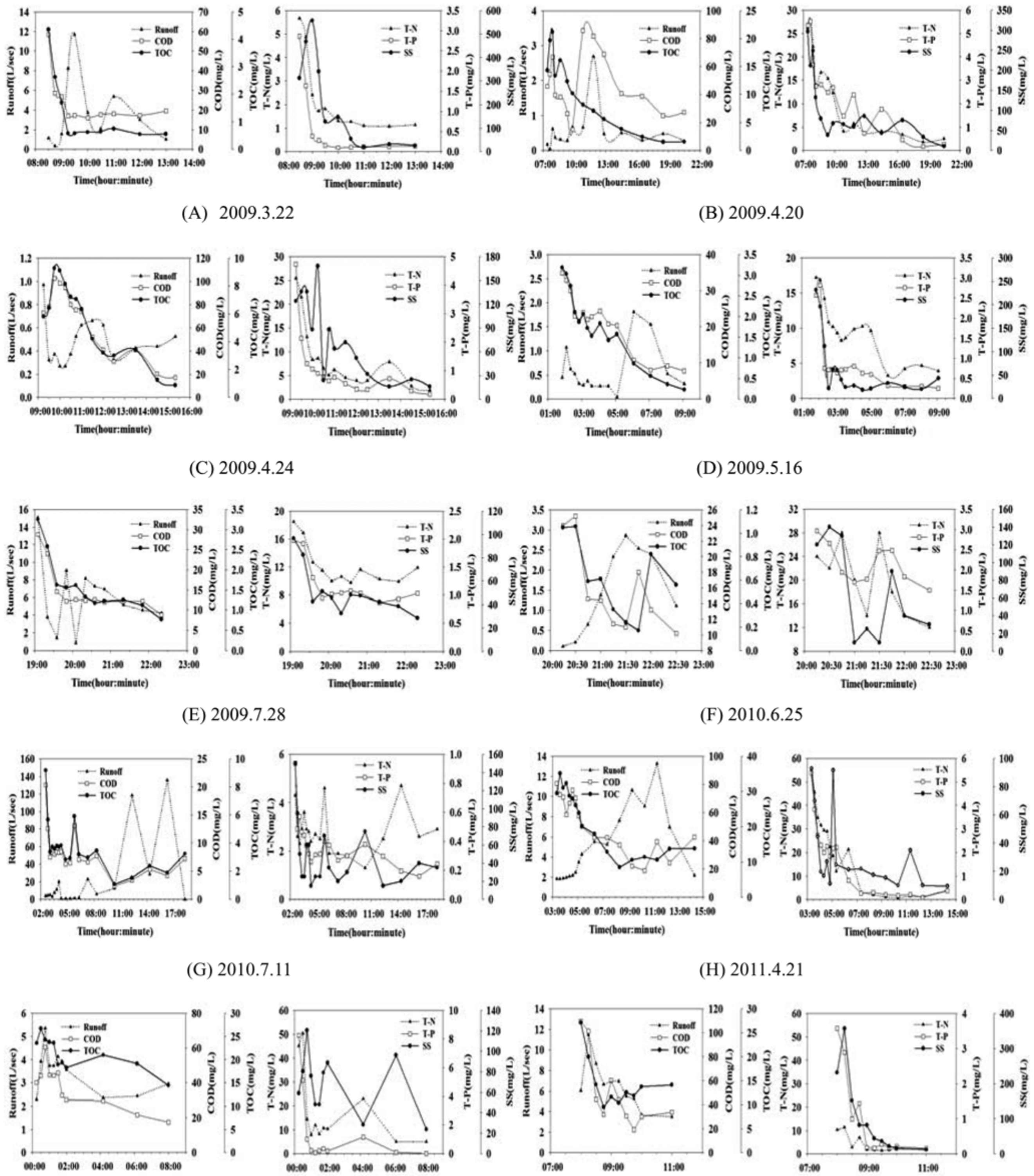

Fig. 2 Temporal changes in COD, TOC, SS, T-N, T-P, and runoff from the study site.

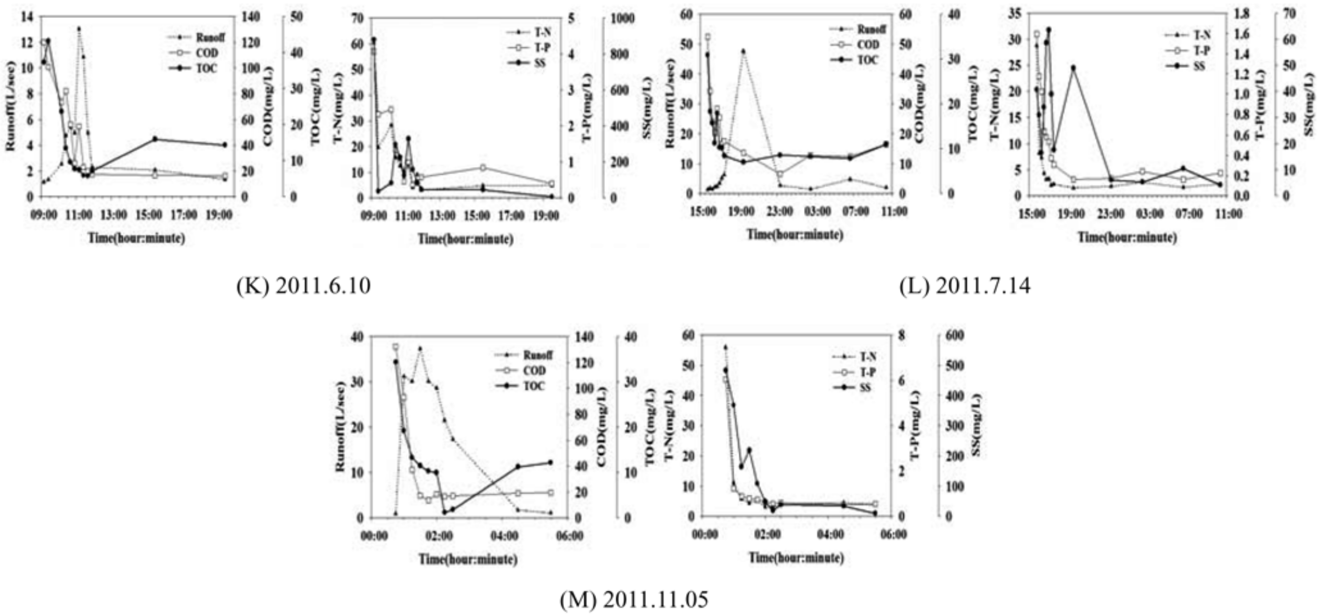

Fig. 2 Continued

would be discharged with the rainfall and runoff processes (Yoon et al., 2010). Runoff showed high concentration levels of COD, TOC, SS, T-N, and T-P. This indicates that runoff of organic matters, SS, nitrogen, and phosphorus is significantly high during rainfall events.

Table 2 Statistical summary of water quality concentrations measured for study site

	COD (mg/L)	TOC (mg/L)	SS (mg/L)	T-N (mg/L)	T-P (mg/L)
Minimum	2.4	0.2	5.9	0.7	0.01
Maximum	132.2	36.9	558.0	58.5	8.26
Median	24.4	5.8	42.0	7.1	0.71
Average	33.9	9.2	74.5	10.6	1.21
Standard deviation.	25.3	9.2	11.3	11.3	1.42

Table 3 EMCs in the study site

Events	Date	COD (mg/L)	TOC (mg/L)	SS (mg/L)	T-N (mg/L)	T-P (mg/L)
1	2009/3/22	17.9	0.7	109.5	1.4	0.17
2	2009/4/20	54.8	5.6	55.8	5.1	1.49
3	2009/4/24	42.2	3.4	43.6	4.7	0.51
4	2009/5/16	11.8	0.8	33.3	5.1	0.40
5	2009/7/28	12.1	1.2	41.8	11.0	1.02
6	2010/6/26	13.3	0.5	42.1	18.5	2.02
7	2010/7/11	4.2	1.9	22.3	2.7	0.24
8	2011/4/21	36.0	13.9	22.7	6.9	0.65
9	2011/4/25	34.7	20.8	64.4	17.8	1.22
10	2011/4/30	53.8	15.2	115.7	4.7	1.12
11	2011/6/10	47.8	15.8	22.3	13.2	1.29
12	2011/7/14	18	9.5	47.2	2.1	0.32
13	2011/11/5	31	10	138.4	5.9	0.83
Max		54.8	20.8	138.4	18.5	2.02
Min		4.2	0.5	22.3	1.4	0.17
Average		29.4	7.6	58.4	7.6	0.87

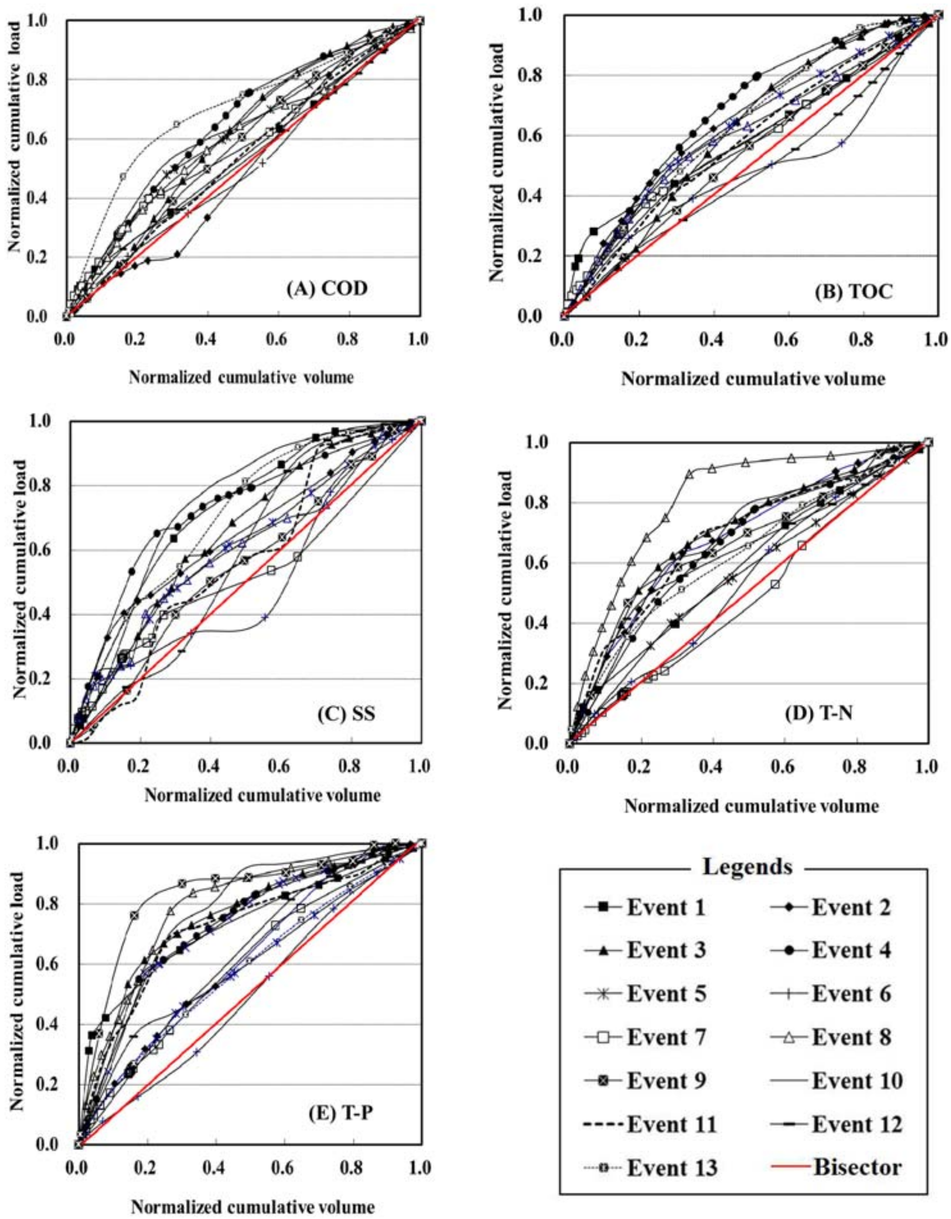

Fig. 3 Normalized cumulative curves for COD, TOC, SS, T-N, and T-P of thirteen rainfall events.

Event mean concentrations (EMCs) of COD, TOC, SS, T-N, and T-P. The calculated EMCs of COD, TOC, SS, T-N, and T-P from the study site are presented in Table 3. EMCs ranged from 4.2-54.8 for COD, 0.5-20.8 for TOC, 22.3-138.4 for SS, 1.4-18.5 for T-N, and 0.17-2.02 mg/L for T-P. The observed average EMCs of the public park were 29.4 for COD, 7.6 for TOC, 58.4 for SS, 7.6 for T-N, and 0.87 mg/L for T-P, respectively. The wide distributions of EMCs depend on the rainfall factors such as the amount, intensity, Antecedent Dry Period (ADP), and runoff depth (Kim et al., 2004). Usually, EMC decreases as the rainfall size increases due to the dilution effect (Yusop et al., 2005; Kim et al., 2007). The present study also showed that most EMCs decreased with increasing of rainfall size (Fig. 2). Especially, the biggest rainfall on 11 July 2010 observed the lowest COD, TOC, and SS. However, the smallest rainfall on 26 June 2010 demonstrated the highest T-N and T-P.

Lee et al. (2000) monitored storm runoff quality of four residential areas, four industrial areas, and an undeveloped area in Korea. The average EMCs were 163- 369 for COD, 73-1,021 for SS, 9.7-16 for T-N, and 7.7 -10.2 mg/L for T-P in residential area. The average EMCs were 118- 291 for COD, 99-221 for SS, 3.5-10.4 for T-N, and 1.2 -5.0 mg/L for T-P, industrial areas; The average EMCs were 50 for COD, 365 for SS, 7.4 for T-N and 5.5 mg/L for T-P, in undeveloped area. On the other hand, Kim et al.

Table 4 Average values of MFF*n*s in the public park

MFF_n	COD	TOC	SS	T-N	T-P
MFF10	1.6	1.8	2.0	2.3	2.9
MFF20	1.6	1.7	1.8	2.1	2.5
MFF30	1.4	1.4	1.7	1.7	1.9
MFF40	1.3	1.4	1.6	1.5	1.7
MFF50	1.2	1.2	1.3	1.4	1.5
MFF60	1.1	1.2	1.2	1.3	1.3
MFF70	1.1	1.1	1.2	1.2	1.2
MFF80	1.1	1.1	1.1	1.1	1.2
MFF90	1.0	1.0	1.1	1.1	1.1

(2007) monitored runoff quality of highway in Korea and found that average EMCs were 73.8 for COD, 85.6 for SS, 3.13 for T-N, and 0.42 mg/L for T-P. EMCs of COD and T-P for the public park were much lower than those of other land used. The results confirmed that EMCs would be affected by land use.

Analysis of the first flush effect. The first flush effect can be clearly identified by plotting the normalized cumulative runoff volume against normalized cumulative load (Lee and Bang, 2000). If the rate of pollution load is higher than that of storm runoff, the curves will be above the bisector. The difference between the curves and bisector is accounted for by the magnitude of the first flush (Park et al., 2010). The normalized cumulative load of water quality parameters as a function of the normalized cumulative runoff volume are presented in Fig. 3. The first flush effect was obvious - the slope of the mass emission line ascended above the bisector line - in most rainfall events except Event 6. It showed a weak first flush. Event 6 has relatively small rainfall factors including rainfall amount, rainfall intensity, and runoff depth, indicating that the first flush effect was greatly affected by rainfall factors (Table 1). Taebi and Droste (2004) reported that the first flush phenomenon is influenced by many factors such as rainfall intensity, rainfall amount, and runoff depth. Several researchers provided an explanation for these situations. Low rainfall intensity like Event 6 normally shows a weak first flush due to lack of time for the runoff flow to provide sufficient energy to wash out pollutants (Kang et al., 2006; Barco et al., 2008). In addition, because small rainfall events may not provide sufficient time to wash out the pollutants, a decline in concentrations can be observed near the end of the storm (Park et al., 2010). On the other hand, the patterns of the first flush for SS, T-N, and T-P showed a similar trend. Since the public park consists of 64% pervious area, soil erosion would occur and soil-attached phosphorous and nitrogen could be transported (Gaynor and Findlay, 1995).

First flush quantification using MFF ratios. The mean values of MFF*n* for all events and water quality parameters with *n* ranging from 10 to 90% are presented in Table 4. Results showed that the mean values of MFF*n* for all water quality parameters have the highest values of MFF_{10}, and thereafter decreased gradually. The mean values of MFF_{20} of COD, TOC, SS, T-N, and T-P are 1.6, 1.7, 1.8, 2.1 and 2.5 in the public park, indicating that 32% of COD load, 34% of TOC load, 36% of SS load, 42% of T-N load, and 50% of T-P load are discharged in the first 20% of the runoff volume, respectively.

Lee et al. (2002) investigated the first flush of urban storm runoff in Korea. They found that the magnitude of the first flush phenomenon was found to be greater for some pollutants (e.g. SS from residential area) and less for others (e.g. COD from industrial areas). The magnitudes of first flush of T-N and T-P were larger than COD, TOC, and SS in the present study.

Li et al. (2007) reported that 59% of COD load, 62% of SS load, 47% of T-N load, and 54% of T-P load were discharged in the first 30% of the runoff volume from 4.8 km^2 urban catchment China, where impervious ratio was 85%. However, 42% of COD load, 51% of SS load, 51% of T-N load, and 57% of T-P load were discharged in the first 30% of the runoff volume from the public park of our study. Based on these results, we provide principal information for the design and operation of a non-point source pollution treatment facility of the public park.

Lee et al. (2000) revealed that relative magnitude of the pollutant loading rate per unit area during storm event was in the following order: high density residential > low density residential > industrial > undeveloped watershed. Although the public park is considered as one of the urban land use, EMCs and first flush characteristics were different from those of other urban land use. Therefore, pollution abatement measures and criteria of public parks should be different from other urban land use. Further monitoring study on various public parks is recommended for better understanding of storm water management for the public park.

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