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Long-term monitoring and characterization of non-point source pollution from various land-use types in Korea

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ABSTRACT

This study investigated the long-term runoff characteristics of non-point source (NPS) pollutants from various land-use types through analysis of the event mean concentration (EMC) and peak concentration (PC), to determine management methods for different NPS pollutants by land-use type. For this study, NPS runoff long-term monitoring project data for the period of 2008–2016 were used, which were collected by the preliminary survey project on the environment at the Four Major Rivers Environment Research Centres. As a result of the EMC analysis by land-use type, biochemical oxygen demand (BOD) showed the highest values in commercial areas at 35.6 mg/L, suspended solids showed the highest values in other cultivated areas at 1,731.4 mg/L, and the highest total nitrogen and total phosphorous EMC were observed in fields at 11.68 and 4.79 mg/L, respectively. However, in the case of forests, the EMC of all pollutants analyzed were the lowest at BOD 1.2–1.5 mg/L, SS 8.5–22.5 mg/L, and TP 0.03–0.09 mg/L. The analysis showed that the land-use type and rainfall characteristics had significant effects on the results. Analysis using the PC concept, showed that >90% of high-concentration pollutants could be reduced by treating 20 mm of rainfall in urban areas and 50 mm of rainfall in other areas.

Keywords: Event mean concentration (EMC); Land-use; Long-term monitoring; Non-point source (NPS); Peak concentration (PC)

1. Introduction

Non-point sources (NPS) refer to cities, roads, farmland, mountain areas, and construction sites, where water pollutants are discharged but the source of the discharge is difficult to identify. Compared with point source (PS) pollutants that are discharged from specific points, NPS pollutants are difficult to monitor and control owing to their unspecified discharge points. The categories of NPS pollutants vary according to the land-use types. Various NPS pollutants accumulate at the ground surface; when it rains, they quickly flow into water bodies through rainfall runoff. This adversely affects the water quality of rivers and aquatic ecosystems by increased NPS pollutant discharge, urban flooding, and more frequent inundation [1–3].

Regarding domestic policies for controlling NPS pollution, the importance of NPS was recognized through the NPS monitoring project in 1995 and the monitoring project by unit load of NPS pollutants in 2002. The NPS institutionalization began by establishing comprehensive measures for controlling NPSs for 2004–2020. In 2012, the 2nd comprehensive measures for controlling NPS pollution were jointly formulated by eight government departments including the Ministry of Environment (MOE), and countermeasures were formulated for each sector, such as urban, rural, and mountain areas [4]. Assessing the current state of NPS should be the priority to efficiently control NPS, and to accomplish this, studies that focus on long-term monitoring of NPS pollution runoff are urgently required. Moreover, recent changes in rainfall characteristics have

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impacted NPS management by increasing the uncertainty, thereby prompting the need for long-term studies. Most of the earlier studies on the characteristics of rainfall runoff associated with NPSs presented the event mean concentration (EMC) by land-use as a representative index. Research has been conducted on various land-use types, such as urban, rural, mountains, and grasslands, to obtain the EMCs for each land-use type [5–10]. The EMC is a representative value of rainfall runoff; however, the water concentration that considers the rate of flow is not appropriate to reflect the characteristics of rainfall runoff over time. Therefore, some studies developed the dynamic EMC and modified EMC, which consider time and rainfall to understand the characteristics of rainfall runoff over time [11–13]. Other studies have introduced the peak concentration (PC), namely the highest concentration of a pollutant in rainfall runoff, using the maximum value as the standard concentration for NPS pollution management. These studies have been conducted by utilizing evaluation factors, such as the PC, accumulated rainfall to PC (P_{pc}), time to PC (T_{pc}), and EMC to PC [14,15]. Long-term research and analysis of rainfall runoff are necessary to understand the runoff characteristics of NPS with uncertainty. This study was conducted to understand the long-term runoff characteristics through the analysis of the EMC and PC and to develop NPS pollution management according to land-use type.

2. Materials and methods

2.1. Study sites

For this study, long-term NPS runoff monitoring data for 2008–2016 were used, which were collected by the preliminary survey project on environment at the Four Major Rivers Environment Research Center [16–23]. Fig. 1 shows the locations of the monitoring sites.

Land-use types were categorized according to the categories of the land cover map of the MOE. There were 128 monitoring sites that were classified as uplands (32), paddy fields (13), forest lands (7), building sites (59), and others (17). The uplands included fields, greenhouses, orchards, and other cultivated areas; paddy fields included rice fields; forest lands included deciduous forest, coniferous forest, and mixed forest; building sites included residential, industrial, commercial, transportation, public, and cultural areas; and others included natural grassland, artificial grassland, and other bare lands (Fig. 2). Building sites accounted for the highest proportion (46%) of the study sites.

2.2. Monitoring and analysis method

NPS runoff monitoring was conducted to measure and analyze the flow rate and water quality in accordance with the rainfall runoff survey method [24]. Some of the monitored water quality parameters included biochemical oxygen demand (BOD), suspended solids (SS), total nitrogen (TN), and total phosphorous (TP), and an analysis was conducted on the EMC and runoff coefficient. The contamination level due to rainfall runoff events could be estimated by calculating the EMC. The EMC for individual rainfall runoff events was calculated using the following Eq. (1), with the flow rate and water quality of the runoff water measured simultaneously.

$$\text{EMC}_x = \frac{\sum_{n=1}^{N}\left(Q_n \times \Delta t_n \times C_n\right)}{\sum_{n=1}^{N}\left(Q_n \times \Delta t_n\right)} \tag{1}$$

Here, EMC_x represents the EMC (mg/L) by rainfall runoff event (x), which is the ratio of the total pollutant volume to the total runoff volume; Q is the runoff volume (m^3/s); C is the concentration of a specific pollutant (mg/L); Δt is the measurement time interval, and N is the total number of measurements.

The runoff coefficient for an individual rainfall runoff event was calculated using the total rainfall volume of the rainfall event and the rainfall runoff water depth, using the following Eq. (2):

$$R_x = \frac{\text{Runoff depth}}{\text{Total rainfall volume}} = \frac{\sum_{n=1}^{N}\left(Q_n \times \Delta t_n\right)/A}{\sum_{m=1}^{M} P_m / 1{,}000} \tag{2}$$

Here, the runoff ratio (R_x) by rainfall event is the ratio of runoff depth (H) to total rainfall; Q is the runoff volume (m^3/s); P is the precipitation volume (mm); A is the water collection area (m^2); N is the total number of measurements of Q, and; M is the total number of measurements of P.

Fig. 3 illustrates the characteristics of rainfall and runoff and describes the terminology definitions.

Here, C is the concentration, Q is the flow rate, T is the time, P is the total rainfall, PC is the peak concentration, T_{pc} denotes the time until reaching the PC, and P_{pc} represents the rainfall during the T_{pc}.

3. Results and discussion

3.1. Monitoring results

Monitoring was conducted from March 8, 2008, to October 5, 2016. A total of 2,506 rainfall events were observed (Table 1). By land-use type, building sites were the most monitored, accounting for 40% of the total monitoring sites, followed by wet fields (28%), others (14%), dry fields (11%), and forest lands (8%). The frequency of monitoring for the four rainfall ranges varied from 18% to 34%. 34% of the total number of monitoring is carried out in the 10–30 mm rainfall range and accounts for the highest percentage. Monitoring was conducted in compliance with the appropriate amount of monitoring by rainfall range recommended by the National Institute of Environmental Research [24], therefore, the frequency of monitoring were considered as representative of each rainfall range.

Fig. 4 illustrates the cumulative probability distribution of rainfall and monitored rainfall events during the monitoring period. The cumulative rainfall frequency is presented using daily rainfall data from 63 synoptic weather stations nationwide. The monitoring was considered to have been conducted based on the following results. As

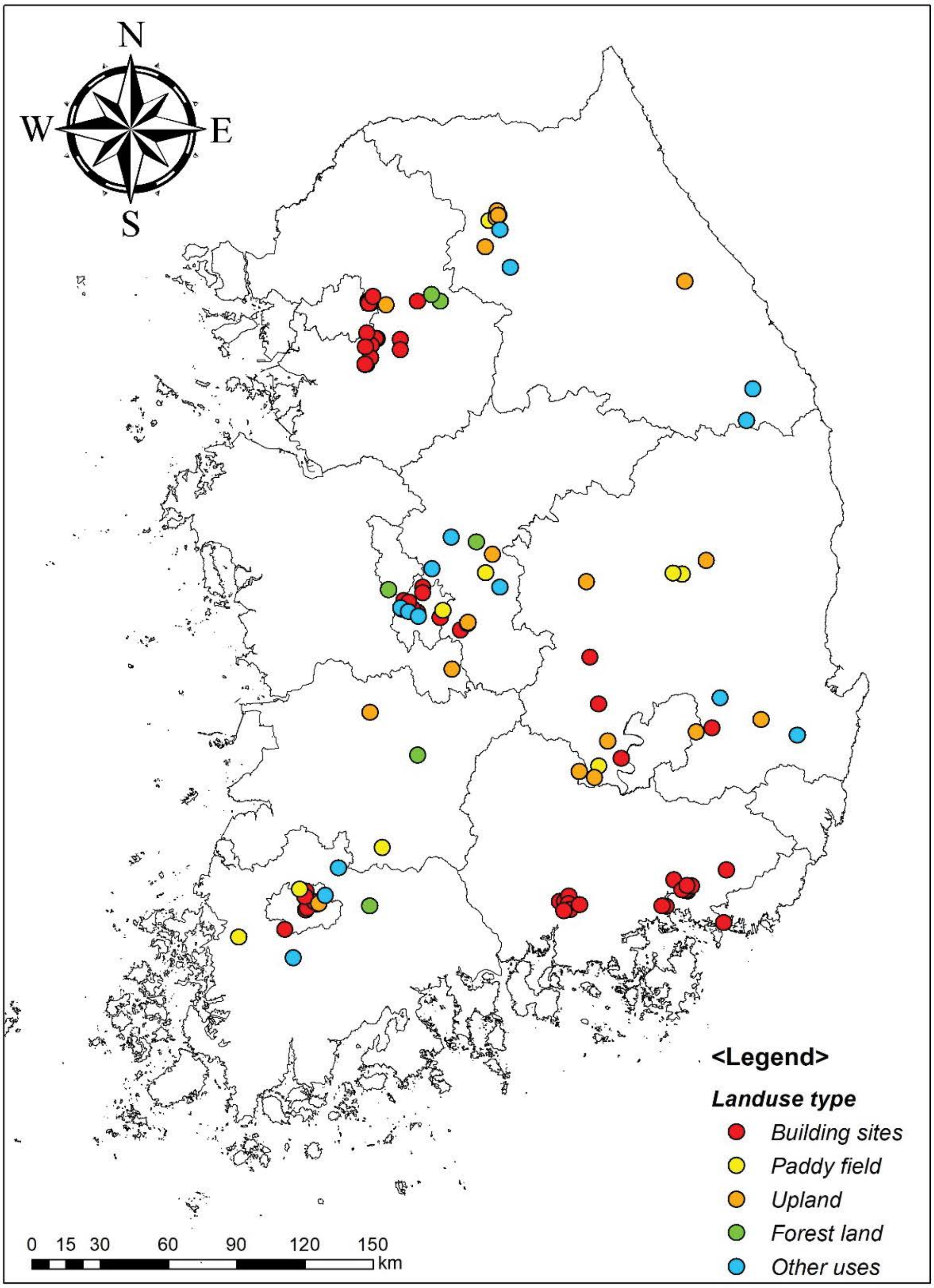

Fig. 1. Location of the monitored sites.

the amount of rainfall decreased, the probability distribution increased. Similar trends were found between actual rainfall data and monitored events. In addition, the *t*-test result showed a significant difference ($p < 0.001$), indicating that monitoring was performed considering various rainfall events during the period.

A summary of the monitored event data is presented in Table 2. It also includes antecedent dry days (ADD), total rainfall, runoff duration, and runoff coefficients. The area of the monitored watersheds ranged from 45 to 1,206,730 m^2. The monitoring duration varied according to land-use type, with a mean of 1.2–2.1 d. The mean ADD was 3.9–7.0 d, total rainfall was 20.0–74.1 mm, and the rainfall duration was 8.4–20.9 h. The climate in Korea is Asian Monsoon, which means that most rainfall is concentrated during the summer months from June to

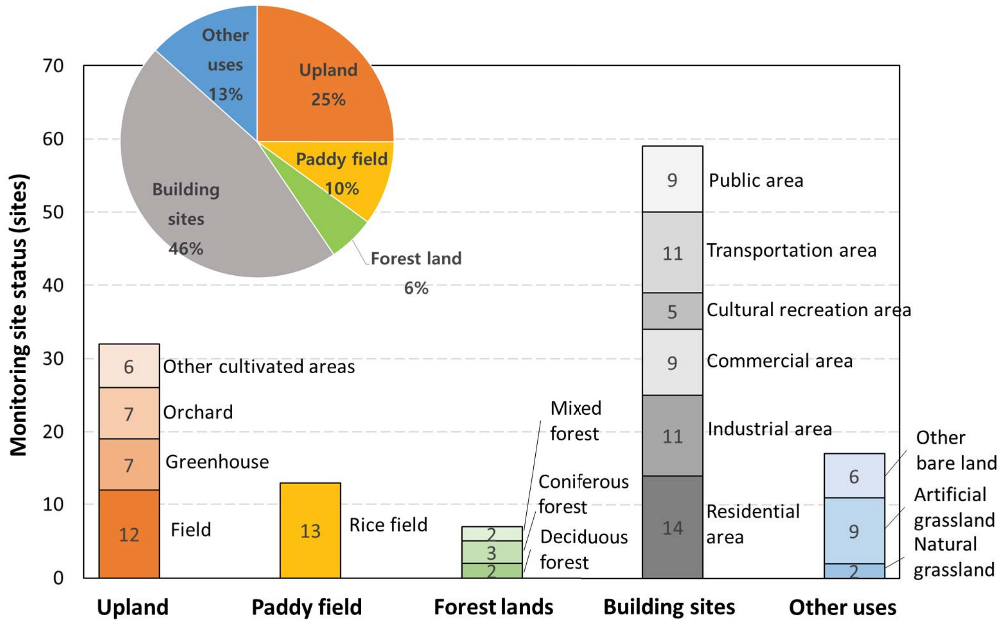

Fig. 2. Status of the monitored sites.

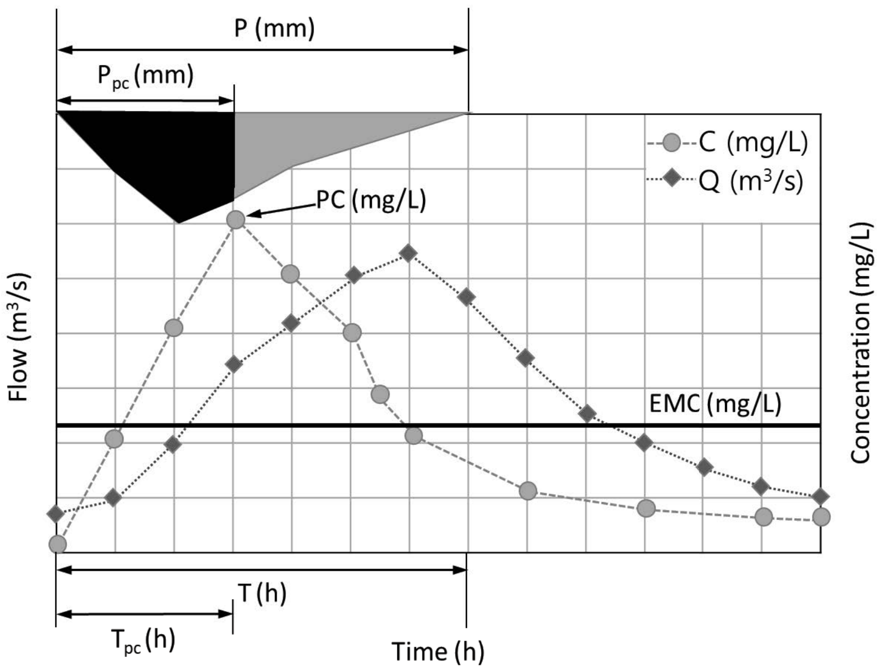

Fig. 3. Rainfall and runoff characteristics and terminology definitions.

September [25]. Due to the domestic climate characteristics, it was most often performed runoff monitoring in July, which accounts for 25% of the total monitoring events, and within 10% of the total monitoring events were performed from April to September. During the monitoring period, the highest total rainfall (536 mm) and the longest rainfall duration (151.8 h) occurred in July 2011. However, the longest ADD (10 d) occurred in October 2012.

Runoff coefficient is an important factor affecting the total runoff of NPS pollutants during rainfall and is greatly influenced by rainfall, rainfall intensity, and number of ADD, rainfall duration, and the characteristics and area of the watershed. As for the runoff coefficient by land-use type, the commercial area of building sites had the highest value with a mean runoff coefficient of 0.612. The runoff coefficient of greenhouse was 0.326, which was higher than

Table 1
Frequency of monitoring according to rainfall range

Land-use type		Rainfall range				Total
		Under 10 mm	10–30 mm	30–50 mm	Above 50 mm	
Building sites	Residential area	74	81	57	53	265
	Commercial area	33	46	22	18	119
	Cultural area	28	36	19	18	101
	Transportation area	42	64	24	23	153
	Industrial area	50	61	22	15	148
	Public area	65	68	36	37	206
Paddy fields	Rice field	83	88	42	56	269
Uplands	Field	60	85	47	115	307
	Greenhouse	40	44	17	17	118
	Orchard	50	54	27	23	154
	Other cultivated area	43	41	15	17	116
Forest lands	Coniferous forest	3	25	14	18	60
	Deciduous forest	13	25	14	14	66
	Mixed forest	5	22	14	21	62
Others	Artificial grassland	57	75	44	38	214
	Natural grassland	1	10	2	1	14
	Other bare land	17	34	28	55	134
Total		664	859	444	539	2,506
Ratio (%)		26	34	18	22	100

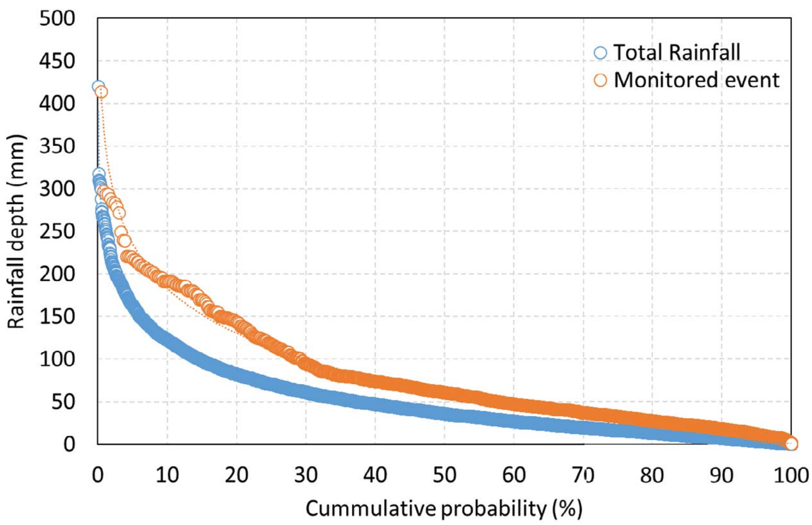

Fig. 4. Cumulative probability distribution of rainfall during the monitoring period.

that of other cultivated land-use types. Meanwhile, the runoff coefficient of other cultivated land was 0.036, which was the lowest among all land-use types. The runoff coefficient is closely related to direct runoff and is affected by land-use. The lower runoff coefficient reflects infiltration and evaporation during the rainfall event, which are more significant in smaller rainfall events. ADD are also known to affect runoff coefficients [26]. According to the sewerage system standard in Korea [27], the runoff coefficient of the urbanization area is 0.60~0.75, other areas are 0.10~0.40.

3.2. EMC and peak concentration

To understand the characteristics of rainfall runoff by land-use type during rainfall, we analyzed the EMC and PC. As the simple calculation of the arithmetic mean concentration may result in a large difference in the actual concentration, the calculation of rainfall runoff concentration should be conducted as the EMC factoring in the flow rate to accurately calculate the load. In other words, the EMC was determined using the total amount of pollutants released

Table 2
Monitoring results according to land-use type (mean ± S.D.)

Land-use type		Catchment area (m^2)	ADDs (d)	Runoff duration (d)	Total rainfall (mm)	Rainfall duration (h)	Runoff coefficient
Building sites	Residential area	2,870–125,038	6.6 ± 5.0	1.9 ± 1.2	42.4 ± 66.9	17.4 ± 23.3	0.472 ± 0.251
	Commercial area	1,800–134,449	6.4 ± 5.9	1.2 ± 0.6	33.9 ± 45.1	10.8 ± 8.7	0.612 ± 0.222
	Cultural area	7,304–34,116	4.7 ± 4.2	1.4 ± 0.6	31.7 ± 36.2	13.1 ± 9.3	0.270 ± 0.211
	Transportation area	45–12,400	6.7 ± 5.7	1.2 ± 0.5	28.3 ± 27.2	9.7 ± 6.8	0.485 ± 0.268
	Industrial area	1,507–1,206,730	6.3 ± 5.9	1.3 ± 0.6	24.9 ± 28.1	8.4 ± 7.4	0.494 ± 0.330
	Public area	1,503–88,124	6.2 ± 5.5	1.7 ± 0.9	36.5 ± 54.6	14.3 ± 16.4	0.282 ± 0.231
Paddy fields	Rice field	874–136,900	5.0 ± 5.0	1.8 ± 1.0	31.0 ± 33.2	18 ± 13.3	0.186 ± 0.283
Uplands	Field	235–18,038	3.9 ± 4.1	1.7 ± 0.8	51.7 ± 59.9	19.3 ± 15.2	0.141 ± 0.198
	Greenhouse	639–20,774	5.8 ± 3.7	1.6 ± 0.6	29.0 ± 38.3	13.4 ± 8.4	0.326 ± 0.309
	Orchard	864–4,299	4.2 ± 4.2	1.9 ± 0.4	28.2 ± 29.7	13.6 ± 8.5	0.115 ± 0.183
	Other cultivated area	631–1,841	4.2 ± 4.2	1.5 ± 0.7	24.9 ± 29.3	14.4 ± 12.8	0.036 ± 0.124
Forest lands	Coniferous forest	10,735–354,000	5.5 ± 8.3	2.1 ± 1.5	44.6 ± 37.8	13.2 ± 12.1	0.310 ± 0.283
	Deciduous forest	169,900–183,000	6.1 ± 6.5	2.1 ± 1.5	37.9 ± 38.4	12 ± 10.2	0.210 ± 0.264
	Mixed forest	142,600–177,000	4.1 ± 5.0	2.0 ± 1.3	74.1 ± 138.8	11.5 ± 8.1	0.279 ± 0.265
Others	Artificial grassland	80–327,160	7.0 ± 12.7	1.4 ± 0.7	29.3 ± 26.1	13.9 ± 10	0.200 ± 0.263
	Natural grassland	355–1,543	5.5 ± 3.9	1.6 ± 0.5	20.2 ± 13.9	13.5 ± 10	0.100 ± 0.145
	Other bare land	2,800–460,000	4.5 ± 4.5	1.8 ± 0.7	55.7 ± 54.8	20.9 ± 13.3	0.276 ± 0.274

from the watershed and the total volume of rainfall runoff during the rainfall period.

Table 3 shows the results of the EMC and PC statistical analysis by land-use type. According to the results, the EMC of BOD was the highest in commercial areas at 35.6 mg/L, SS EMC showed the highest values in other cultivated areas at 1,731.4 mg/L, and the highest TN and TP EMC were observed in fields at 11.68 and 4.79 mg/L, respectively. However, in the case of forests, the EMC of all pollutants analyzed were the lowest at BOD 1.2~1.5 mg/L, SS 8.5~22.5 mg/L, and TP 0.03~0.09 mg/L. The results of EMC analysis in NPS studies can be regarded as important data that can represent representative rainfall runoff concentrations for various land-use types.

To determine the maximum concentration of each pollutant released during rainfall, also, PCs by each land-use type and pollutant were investigated. The BOD ranged from 1.9 to 141.3 mg/L, SS ranged from 37.2 to 4,093.9 mg/L, TN ranged from 2.06 to 17.76 mg/L, and TP ranged from 0.08 to 7.27 mg/L. BOD and TN showed the highest concentrations in commercial areas and SS and TP showed the highest concentrations in other cultivated areas and fields.

The comparison of EMC and PC by land-use type and pollutant showed differences among pollutants. The largest difference between EMC and PC for land-use type ranked building site (3.2 times) > forest lands (2.4 times) > others (2.3 times) > uplands (1.9 times) > paddy fields (1.7 times). The largest difference between EMC and PC for pollutants ranked SS (3.5 times) > TP (2.4 times) > BOD (2.2 times) > TN (1.9 times). This is because the building sites observed the first flush phenomenon during the initial rainfall, while other sites, as rainfall increases, high concentrations of pollutants are discharged due to soil loss. Based on the results, it is shown that the characteristics of land-use and rainfall have a close effect on EMC and PC.

3.3. Analysis of runoff characteristics by land-use type using peak concentration

To derive the rainfall factor for the optimal design of best management practices (BMPs) and low impact development (LID) techniques according to land-use type, this study conducted an analysis using factors, such as rainfall duration (T), time to PC (T_{pc}), the total rainfall (P), and accumulated rainfall to PC (P_{pc}) and summarized in Fig. 5.

The time to PC (T_{pc}) compared to the total rainfall period (T) shown in the Fig. 5a. The uplands and other land-use types observed T_{pc} was 44% of the total rainfall duration. However, building sites T_{pc} was 20% of the total rainfall duration. Especially, in commercial, residential, and traffic areas T_{pc} was 13.4%–28.9% of the total rainfall duration, thereby indicating the importance of initial rainfall management in NPS pollution control in the building sites.

Fig. 5b shows accumulated rainfall to PC (P_{pc}) compared to total rainfall (P). For building sites, P_{pc} occurred at 20%–39% of the total rainfall. On the other hand, for other land-use types, P_{pc} occurred at approximately 50% of the total rainfall. As in the previous analysis of T_{pc}/T, management in the initial stage of rainfall is required to control NPS pollution in building sites. For other land-use types, management in the middle stage of rainfall and beyond is required.

Therefore, the appropriate NPS control timing by land-use was derived using factors such as P, T, and PC. If these results are utilized for forecasting NPS runoff and designing BMPs and LID techniques, cost-effective facilities can be designed.

3.4. Establishing appropriate monitoring methods for NPS pollution control

Fig. 6 shows the rainfall event ratio by land-use and P_{pc} of each pollutant. It shows the rainfall event ratios compared

Table 3
Event mean concentration (EMC) and peak concentration (PC) by land-use type (mean ± S.D.)

Land-use type		EMC (mg/L)				PC (mg/L)			
		BOD	SS	TN	TP	BOD	SS	TN	TP
Building sites	Residential area	5.6 ± 4.9	34.8 ± 41.5	4.42 ± 3.23	0.27 ± 0.26	15.8 ± 14.9	125.9 ± 169.4	9.99 ± 7.71	0.75 ± 0.82
	Commercial area	35.6 ± 64.3	51.0 ± 64.9	5.73 ± 4.53	0.62 ± 0.74	141.3 ± 238.8	246.6 ± 374.9	17.76 ± 21.52	2.04 ± 1.80
	Cultural area	12.1 ± 16.6	73.2 ± 78.9	4.35 ± 5.40	0.50 ± 0.60	39.7 ± 56.0	236.5 ± 232.1	13.31 ± 17.26	1.87 ± 2.35
	Transportation area	8.2 ± 10.9	31.1 ± 38.8	3.77 ± 4.13	0.24 ± 0.26	24.0 ± 37.5	96.6 ± 152.9	8.92 ± 12.58	0.64 ± 0.99
	Industrial area	14.5 ± 32.5	27.6 ± 35.6	3.33 ± 3.80	0.39 ± 0.52	46.2 ± 78.6	106.6 ± 132.5	11.65 ± 13.29	1.62 ± 2.65
	Public area	7.8 ± 10.6	88.4 ± 119.3	5.00 ± 5.42	0.33 ± 0.46	20.3 ± 30.1	322.2 ± 541.4	10.32 ± 9.46	0.88 ± 1.10
Paddy fields	Rice field	5.8 ± 9.6	71.5 ± 99.7	3.64 ± 9.93	0.40 ± 0.59	7.6 ± 5.4	182.8 ± 254.5	4.52 ± 3.72	0.74 ± 0.64
Uplands	Field	16.6 ± 25.0	1,519 ± 2,121.8	11.68 ± 11.38	4.79 ± 6.16	31.4 ± 66.8	3,125.4 ± 4,676.1	17.17 ± 16.99	7.27 ± 8.64
	Greenhouse	7.9 ± 8.3	214.4 ± 276.2	3.97 ± 3.15	1.79 ± 1.95	13.3 ± 10.5	633.5 ± 797.1	5.96 ± 4.53	3.40 ± 3.90
	Orchard	3.5 ± 2.4	115.5 ± 175.0	7.29 ± 7.59	0.77 ± 0.78	5.4 ± 3.8	428.9 ± 711.5	8.14 ± 8.11	1.03 ± 1.00
	Other cultivated area	5.2 ± 3.4	1,731.4 ± 2,998.3	6.83 ± 6.52	1.79 ± 1.95	9.1 ± 6.8	4,093.9 ± 8,048.5	11.13 ± 10.97	3.55 ± 3.69
Forest lands	Coniferous forest	1.2 ± 0.7	8.5 ± 18.8	2.16 ± 1.63	0.03 ± 0.04	1.9 ± 1.2	37.2 ± 77.6	2.92 ± 1.66	0.08 ± 0.11
	Deciduous forest	1.5 ± 1.0	22.5 ± 43.2	2.75 ± 2.31	0.09 ± 0.15	2.3 ± 1.7	57.8 ± 106.5	3.88 ± 5.03	0.28 ± 0.99
	Mixed forest	1.5 ± 0.8	12.5 ± 17.8	1.51 ± 0.81	0.04 ± 0.06	2.9 ± 1.8	59.4 ± 206.9	2.06 ± 1.21	0.08 ± 0.10
Others	Artificial grassland	4.4 ± 2.8	29.0 ± 48.2	5.07 ± 8.14	0.61 ± 0.80	6.8 ± 6.4	148.2 ± 460.7	8.73 ± 15.12	0.92 ± 1.02
	Natural grassland	4.4 ± 1.7	51.9 ± 36.6	1.39 ± 0.29	0.99 ± 0.48	6.2 ± 1.3	231.9 ± 136.0	3.37 ± 2.37	1.50 ± 0.65
	Other bare land	8.8 ± 10.8	404.8 ± 952.3	3.93 ± 4.44	0.37 ± 0.40	17.7 ± 26.7	1,022.9 ± 1,797.9	5.57 ± 5.74	0.75 ± 1.03

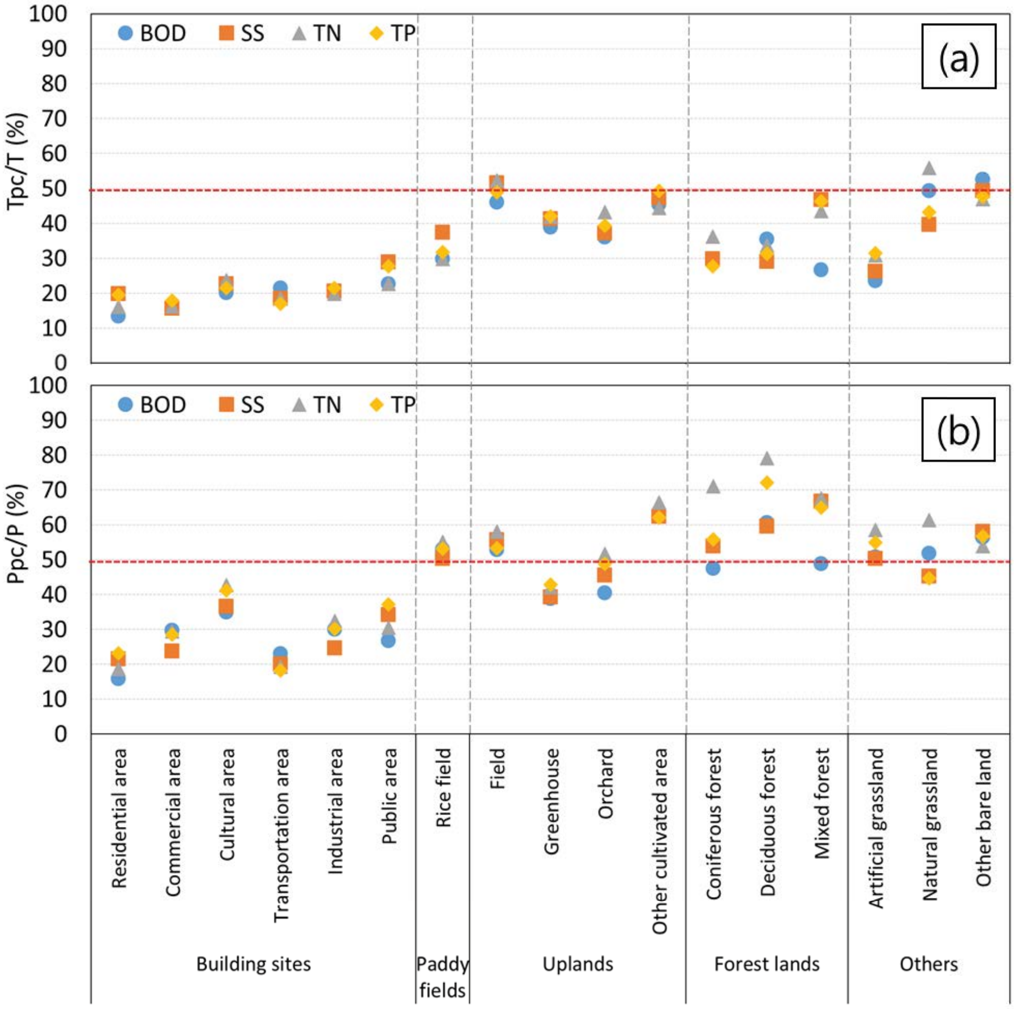

Fig. 5. (a) Time to PC (T_{pc}) compared to the total rainfall duration (T) and (b) accumulated rainfall to PC (P_{pc}) compared to total rainfall (P).

to the cumulative rainfall and the occurrence of high pollutant concentrations. For building sites, 90% of the total rainfall events tended to PC at the cumulative rainfall of approximately 20 mm. On the other hand, for uplands, paddy fields, and other areas, 90% of the total rainfall events tended to occur with a rainfall of 50 mm or greater. Therefore, this analysis could be used to select suitable pollutants by land-use type, and could be helpful to determine for the optimal design rainfall of BMPs and LID techniques.

Using the rainfall runoff data by land-use type, this study performed a basic statistical analysis of the rainfall runoff characteristics. Based on the analysis of the relationship between the factors related to rainfall runoff, determined the pollutants to control and the timing of control and draw design rainfall by land-use type, which could be used to effectively manage NPS pollution.

4. Conclusions and recommendations

Analysis of the long-term runoff characteristics of NPS pollutants in various land-use types revealed that the runoff coefficient were >0.5 in commercial and industrial areas, which are urban areas with relatively high impervious area. The EMC and PC of most water quality parameters, BOD showed the highest values in commercial area. Such as TN, TP, and SS, showed the highest values in fields or other cultivated areas (agricultural areas). The results of the analysis of cumulative rainfall ratio until reaching the PC compared to the total rainfall (using the concept of P_{pc}) showed that agricultural areas (such as uplands and paddy fields) had high levels of P_{pc}/P around 50%; however, urban areas showed relatively low levels of P_{pc}/P approximately 20%. In other words, initial rainfall management is important to minimize the influence of NPS pollution runoff in urban areas. In the future, urban water circulation improvement strategies and LID techniques can be proposed through the analysis of rainfall runoff data collected over a long period.

For building sites were a high runoff coefficient and as direct runoff occurred even with a small amount of rainfall. This characteristic led to the runoff of high concentrations of pollutants from the runoff in the early stage of rainfall. BMPs and LID techniques is required in order to

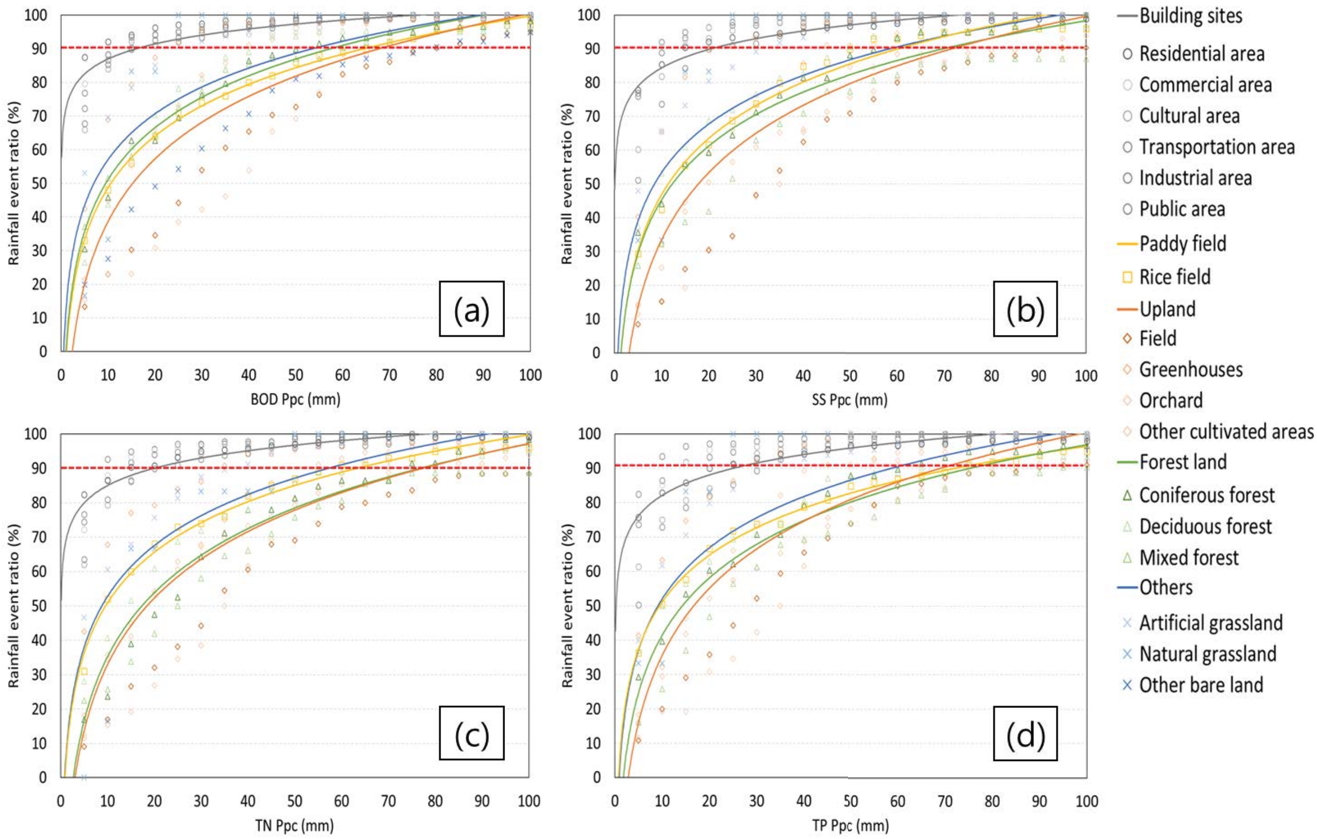

Fig. 6. Rainfall event ratio by land-use type and P_{pc} of pollutant (a) BOD, (b) SS, (c) TN, and (d) TP.

reduce direct runoff by measures such as the control of the impervious surface area. When BMPs and LID techniques are designed, the recommended design rainfall should be at least 20 mm.

For other than building sites, such as uplands, paddy fields, forest lands, and other land-use, when there was more rainfall, more runoff of high concentration NPS pollutants occurred. In this case, BMP for Soil loss should be reorganized (e.g., vegetation zones, diversion ditches, field bank protections, and retention basin), and design rainfall of 50 mm or greater is required. It may be necessary to continuously update design factors by analyzing various long-term NPS monitoring data in the future.

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References

[1] L.H. Kim, J.H. Kang, Determination of Event Mean Concentrations and Pollutant Loadings in Highway Storm Runoff, J. Korean Soc. Water Environ., 20 (2004) 631–340.

[2] H.G. Kwon, J.W. Lee, Y.J. Yi, Y.S. Yoon, C.S. Lee, J.K. Lee, The applicability for estimating MFFn by SWMM in the trunk road, J. Korean Soc. Water Environ., 27 (2011) 605–616.

[3] C.M. Kim, J.Y. Choi, J.M. Lee, H.J. Cho, L.H. Kim, Characteristics of stormwater runoff with respect to pavement types, J. Wetlands Res., 16 (2014) 423–429.

[4] J.H. Ahn, S.L. Yun, S.K. Kim, Runoff characteristics of non-point source according to cultivation activity in river district, J. Korean Soc. Environ. Eng., 34 (2012) 480–487.

[5] D.H. Jeong, D. Shin, D. Rhew, D. Jung, Stormwater runoff characteristics of non-point source pollutants according to landuse of urban area, J. Environ. Impact Assess., 16 (2007) 525–532.

[6] H.S. Lee, S.H. Lee, Runoff characteristics of stormwater in small city urban area, J. Korean Soc. Environ. Eng., 31 (2009) 193–202.

[7] J.Y. Choi, S.Y. Lee, L.H. Kim, Wash-off characteristics of NPS pollutants from forest landuse, J. Korean Soc. Hazard. Mitigation, 9 (2009) 129–134.

[8] L.H. Kim, H.M. Kang, W. Bae, Treatment of particulates and metals from highway stormwater runoff using zeolite filtration, Desal. Water Treat., 19 (2010) 97–104.

[9] S.M. Cha, S.W. Lee, L.H. Kim, K.S. Min, S.Y. Lee, J.H. Kim, Investigation of stormwater runoff strength in an agricultural area, Korea, Desal. Water Treat., 38 (2012) 360–365.

[10] J.C. Jeon, K.H. Kwon, L.H. Kim, J.H. Kim, Y.J. Jung, K.S. Min, Application of coagulation process for the treatment of combined sewer overflows (CSOs), Desal. Water Treat., 51 (2013) 4063–4071.

[11] L.H. Kim, S.H. Lee, Characteristics of washed-off pollutants and dynamic EMCs in a parking lot and a bridge during storms, J. Korean Soc. Water Environ., 21 (2005) 248–255.

[12] E.J. Lee, M.C. Maniquiz, J.B. Gorme, L.H. Kim, Determination of cost-effective first flush criteria for BMP sizing, Desal. Water Treat., 19 (2010) 157–163.
[13] M.C. Maniquiz, J.Y. Choi, S.Y. Lee, H.J. Cho, L.H. Kim, Appropriate methods in determining the event mean concentration and pollutant removal efficiency of a best management practice, Environ. Eng. Res., 15 (2010) 215–223.
[14] National Institute of Environmental Research (NIER), Customized Policy Support for Nonpoint Pollution Management and Water Circulation Improvement (I), National Institute of Environmental Research, Incheon, Korea, 2016.
[15] B.S. Kal, J.B. Park, H.G. Kwon, T.H. Im, J.H. Lee, A study on the management of non-point source using peak water quality concentration, J. Wetlands Res., 19 (2017) 287–295.
[16] Geum River Watershed Management Committee (GWMC), Long-Term Monitoring of Non-point Source Pollutants Discharge and Reduction Measures Study, Geum River Watershed Management Committee, Daejeon, Korea, 2008–2012.
[17] Geum River Watershed Management Committee (GWMC), Monitoring of Non-point Source Pollutants, Geum River Watershed Management Committee, Daejeon, Korea, 2013–2016.
[18] Han River Watershed Management Committee (HWMC), Long-Term Monitoring and Control Measures of Non-point Source Pollution from Major Land-Uses, Han River Watershed Management Committee, Hanam-si, Gyeonggi-do, Korea, 2008–2012.
[19] Han River Watershed Management Committee (HWMC), Integrated Monitoring and Management Plan for Non-point Pollution, Han River Watershed Management Committee, Hanam-si, Gyeonggi-do, Korea, 2013–2016.
[20] Nakdong River Watershed Management Committee (NWMC), Long-Term Monitoring and BMPs for the Non-point Source Pollutants Discharge, Nakdong River Watershed Management Committee, Changwon-si, Gyeongsangnam-do, Korea, 2008–2012.
[21] Nakdong River Watershed Management Committee (NWMC), A Monitoring and Management Scheme for the Non-point Sources, Nakdong River Watershed Management Committee, Changwon-si, Gyeongsangnam-do, Korea, 2013–2016.
[22] Yeongsan-Seomjin River Watershed Management Committee (YWMC), Research on Long-Term Monitoring and BMPs for the Non-point Source Discharge, Yeongsan-Seomjin River Watershed Management Committee, Gwangju, Korea, 2008–2012.
[23] Yeongsan-Seomjin River Watershed Management Committee (YWMC), Research on Long-Term Monitoring for the Non-point Source Discharge, Yeongsan-Seomjin River Watershed Management Committee, Gwangju, Korea, 2013–2016.
[24] National Institute of Environmental Research (NIER), Stormwater Runoff Monitoring Program, National Institute of Environmental Research, Incheon, Korea, 2012.
[25] J.Y. Choi, C.M. Marla, B.S. Lee, S.M. Jeong, L.H. Kim, Characteristics of contaminant and phosphorus existence types in sediment of a constructed wetland, Desal. Water Treat., 38 (2012) 285–291.
[26] L.H. Kim, K.D. Zoh, S.M. Jeong, M. Kayhanian, M.K. Stenstrom, Estimating pollutant mass accumulation on highways during dry periods, J. Environ. Eng., 132 (2006) 985–993.
[27] Korea Water and Wastewater Works Association (KWWA), Sewerage System Standard, Minister of Environment, Sejong, Korea, 2011.