

Runoff characteristics of non-point pollutants caused by different land uses and a spatial overlay analysis with spatial distribution of industrial cluster: a case study of the Lake Sihwa watershed

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Abstract To characterize a runoff pattern of non-point pollutants in relation with different land uses in a watershed, a monitoring activity and field measurements were carried out and data points were recorded during the rainfall events for 2 years. The study area includes industrial, urban, and rural sectors, which can represent a model case for the runoff study. Each sector was monitored with methodology and parameters including partial event mean concentration, first flush effect, mass first flush ratios, and correlation analysis. The Banwol Industrial Outfall No. 4 (4TG), an industrial area, showed a strong first flush effect, indicating that pollutants such as suspended solids, chemical oxygen demand, total nitrogen, and total phosphorus, were discharged at the early stage of a storm. An MFF_{30} analysis of the runoff

revealed a mean pollutant load was over 50 %. In the Ansan Stream, an urban area, a strong first flush effect did not appear; however, the concentrations of pollutants reached a peak some time later during a storm event. Then, the concentrations of pollutants quickly reduced. On the other hand, Jangjunbo and Munsan Stream, rural areas, did not exhibit the first flush effects, and when considering the value of MFF_{30} , 30 % or fewer pollutants on average were discharged at the initial stage of a storm. This means most of pollutants were streamed out at the later time of a storm event. The monitoring results found that the runoff characteristics of non-point pollutants in industrial, urban, and rural areas were distinctly different and site-specific. Therefore, each watershed management plan should be prepared to meet its own characteristics. Also, this kind of data can be an important base in designing and sizing a regional wastewater treatment facility to treat pollutants from a contaminated watershed.

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Introduction

Until the mid-1990s, lake and river water quality management in South Korea had focused on point sources having certain runoff paths, such as domestic sewage and industrial wastewater. However, the need to manage non-point sources has gradually increased, as non-point sources are a hindrance to water quality improvement for rivers and lakes (Park et al. 1998; Novotny 1999). Therefore, impervious areas rapidly increased as lands became urbanized and industrialized with the construction of new cities, factory areas, paved roads, and parking areas (Liu et al. 2013; Stenstrom et al. 2001; Vorreiter and Hickey 1994). Non-point source pollution is driven

by the intensity of the rainfall (Wang et al. 2011), and the control on it is a key matter to reducing non-point source pollutants. Non-point pollutants do not refer to specific pollutants, but to all pollutants discharged into the environment. The US Environmental Protection Agency (USEPA) conservatively defines that non-point sources do not have clear pollutant runoff paths, but include pollutants from rainfall sources in farmlands, forests, mines, construction sites, landfills, and urban areas [Environmental Protection Agency (EPA) 1994]. Runoff (or storm water) varies and the movement path changes with many environmental factors that are difficult to control, such as topography, current land use conditions, and hydraulic and hydrologic conditions. Thus, it is somewhat complicated to address runoff characteristics. Moreover, a runoff contains many different types of pollutants with a very high initial concentration (Ichiki and Yamada 1999; Lee et al. 2001; Bedient et al. 1980).

Considering the importance of non-point source control for a systematic water quality management, the target water quality cannot be achieved without managing non-point sources from various land uses (Li et al. 2007). Therefore, a number of studies on water quality improvement have been conducted in major watersheds throughout the analysis of runoff and rainfall characteristics with a focus on the fate and movement of non-point pollutants stemming from different land uses (Aikenhead-Peterson et al. 2009; Elci and Selcuk 2013; Romshoo and Muslim 2011; Tang et al. 2005; Tong and Chen 2002; Wang et al. 2011).

The Lake Sihwa watershed, the project site of this study, has combined watershed characteristics with which industrial, urban, and rural areas coexist. The water quality of the Lake Sihwa has rapidly been deteriorated with untreated wastewater from industrial areas, untreated sewage, and an inflow of non-point pollutants from a rainfall event. Although point sources of pollutants had been successfully controlled through the wastewater collection system, in 1994, an ocean embankment was placed at the end of the Lake Sihwa, which resulted in the slower flow of the water stream to the West Sea and became a major contributor to the deterioration of the water quality of the Lake Sihwa. Now this environmental issue regarding the revival of the water quality brings social attention to the public in Korea. The management of non-point sources and water quality improvement must be made in an appropriate way in this area. In order to carry out this huge project in complicated areas, a long-term monitoring data on the runoff characteristics and behaviors associated with non-point sources was a necessity. The objectives of this study were to identify storm-water pollutants associated with different land uses and to spatially characterize their movement and behaviors. The analyzed data from a specific site can be useful in preparing a master plan for the lake revival program in an area with similar storm characteristics.

Materials and methods

Study area

The Lake Sihwa was artificially designed as a freshwater reservoir for irrigation and industrial water supply to a newly developed land, which resulted from a construction of a long embankment between ocean and estuary. After the construction of an embankment, however, the water quality of the Lake Sihwa became so deteriorated that it was made practically unfeasible for a function of freshwater reservoir to feed a local population. Finally, The Ministry of Environment, Republic of Korea, announced the Water Quality Improvement Master Plan to save the Lake Sihwa. So far, the Korean Government has implemented various management efforts and conducted practical actions through the efforts of private and public sectors. Among actions, contaminant source control was the most significant factor to maximize the effectiveness of the Master Plan, which was closely related to the purpose of this study.

The Lake Sihwa watershed encompasses the three cities of Ansan, Siheung, and Hwaseong, and features mostly low, flat topography. The Lake Sihwa watershed is mainly divided into an industrial area including the Sihwa Industrial Complex in the city of Siheung and the Banwol Industrial Complex in the city of Ansan, an urban area including the Ansan New Town, and a rural area around the city of Hwaseong (Fig. 1). The rural area of the Lake Sihwa watershed has the largest share, 32.1 % of the total watershed, followed by the industrial area with 13.2 %, and the urban area with 10.3 % of area occupancy. The rest is occupied with three small separate watersheds and a tideland in the south bound.

In this study, the runoff characteristics of non-point sources during rainfalls at four sites were analyzed with different land uses of the Lake Sihwa watershed major areas: Banwol Industrial Outfall No.4 (4TG), Ansan Stream (AS), Jangjunbo (JJB), Munsan Stream (MS), as shown in Fig. 1.

The land use categories for the Lake Sihwa watershed are shown in Table 1. For the 4TG (industrial area), its land use is 60.1 %, primarily with factory and manufacturing facilities. For the AS, which is an urban area, the percentages of residential and commercial occupancy, and forest including a city green belt are 21.3 and 38.2, respectively, indicating that the city of Ansan has a relatively high percentage of green area in well-organized city urban planning. For the JJB and the MS, the percentages of agricultural and forest areas representing a rural area are 88.1 (JJB) and 77.7 (MS), respectively.

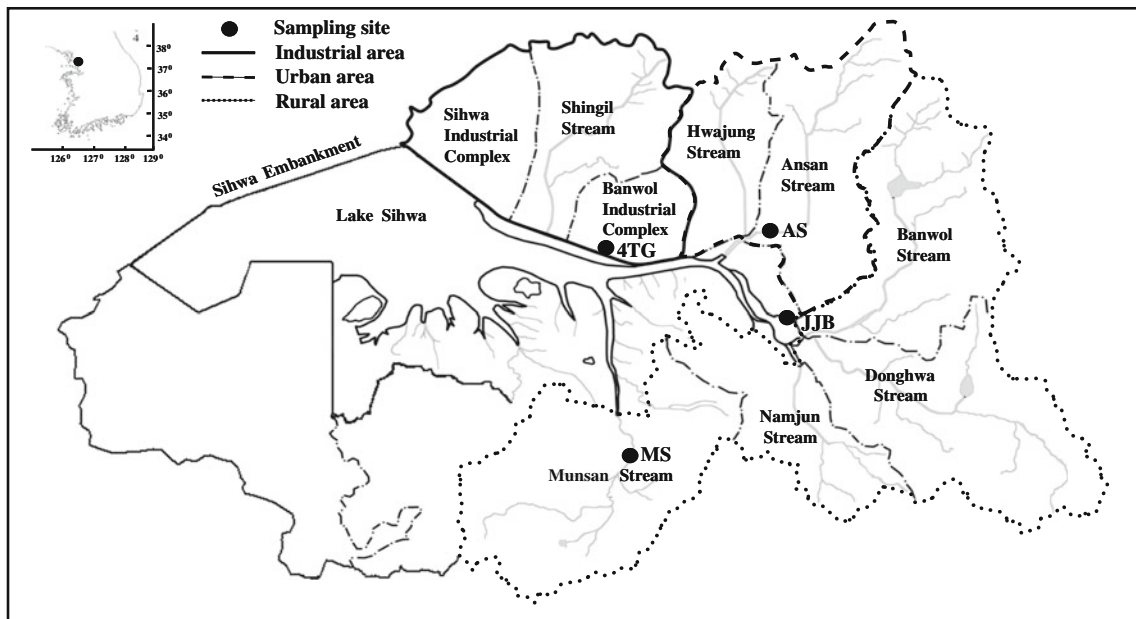


Fig. 1 Site map of the Lake Sihwa watershed

Table 1 Land use conditions of in Lake Sihwa watershed

Sites	Land use (%)					
	Residential	Factory	Agricultural	Forest	Commercial	Others
Industrial area						
4TG	–	60.1	–	35.6	–	4.3
Urban area						
AS	17.5	0.5	13.5	38.2	3.8	26.5
Rural area						
JJB	6.4	–	35.5	52.6	–	5.5
MS	5.6	1.2	51.4	26.3	–	15.5

Field investigation and analysis methods

In order to characterize runoff events, each site was monitored on a regular basis and data collected were analyzed between 2008 and 2009, as presented in Tables 2 and 3. Flowmeters (Flo-Tote 3, Marsh Mcbirney), ultrasonic water gauges (SLM-1000, Sondar, CMDA), and auto sampler (Robo-Chem™ Auto sampler, P1-1224) were installed at different locations of the four sites to collect water quality data and various hydrologic information during monitored rainfall events. Auto sampler was installed with a flowmeter to measure rainfall amount per time period. Before starting the measurement of rainfall, preliminary trips were made to survey the trend of rains associated with pollutants locally produced in specific sites. Based on preliminary trips, the optimum intervals of sample collecting related to the local precipitation were determined. As the industrial and urban areas are considered to have a strong first flush effect, the

interval of sampling was 15–30 min with cumulative rain (10 mm); and the sampling interval was prolonged to 60 min after the middle term of a rain storm. On the other hand, agricultural areas had a sampling at 60 min interval in early storm time and 120 min in the later time of a storm. For water quality data of the streams during rainfalls, suspended solids (SS) and chemical oxygen demand (COD: Mn method) were measured in accordance with the standard method (APHA 1998), and along with SS and COD, total nitrogen (TN), and total phosphorus (TP) were measured with an automatic analyzer (SKALAR, SAN^{plus} Analyzer 5000).

Analytical methods to characterize runoff pollutants

For the purpose of comparing the runoff characteristics of non-point sources from different land use activities, basic rainfall event data, partial event mean concentration (PEMC), first flush effects, mass first flush (MFF) ratios,

Table 2 Hydrologic information of runoff events in industrial and urban areas of the study area

Land use	Site	Storm event	Event date (yy/mm/dd)	Total rainfall (mm)	Rainfall intensity (mm/h)	Duration (h)	Antecedent dry days (ADD)	Runoff depth (mm)	Runoff coefficient
Industrial area	4TG	Event 1	08/03/29	8.5	0.0–3.0	9.5	6	7.7	0.91
		Event 2	08/04/09	9.0	0.0–3.0	8.5	10	6.0	0.67
		Event 3	08/05/18	41.0	0.0–10.0	8.5	22	22.0	0.54
		Event 4	08/05/28	24.0	0.0–8.5	9.5	9	18.0	0.75
		Event 5	08/06/02	46.2	0.0–21.5	15	4	27.4	0.59
		Event 6	08/08/15	13.0	0.0–3.0	9.5	2	9.2	0.71
		Event 7	09/06/09	26.0	0.0–8.0	11.5	18	29.3	1.13
		Event 8	09/07/09	110.0	0.0–27.0	10	9	137.5	1.25
		Event 9	09/08/11	77.0	0.0–12.5	10	16	80.4	1.04
		Event 10	09/10/31	18.5	0.0–7.0	10.5	11	34.8	1.88
Urban area	AS	Event 1	08/04/25	13.0	0.0–5.0	21	2	6.2	0.48
		Event 2	08/05/18	44.0	0.0–16.5	8.5	22	22.8	0.52
		Event 3	08/06/02	38.0	0.0–21.0	8.5	4	12.9	0.34
		Event 4	08/06/18	47.0	0.0–10.0	14	9	14.0	0.30
		Event 5	08/06/28	23.5	0.0–5.5	8.5	9	8.3	0.35
		Event 6	08/11/27	10.5	0.0–2.5	11	26	6.4	0.61
		Event 7	09/02/13	11.0	0.0–4.5	19	19	13.6	1.23
		Event 8	09/06/29	17.5	0.0–5.5	11	8	13.5	0.77
		Event 9	09/07/09	129.5	0.0–29.5	14	9	67.5	0.52
		Event 10	09/08/11	113.5	0.0–15.5	19.5	16	60.5	0.53

Table 3 Hydrologic information of runoff events in a rural area of the study area

Land use	Site	Storm event	Event date (yy/mm/dd)	Total rainfall (mm)	Rainfall intensity (mm/h)	Duration (h)	Antecedent dry days (ADD)	Runoff depth (mm)	Runoff coefficient
Rural area	JJB	Event 1	08/05/18	59.0	0.0–21.0	26	22	20.9	0.35
		Event 2	08/06/02	40.0	0.0–22.5	19	4	29.7	0.74
		Event 3	08/06/18	62.0	0.0–12.5	38	9	53.0	0.86
		Event 4	08/07/19	180.5	0.0–20.5	40	2	178.5	0.99
		Event 5	08/07/24	139.5	0.0–23.5	38	3	171.5	1.23
		Event 6	08/08/12	45.3	0.0–9.5	37	9	31.9	0.70
		Event 7	09/06/10	34.0	0.0–12.0	10	19	8.4	0.25
		Event 8	09/07/09	115.5	0.0–27.0	18.5	9	125.6	1.09
		Event 9	09/07/12	191.0	0.0–49.0	31	2	133.8	0.70
	MS	Event 1	08/05/18	63.0	0.0–19.0	19	22	7.2	0.11
		Event 2	08/06/18	97.4	0.0–31.0	19	9	13.3	0.14
		Event 3	08/07/19	84.5	0.0–12.0	19	2	13.9	0.17
		Event 4	08/07/24	128.0	0.0–20.0	19	3	18.4	0.14
		Event 5	08/08/11	121.5	0.0–45.0	30	8	18.6	0.15
		Event 6	08/08/18	41.5	0.0–8.5	19	5	5.2	0.13
		Event 7	09/06/20	32.5	0.0–10.0	19	9	2.7	0.08
		Event 8	09/07/09	118.0	0.0–25.5	19	18	11.8	0.10
		Event 9	09/07/12	178.0	0.0–46.5	17	2	48.6	0.27
		Event 10	09/08/11	122.5	0.0–14.0	19	16	12.6	0.10

and correlation analyses among collected data were continuously studied at the Lake Sihwa watershed’s representative sites during the monitoring period between 2008 and 2009.

Partial event mean concentration

Event mean concentration (EMC) well describes the mean concentration of pollutants from rainfall events. It is an effective indicator for determining a pollutant load and contribution rate of pollutants discharged from a watershed. However, EMC is a singular factor relatively for a complicated rain event; therefore, it cannot explain various runoff characteristics such as the fluctuations of pollutant concentration caused from different storm events and first flush effect, which are unique to non-point sources (Kim et al. 2007). Thus, in order to identify a number of runoff characteristics of non-point sources and to provide threshold points for non-point pollutant eventually streaming down to a treatment facility, the modified PEMC was used for this study, as shown in Eq. 1 (Lee et al. 2002; Kim et al. 2005):

$$PEMC = \frac{m(t)}{v(t)} = \frac{\int_0^t C_t Q_t dt}{\int_0^t C_t dt} \approx \frac{\sum_{t=0}^{t=t} C_t Q_t}{\sum_{t=0}^{t=t} Q_t} \quad (1)$$

where m is mass of pollutants during rainfall time (g), v is flow volume during rainfall time (m^3), C is pollutant concentration during rainfall time (mg/L), and Q is flowrate during rainfall time (m^3/min).

First flush effect

In this study, the first flush effect was employed to analyze the relationships between the percentage of cumulative mass in the total mass, the percentage of cumulative volume in the total volume, and a cumulative time (Gupta and Saul 1996). As shown in Fig. 2, it can be determined that there is a first flush if the difference between a cumulative mass and a cumulative volume is 0.2 or higher. This method is useful for expressing a time concept for the first flush effect because the graph can sufficiently explain the changes of mass versus volume over time (Sansalone and Buchberger 1997; Helsel et al. 1979).

MFF ratio

The MFF ratio is also a method to explain for the first flush by quantifying the volume of pollutants discharged during a rainfall through the determination of the percentages of cumulative volume and cumulative load at a certain point of time throughout the duration of a storm. A mathematical

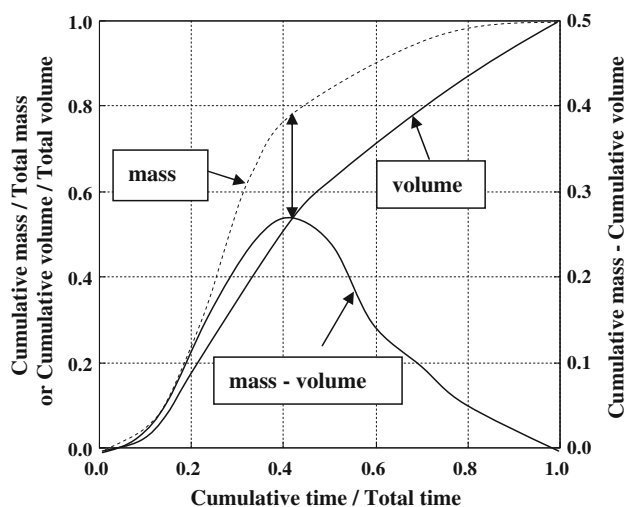


Fig. 2 Graph of the first flush effect (after Gupta and Saul 1996)

expression is shown in Eq. 2 (Luo et al. 2009; Li et al. 2007; Stenstrom and Kayhanian 2005).

$$MFF_n = \frac{\int_0^{n\%} C(t)Q(t)dt}{\int_0^{n\%} Q(t)dt} \cdot \frac{V}{M} \quad (2)$$

MFF is a mass first flush ratio, n is index or point in the storm, and corresponds to a percentage of a runoff, ranging from 0 to 100 %. M is a total mass of discharged pollutants, V is a total runoff volume, C and Q are a pollutant concentration and a flowrate of runoff, respectively. If average MFF_{30} is equal to 2.0, 60 % of the pollutant mass was discharged in the first 30 % of total runoff volume.

Correlation of pollutant load and runoff volume

As a pollutant load during an early rainfall is closely related to increasing runoff volume, it is possible to predict runoff pollutant loads in accordance with unpredictably fluctuating runoff volumes. Furthermore, absolute comparisons among different watershed areas can be made by dividing a runoff volume and load with an area of a selected watershed; the regression equation can be expressed as Eq. 3 (Lee and Bang 2000).

$$L/A = \alpha(Q/A)^\beta \quad (3)$$

where L is a pollutant runoff load (kg/ha), A is a watershed area (ha), Q is a flowrate of runoff (m^3/h), and α and β are regression coefficients. Coefficient α indicates a base pollutant load and β a runoff response to a storm event. If β is higher than 1, the pollutant load rapidly increases for a certain volume of runoff at a rainfall time.

Results and discussion

Runoff characteristics of non-point pollutants

In Fig. 3, the runoff characteristics of non-point pollutants in the study areas are shown. Runoff characteristics vary to different land uses (Romshoo and Muslim 2011). For the industrial area (4TG), the concentrations of pollutants such as SS, COD, and TP reached the highest level after 1 h of the start of rainfall with approximately 10 mm of cumulative rain water. The results for the runoff characteristics for each watershed area, by rainfall event and land use, are shown in Fig. 3. At the 4TG, the concentrations of pollutants including SS, COD, and TP reached the highest levels within 1 h of the start of rainfall (cumulative rainfall, 10 mm). During a storm event in the 4TG, high concentrations of pollutants such as SS (600 mg/L), COD (107.7 mg/L), TN (18.8 mg/L), and TP (5.0 mg/L) were discharged. The concentrations of organic matter and nutrients were five times higher than those in urban and rural areas. Even small runoff from the industrial areas generally contains high concentration of pollutants in a relatively short-term rain storm (Liu et al. 2013). After the rapid increase of the concentration of pollutants, it quickly decreased thereafter because of a dilution effect.

For the site of AS, the concentrations of SS, COD, and TP reached the maximum with the cumulative rainfall, 25–30 mm in 2–3 h after the start of rainfall. The parks and green lands along the stream in the site of AS resulted in delaying the time required for pollutants to flow into the stream during the rainfall. Thus, the runoff characteristics of non-point pollutants differed from those of industrial area streams. TP concentration from the site of AS is related to detergent chemicals from urban areas (Elci and Selcuk 2013). The concentrations of SS, COD, and TP in samples from the site of JJB were the highest with the cumulative rainfall, 70 mm, approximately 7–8 h after the start of the rainfall. In particular, the concentration of SS abruptly increased to 814 mg/L, while relatively low concentration of TN was shown regardless of the increasing runoff volume during the rainfall. For the site of MS, the runoff response of pollutants was slow, showing the characteristics similar to a typical stream in rural areas. Therefore, the rainfall effect analysis on the dynamic changes of pollutant concentrations over time will be a basis in building a facility to reduce the concentrations of non-point pollutants.

Partial event mean concentration

The PEMC results for non-point pollutants from the each study stream are shown in Fig. 4. PEMC from the site of 4TG rapidly increased between 40 and 60 min after the

runoff started, and quickly decreased after 60 min. With a PEMC analysis, it can be translated that the initial rainfall is correlated with the estimation of sizing and designing the optimum capacity of treating non-point pollutants. The cumulative rainfall of 8.0–11.5 mm was obtained for the site of 4TG.

The PEMCs from the site of AS, SS, COD, and TP increased between 120 and 150 min after the start of rainfall. The PEMC range was not wide. The cumulative rainfall was from 6.5 to 31.0 mm. As shown in Fig. 4c, the PEMC of pollutants for the site of JJB greatly increased between 240 and 360 min after the start of rainfall, and the PEMC recovery time to the level before the rainfall was longer. The PEMC range of SS was wide, and the fluctuation patterns of the PEMCs for COD and TP were similar to that of SS. The PEMC fluctuating rate of pollutants from the site of MS was low and the PEMC range was relatively narrow.

After the runoff from the site of MS was finished, it took a long time for the PEMC to recover to the level before the rainfall. Based on the PEMC results, it was difficult to determine a cumulative rainfall for such a rural area as the site of MS. It was found that rural areas took a longer time for the PEMC to recover to the level before rainfall. Planning on a reduction of storm pollution for a rural area will be different from industrial and urban areas. Therefore, with a sufficient runoff study, reduction plans should be prepared, characterizing the fate and movement of the non-point pollutants in a quantitative and qualitative way.

First flush effect

The occurrence of first flush effects depends on watershed size, rainfall intensity, storm duration, the area ratio of an impervious layer, and the number of dry days before a rainfall event, and also tends to show different modes with water quality parameters (Deletic 1998). The biggest differences between cumulative mass and cumulative volume for SS, COD, TN, and TP for the site of 4TG were 0.30, 0.26, 0.14, and 0.39, respectively (Fig. 5). All were higher than 0.2, except for TN, which indicates the occurrence of a strong first flush effect at the site of 4TG. Industrial areas are likely to have higher pollutant flowrates and concentrations including various toxic substances. Therefore, they can have a negative impact on the water quality of the Lake Sihwa, requiring intensive water resource management.

The biggest differences between cumulative mass and cumulative volume for SS, COD, TN, and TP for the site of AS were 0.11, 0.09, 0.05, and 0.07, respectively, indicating no strong first flush effect. Also, the differences between cumulative mass and cumulative volume for the site of JJB were 0.24, 0.17, 0.17 for SS, COD, TP, respectively. A relatively high first flush effect was shown. However, for

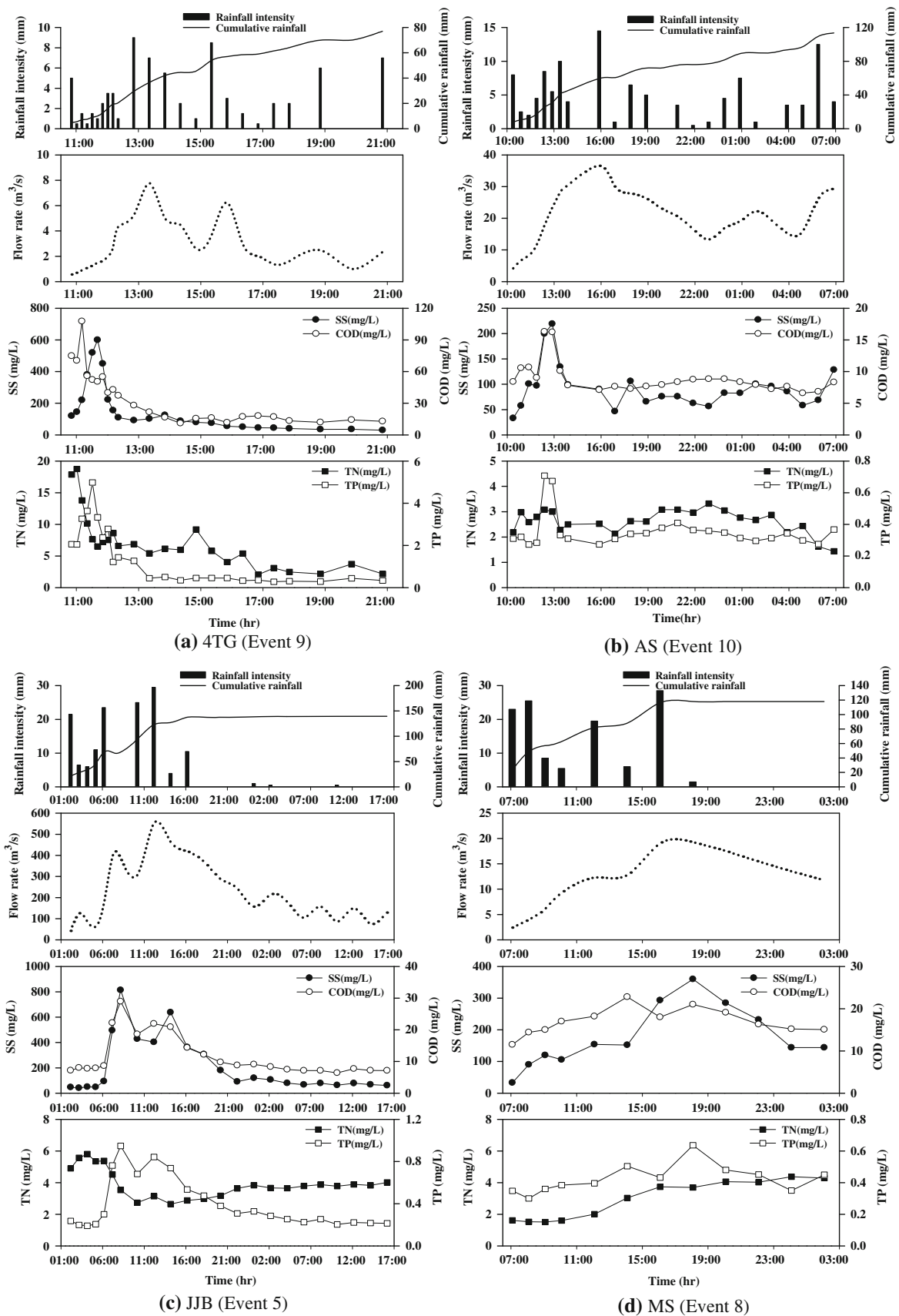


Fig. 3 Fluctuation graphs of pollutant concentration for each study area during storm events

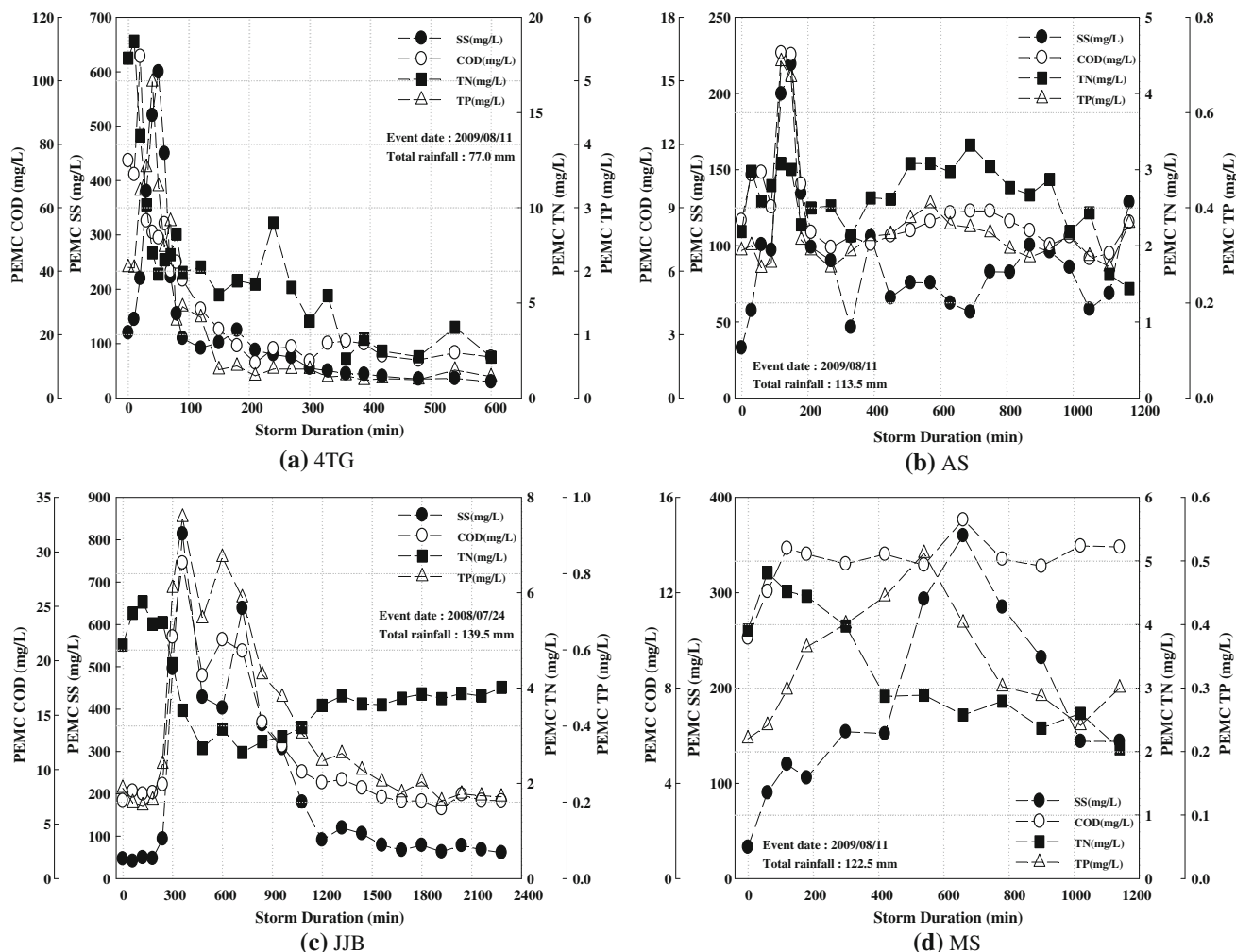


Fig. 4 PEMC data for each study area

the site of JJB, the first flush effect appeared some time after the start of a storm event, not during the initial stage of the storm. This means the runoff pollutants appear in the later stage of a storm.

The biggest differences between cumulative mass and cumulative volume for SS, COD, TN, and TP for the site of MS were 0.06, 0.04, 0.01, and 0.02. The site of MS had no first flush effect caused from the rainfall runoff with 0.06 for SS, 0.04 for COD, 0.01 for TN, and 0.02 for TP. The analysis of the first flush effects found that the relationship of the intensity of the first flush effect was $TP > SS > COD > TN$ for the industrial area, and $SS > COD > TP > TN$ for the urban and rural areas.

Correlation analysis of EMC and rainfall characteristics

The Pearson coefficients between EMC and rainfall parameters with different land uses were prepared in Table 4, 5, 6, 7. For the 4TG, the antecedent dry days (ADD) and SS showed the high correlation of 0.65

($p < 0.05$), implying that ADD has some impact on the discharge of particulate pollutants accumulating in the outfall of industrial areas. On the other hand, other rainfall runoff variables such as average rainfall intensity (ARAIN), total volume of rainfall (TRAIN), and total volume of runoff (TRUNOFF), seemed not to be correlated with the discharge characteristics of runoff pollutants.

The site of AS showed a high correlation between ARAIN and SS with 0.70 ($p < 0.05$), and also showed a high pollutant correlation between SS and TP with 0.72 ($p < 0.05$). For the site of JJB, the hydrogeologic characteristics of the upstream region have a great impact on the discharge of pollutants. JJB is located in a combined watershed including three rivers, which serves to feed an agricultural area in the upstream. In dry season, a water sluice gate is closed, while, in wet season, the gate is rapidly opened. Thus, all the solids collected around a sluice gate are likely to abruptly flush out, which is related to increased concentration of pollutants in the beginning of the storm. Therefore, the JJB had high correlations for

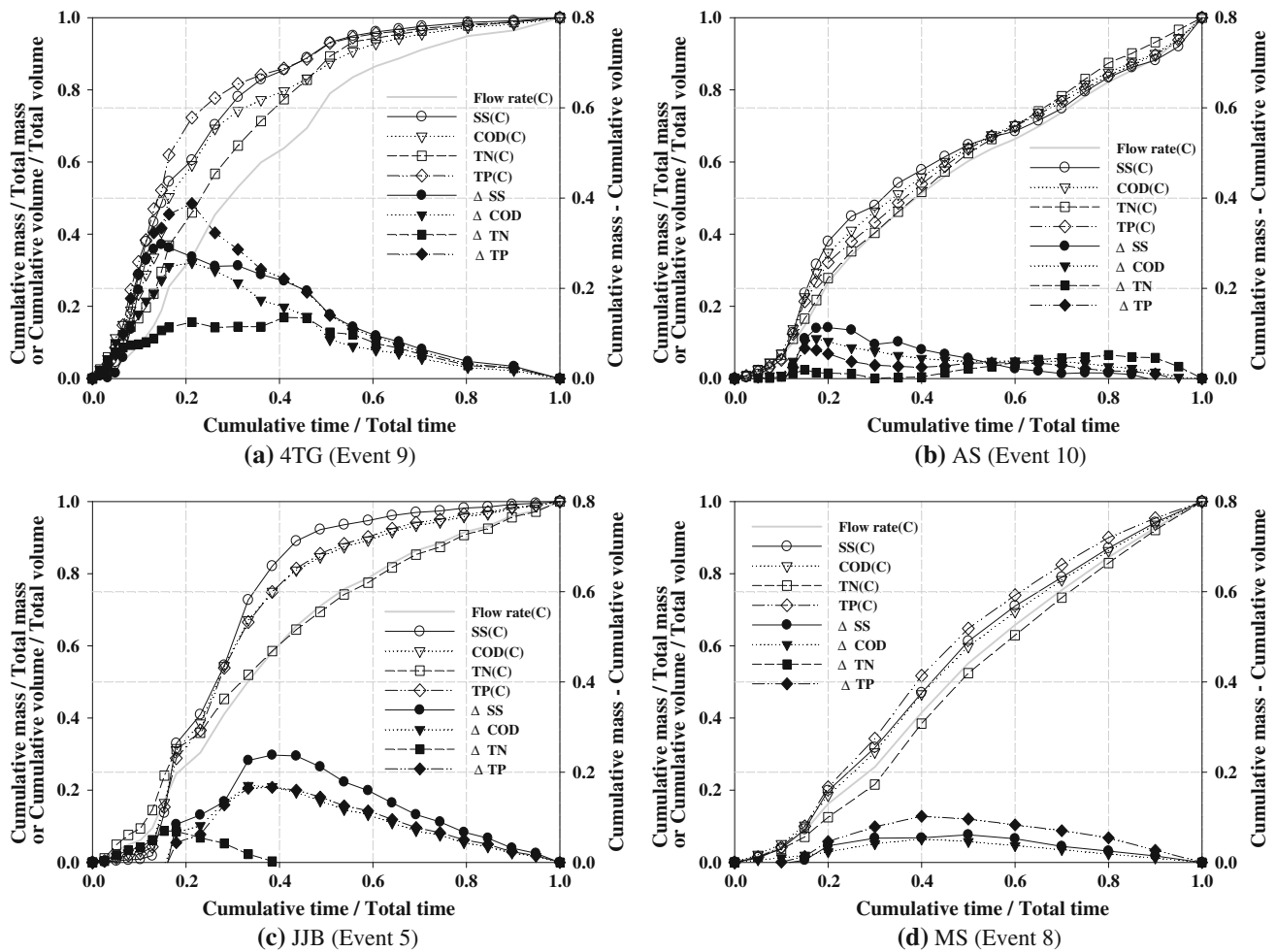


Fig. 5 Cumulative runoff mass and volume curves for study areas in the Sihwa watershed

Table 4 Correlation analysis results of EMCs and rainfall parameters in industrial area, 4TG

Site	SS	COD	TN	TP	ADD	ARAIN	TRAIN	TRUNOFF	DURATION
4TG									
SS	1.00								
COD	0.50	1.00							
TN	-0.10	0.41	1.00						
TP	0.46	0.68*	0.75*	1.00					
ADD	0.65*	0.09	-0.11	0.20	1.00				
ARAIN	0.19	-0.19	-0.38	-0.12	0.21	1.00			
TRAIN	0.21	-0.23	-0.44	-0.18	0.20	0.98**	1.00		
TRUNOFF	0.05	-0.28	-0.44	-0.28	0.14	0.95**	0.95**	1.00	
DURATION	-0.05	-0.15	-0.44	-0.31	-0.29	-0.03	0.16	0.07	1.00

* Correlation is significant at the 0.05 level (two-tailed)

** Correlation is significant at the 0.01 level (two-tailed)

ADD antecedent dry day, ARAIN average rainfall intensity, TRAIN total volume of Rainfall, TRUNOFF total volume of runoff

TRAIN between SS, COD, and TP at 0.86 ($p < 0.01$), 0.79 ($p < 0.05$), and 0.86 ($p < 0.01$), respectively. SS and TP showed a high pollutant correlation with 0.80 ($p < 0.01$).

The reason for this correlation between SS and TP was due to that phosphorus has a bonding capacity with particulate matters such as sand even during a rain storm (Wang et al.

Table 5 Correlation analysis results of EMCs and rainfall parameters in urban area, AS

Site	SS	COD	TN	TP	ADD	ARAIN	TRAIN	TRUNOFF	DURATION
AS									
SS	1.00								
COD	0.29	1.00							
TN	-0.24	0.64*	1.00						
TP	0.72*	0.45	-0.02	1.00					
ADD	0.07	0.25	-0.07	0.49	1.00				
ARAIN	0.70*	-0.46	-0.71*	0.39	-0.08	1.00			
TRAIN	0.42	-0.67*	-0.68*	.24	-0.05	0.90**	1.00		
TRUNOFF	0.42	-0.56	-0.58	0.37	0.05	0.84**	0.97**	1.00	
DURATION	-0.35	-0.18	0.43	-0.13	-0.10	-0.18	0.18	0.26	1.00

* Correlation is significant at the 0.05 level (two-tailed)

** Correlation is significant at the 0.01 level (two-tailed)

Table 6 Correlation analysis results of EMCs and rainfall parameters in rural area, JJB

Site	SS	COD	TN	TP	ADD	ARAIN	TRAIN	TRUNOFF	DURATION
JJB									
SS	1.00								
COD	0.57	1.00							
TN	0.06	0.08	1.00						
TP	0.80**	0.72*	0.44	1.00					
ADD	-0.57	0.04	0.29	-0.25	1.00				
ARAIN	0.86**	0.79*	0.13	0.86**	-0.33	1.00			
TRAIN	0.79*	0.26	-0.11	0.50	-0.65	0.76*	1.00		
TRUNOFF	0.63	0.18	-0.02	0.47	-0.71*	0.68*	0.92**	1.00	
DURATION	0.05	-0.65	-0.21	-0.23	-0.52	-0.17	0.46	0.50	1.00

* Correlation is significant at the 0.05 level (two-tailed)

** Correlation is significant at the 0.01 level (two-tailed)

Table 7 Correlation analysis results of EMCs and rainfall parameters in rural area, MS

Site	SS	COD	TN	TP	ADD	ARAIN	TRAIN	TRUNOFF	DURATION
MS									
SS	1.00								
COD	-0.34	1.00							
TN	0.11	0.36	1.00						
TP	0.72*	0.04	0.45	1.00					
ADD	-0.36	0.73*	0.50	-0.19	1.00				
ARAIN	0.92**	-0.25	0.20	0.73*	-0.21	1.00			
TRAIN	0.85**	-0.35	-0.01	0.57	-0.20	0.94**	1.00		
TRUNOFF	0.91**	-0.29	-0.19	0.58	-0.44	0.88**	0.86**	1.00	
DURATION	-0.25	-0.25	-0.74*	-0.56	-0.00	-0.27	0.06	-0.07	1.00

* Correlation is significant at the 0.05 level (two-tailed)

** Correlation is significant at the 0.01 level (two-tailed)

2011). This phosphorus-bonding soil can be washed away in a stream. For the site of MS, the high correlations with SS were found for ARAIN, TRAIN, and TRUNOFF with

0.92 ($p < 0.01$), 0.85 ($p < 0.01$), and 0.91 ($p < 0.01$), respectively. The particulate pollutants had a high impact on rainfall characteristics for rural areas.

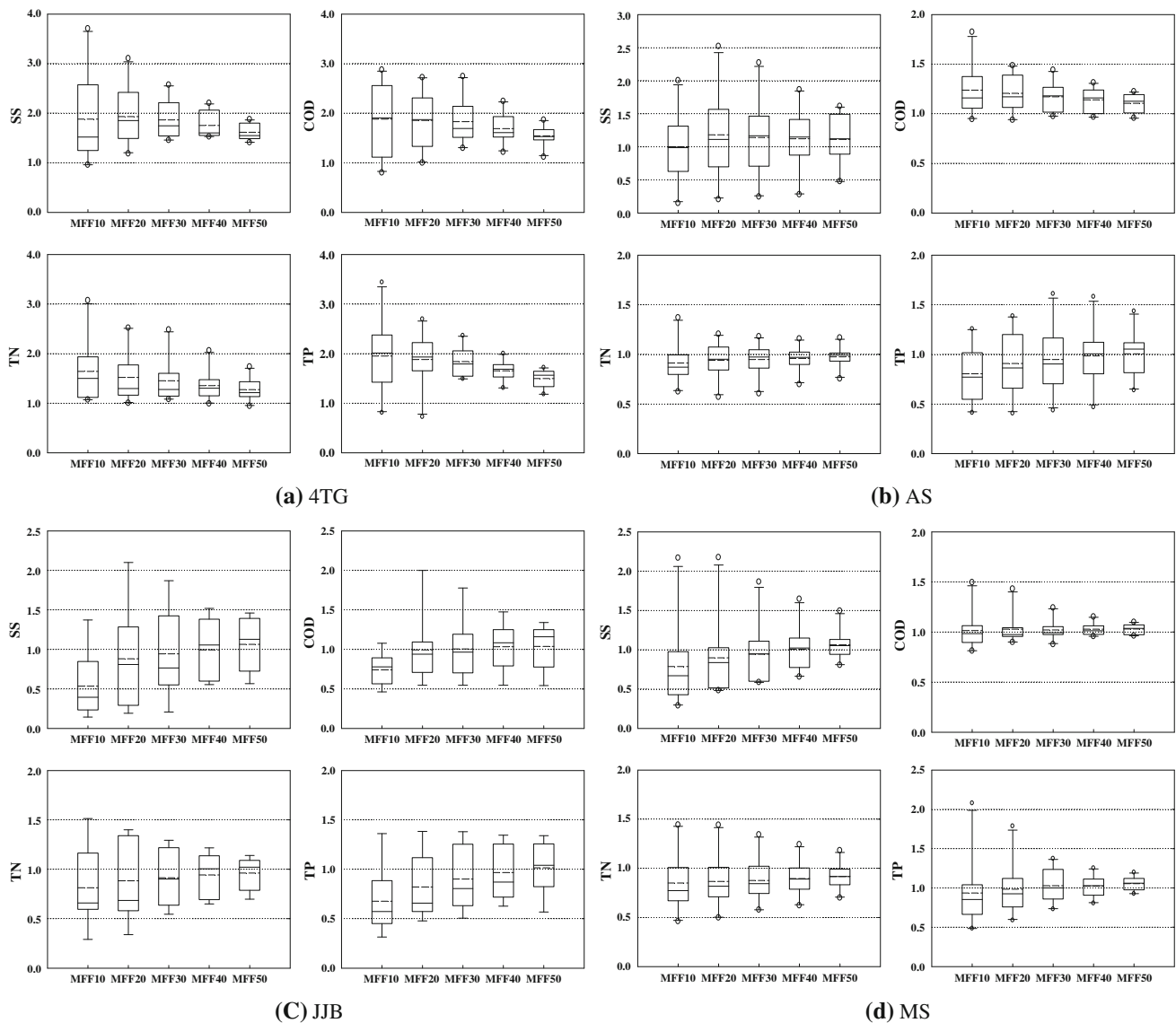


Fig. 6 MFF ratios (10–50 %) of SS, COD, TN, and TP for study areas in the Sihwa watershed

MFF ratio

To quantitatively measure the volume of non-point pollutants discharged by a rainfall runoff, the MFF values for water quality criteria were determined for each site in Fig. 6. The site of 4TG had a maximum pollutant load of SS as 77 % (average 56.1 %) at MFF₃₀, meaning that most particulate pollutants are discharged in the early stage of a storm. The maximum pollutant loads of organic matter and nutrients ranged from 34 to 82 % between MFF₁₀ and MFF₃₀, also meaning that many pollutants are included in the runoff of the early stage of a storm. The site of AS had maximum pollutant loads, 63–81 % between MFF₄₀ and MFF₅₀. With this analysis, it can be suggested that, when characterizing non-point pollutants,

data collected some time after a runoff event should be considered more significant than the one collected instantly after a storm event.

For the sites of JJB and MS, the maximum pollutant loads at MFF₃₀ were 28 and 29 % and the average pollutant loads at MFF₅₀ were similarly 1.02 and 1.01. This means that approximately 50 % of the pollutant load was included in 50 % of a rainfall runoff volume. Considering the runoff characteristics of non-point pollutants in these two streams, it will be more effective to apply pollutant reduction plans at the middle or later stage of a storm. The characteristics of pollutants included in the early rainfall runoff varied greatly depending on different watershed areas. Therefore, these data can be useful for establishing a non-point pollutant reduction facility in a watershed area.

Table 8 Regression coefficients between pollutant load and runoff for each study area

	4TG				AS				JJB				MS			
	α	β	R^2	N	α	β	R^2	N	α	β	R^2	N	α	β	R^2	N
SS	0.025	1.49	0.70	174	0.012	1.77	0.79	168	0.025	1.57	0.86	178	0.028	1.62	0.92	120
COD	0.030	1.02	0.67	174	0.014	0.94	0.74	168	0.010	1.12	0.89	178	0.017	0.94	0.89	120
TN	0.010	0.77	0.66	174	0.007	0.75	0.81	168	0.002	1.11	0.94	178	0.002	1.05	0.90	120
TP	0.0016	1.04	0.65	174	0.0002	1.30	0.76	168	0.0002	1.27	0.93	178	0.0002	1.18	0.89	120

R^2 correlation coefficient, N number of sample

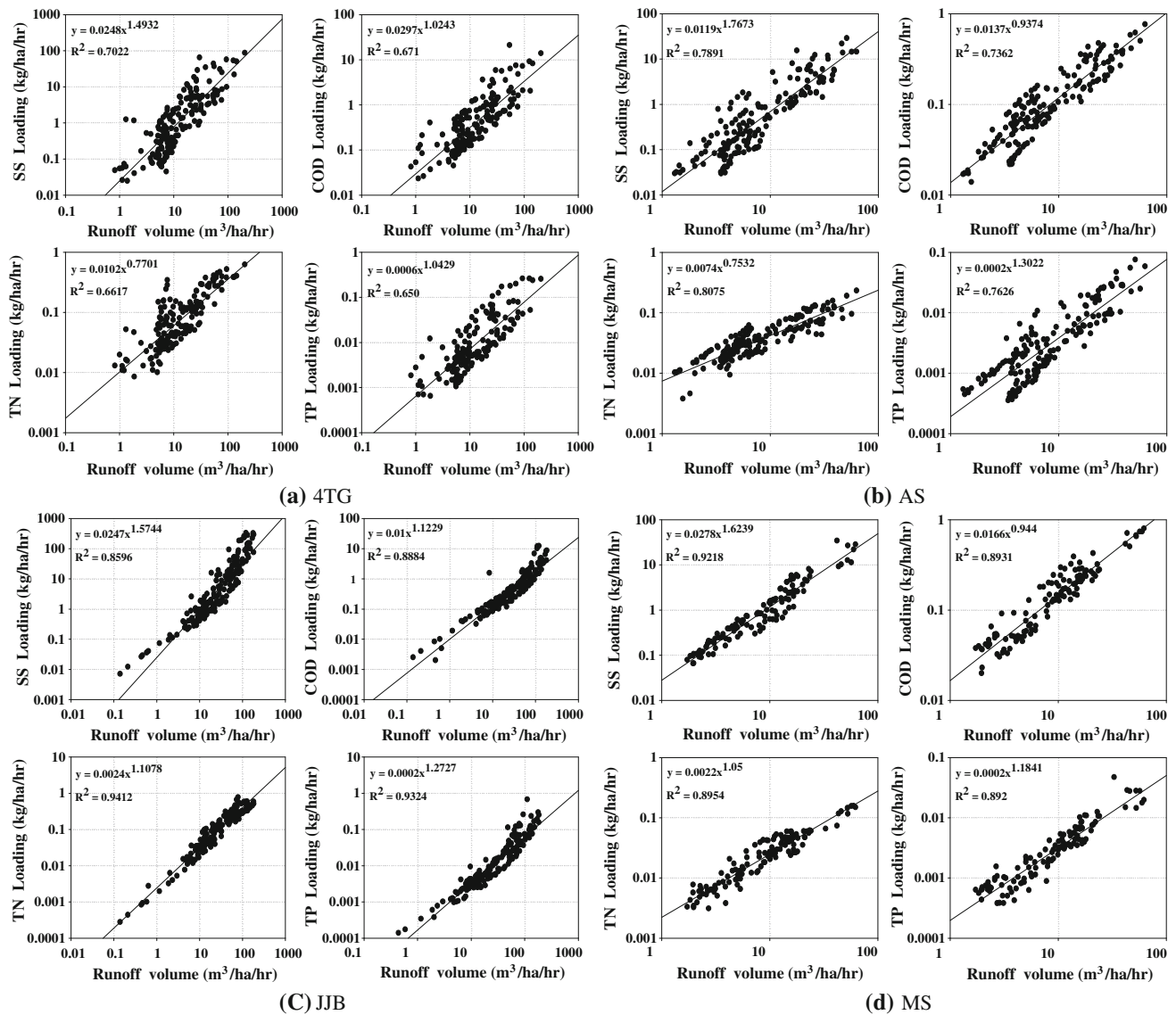


Fig. 7 Relations between pollutant loading and runoff volume for study areas in the Sihwa watershed

Analysis on correlation between pollutant load and runoff

Using a runoff volume and its water quality data measured at the study streams during the specific storm, correlations

between SS, COD, TN, and TP loads per unit area and a runoff volume per unit area in each stream were analyzed, as data presented in Table 8 and Fig. 7.

The analysis results showed that the site of 4TG had the β values for SS, COD, and TP as 1.49, 1.02, and

1.04, which signifies that a pollutant concentration delicately changes in accordance with runoff volumes. The site of AS had a similar trend of results with the 4TG. A fast response of a pollutant load was made with increasing runoff volumes. The β values for the JJB and the MS were in the ranges of 1.11–1.57 and 0.94–1.62 for all the pollutants measured. The coefficients for the two streams were so high that pollutant load was linearly related to runoff volumes during storm events. This was due to the hydrogeologic characteristics of rural areas.

In summary, the industrial area had high concentration of organic compounds and nutrients including nitrogen and phosphorus in its storm water. The urban area had high content of organic compounds while the rural area had high SS concentration. The land use seemed to affect the characteristics of storm water.

Conclusions

The Lake Sihwa has a unique watershed environment, surrounded by small watershed areas with different characteristics, which requires a future watershed management through the establishment of non-point pollutant reduction plans. These plans should be specific to each area of the watershed. Therefore, spatial overlay data with time versus and its analysis were conducted to characterize the fate and movement of non-point pollutants through a site investigation and assessment. The 4TG as an industrial area, showed a high discharge of highly concentrated pollutants during the early stage of a storm with a strong first flush effect. Thus, a pollutant reduction plan should be prepared based on the data collected for an early storm duration. The AS, an urban area, had the highest pollutant concentrations 2–3 h after the storm. Relatively no strong first flush effect was identified. Although the JJB and the MS represent rural areas similarly, they showed somewhat different characteristics for the movement of non-point pollutants. With the PEMC analysis, highly concentrated pollutants from the JJB and the MS were discharged during the more middle or later stage of a storm event, unlike an early pollutant runoff that occurred for the 4TG and the AS. The MFF analysis found that approximately 50 % of the pollutant load was included in MFF₅₀ for rural zones. Therefore, pollutant reduction plans for this rural area should be based on data sets from the later stage of a storm. In addition, runoff characteristics in rural areas showed high correlations with SS and TP, which are presumably major particulate matters from agricultural and rural zones. Therefore, pollutant reduction plans should also address particulate matters.

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