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The study on first flush effect of stormwater runoff generated from rural area

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ABSTRACT

Nonpoint pollutant source have influenced more strong than point pollutant source on the water quality of river. Therefore, the government to control nonpoint pollutant source should try to the effort. Long term monitoring is demanded at research on nonpoint pollutant source because the results of nonpoint pollutant source monitoring is very different through meteorological and geography characteristics such as rainfall, rainfall intensity, catchment area, slope of catchment, soil class and so on. Although, many researches on stormwater runoff characteristics of nonpoint pollutant source at the urban and rural area have been conducted, the research which focused on monitoring of vinyl greenhouse area has been insufficiency. This paper reported results of research that finds out stormwater runoff characteristics. At the first stage of stormwater runoff, the concentration of TSS was the highest because of first flush effect. And then the concentration of BOD and COD was increasing. After discharging stormwater runoff 1 and 2 h later, the concentration of TN and TP was increasing. Rainfall intensity has a great effect on outflow of pollutants. At the vinyl greenhouse, after about 15 mm of rainfall, stormwater runoff was observed. Average runoff ratio of monitoring was 0.53.

Keywords: Precipitation; Storm water; Runoff; Non-point pollutant; First flush effect; Runoff rate

1. Introduction

The major causes that contaminate the river are classed as point and nonpoint pollution source(NPS). In recent 30 years ago in Korea, water management of rivers have been conducted with the goal of removal of pollutants loads from point pollution source such as domestic sewage, factory wastes and livestock wastewater. And water quality of rivers is improved [1]. Despite the strengthening of investment and regulation about the NPS, effect of water quality improvement gradually has been decreased or stopped [2]. To control point pollutants source to improve water quality reach the limit. Meanwhile, according to Ministry of Environment (MOE) in Korea, the ratio of pollutants loads has a range of 22–40% [3], pollutants loads ratio into river will be increased to 65.2% in 2020 [4]. Therefore, it should properly control NPS to improve water quality of rivers. The first flush effects is one among the characteristics of NPS. The first flush effect means high pollutants concentration is contained in stormwater runoff generated in the initial stage during raining and flow into the rivers and lakes [5]. The first flush effect is known that it is shown in impermeable area such as urban, road, parking lot and bridge [6]. As the initial stormwater runoff include high concentration contaminants, the measure to control the NPS has developed as direction that intercept only the initial runoff and treat it. The generation characteristics of NPS in farming area, however, clearly differ from rural area [7], the measure of NPS in farming area should be prepared accordingly. As land use type in farming area include many permeable layer such as rice paddy, field, unpaved road and forest land, it is very likely that the first flush effect is not shown. Therefore, to provide the basic data for preparing NPS measure, this study selected farmland that crop is cultivated in vinyl greenhouse and conducted monitoring during raining and the first flush effect of stormwater runoff was analysed.

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2. Materials and methods

2.1. Study site

This study monitored during raining area that cultivate tomato using vinyl greenhouse. Stormwater runoff generated at outside of investigation target area during raining is not flow into investigation target area. All stormwater runoff generated in catchment is discharged into nearby river and lake through one point in catchment. Catchment is located in Gumgwang dong in Daegu, South Korea, occupy 4,029 m^2 of area (Table 1). Impermeable area covered with vinyl greenhouse in total catchment area is 3,424 m^2, it occupy about 86% of total area. Catchment area has 4 greenhouse that length is 97 m and Width is 4.5 m and there are 0.8 m of drains among greenhouse.

2.2. Monitoring method and pollutants analysis

To determine the first flush effect, 6 samples were collected during the first 1-h with time interval of 5, 10, 15, 30, and 60 min and another 6 samples every one or 2-h time interval. NPS is pollutant source that has very high uncertainty. its reason could be caused by error by measure of rainfall and storm water runoff checked in monitoring with error of method that conduct the pollutants analysis. Therefore, rain-intensity gauge in this study was installed in catchment and it checked rainfall intensity accurate every 1 min. A flowmeter was installed at the point that all stormwater runoff generated in catchment during raining is gathered and stormwater runoff was checked every 1 min. Collected samples was kept under refrigeration and conveyed to laboratory. Water quality parameters such as total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (CODcr), total nitrogen (TN) and total phosphorus (TP) were analysed at the laboratory with accordance to the standard procedure established in KOREA. Antecedent dry days (ADD) selected two days in the light of time when contaminants is accumulated.

3. Results and discussion

3.1. Monitoring results on rainfall

A total of 32 monitoring was conducted in target area between June 2008 May 2012. Table 2 shows the results of statistics analysis on total rainfall, average rainfall intensity, rainfall duration time and total runoff of rainfall events that monitoring was conducted. Rainfall occurred between 5 and 160 mm, average rainfall was analysed as 82.6 mm. And ADD was ranged from 2 to 19 d, average was shown as 10.5 d. Rainfall intensity and total runoff was checked from 0.8 to 5.5 mm/h and 1.9 to 167.8 m^3, respectively. Also, The rate of runoff was ranged between 0.07 and 0.91.

3.2. Polluto and hydrograph

Storm water runoff, pollutants concentration and so on discharged from NPS during rainfall have the difference according to various factors such as rainfall intensity, rainfall, an underground water level, ADD and the physical property of soil. Because 80 to 95% of target area investigated in this research is consist of impervious surface by vinyl greenhouse, the effusion of rainfall effluent tend to occur very easily compared with other land type in rural area. As shown in the Figs. 1–3, stormwater runoff was occurred after about 2–4 h raining. Rainfall fallen until occurrence of stormwater runoff was difference depending on the rainfall intensity. Overall, stormwater runoff in this study was flowed when about 15 mm of rainfall occurred. According to the study result on the runoff characteristic of NPS generated from high land during rainfall [8], the rainfall fallen until the storm water runoff started to flow on the surface was about 30 mm. From this results, the ratio of runoff of stormwater runoff from field covered with vinyl greenhouse compared with other land use type in a rural area seems to know the difference clearly. In the Fig. 1, TSS showed the first flush effect. TSS concentration in the stormwater runoff generated during the initial 20 min after stormwater runoff just flowed on the surface was

Table 1
Summary of the monitoring site

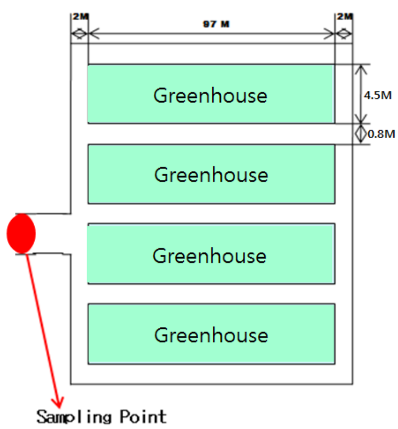
Crops of cultivation	Address	Coordinate	Area of catchment	Photograph
Tomato	Kum-kang dong, Daegu, South Korea	N 35° 51' 41", E 128° 43' 34"	4,029 m^2 (Impermeable ratio:85.8%)	

Table 2
Statistical analysis of Rainfall event

Parameter	ADD (days)	Total rainfall (mm)	Average rainfall intensity (mm/h)	Rainfall duration (h)	Total runoff (m^3)	Runoff rate
Minimum	2.0	5.0	0.8	3.2	1.9	0.07
Maximum	19.0	160.4	5.5	40.9	167.8	0.91
Mean	10.5	82.6	3.1	22.1	84.9	0.53
S.D.	4.0	33.5	1.4	10.2	48.1	0.21

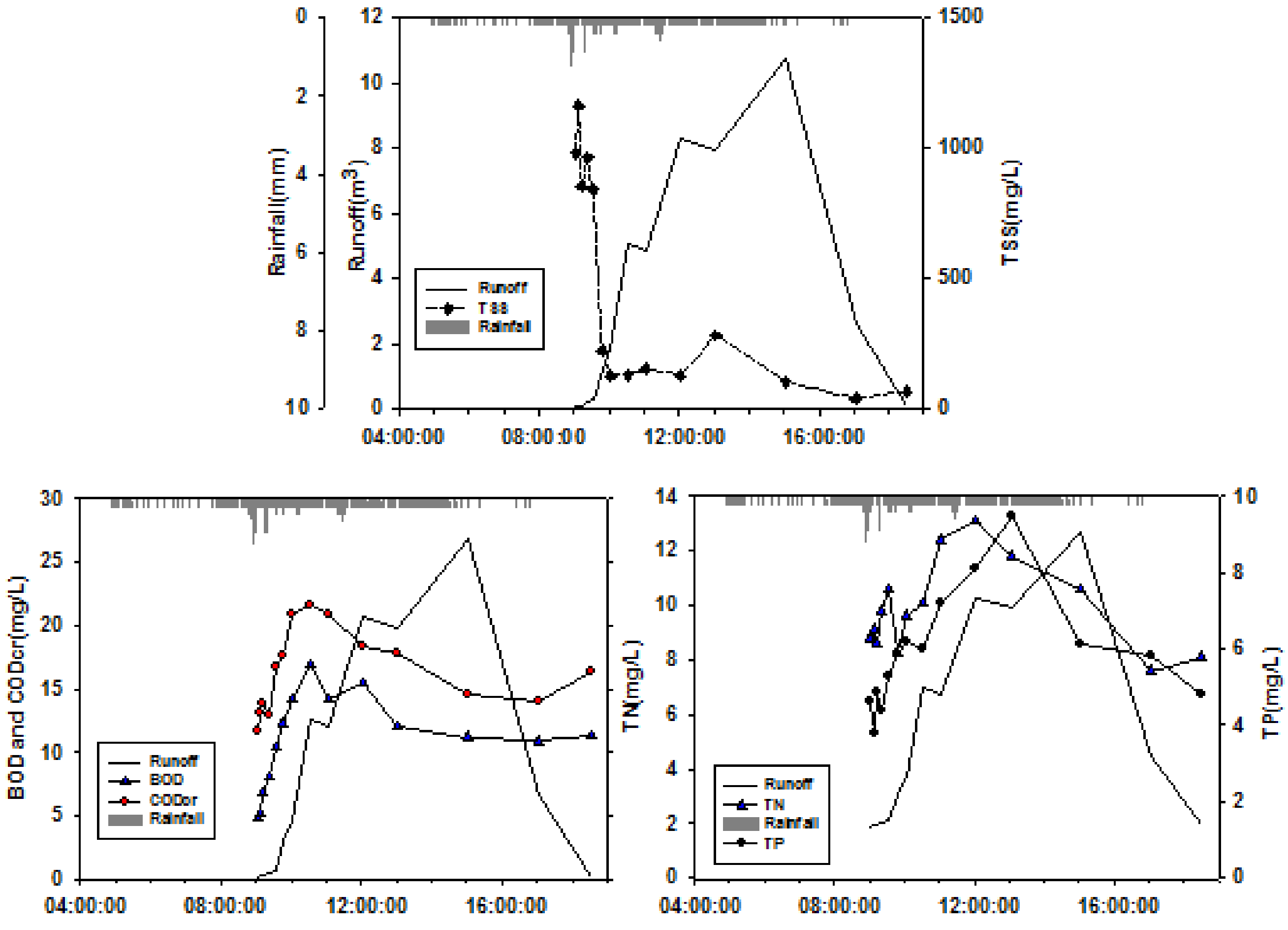


Fig. 1. Hydro and polluto graph(Event 3) Jeon et al.

1162 mg/L, this is very higher value than the 170.2 mg/L that was average TSS concentration included in total storm water runoff. However, BOD and COD_{Cr} concentrations with the occurrence of stormwater runoff started to increasing concentrations were shown after about 50 min. And then their concentrations again decreased. Meanwhile, TN concentration showed about 7 mg/L of low value in the beginning stage of the occurrence of storm water runoff, the highest TN concentration was shown with peak of stormwater runoff in the late stage of rainfall. TP concentration showed the first flush effect with the occurrence of storm water runoff, but it decreased after a short while. And then, it again increased like trend of TN at the point when stormwater runoff became the peak. As shown in Fig. 2, TSS showed the first flush effects in common with Fig. 1. Meanwhile, it found that concentration of the organic material (BOD and CODcr) was increased after stormwater runoff was occurred and 1 and 2 h later. And it increased again before peak of runoff was occurred in middle stage of raining. In the case of the nutrient salts (TN and TP), its low concentration lasted in the initial and middle stage of raining. And then, TN and TP was increased to the highest concentration at that point when stormwater runoff was peak. It is likely that organic materials and nutrient salts accumulated in layer under soil surface revealed after

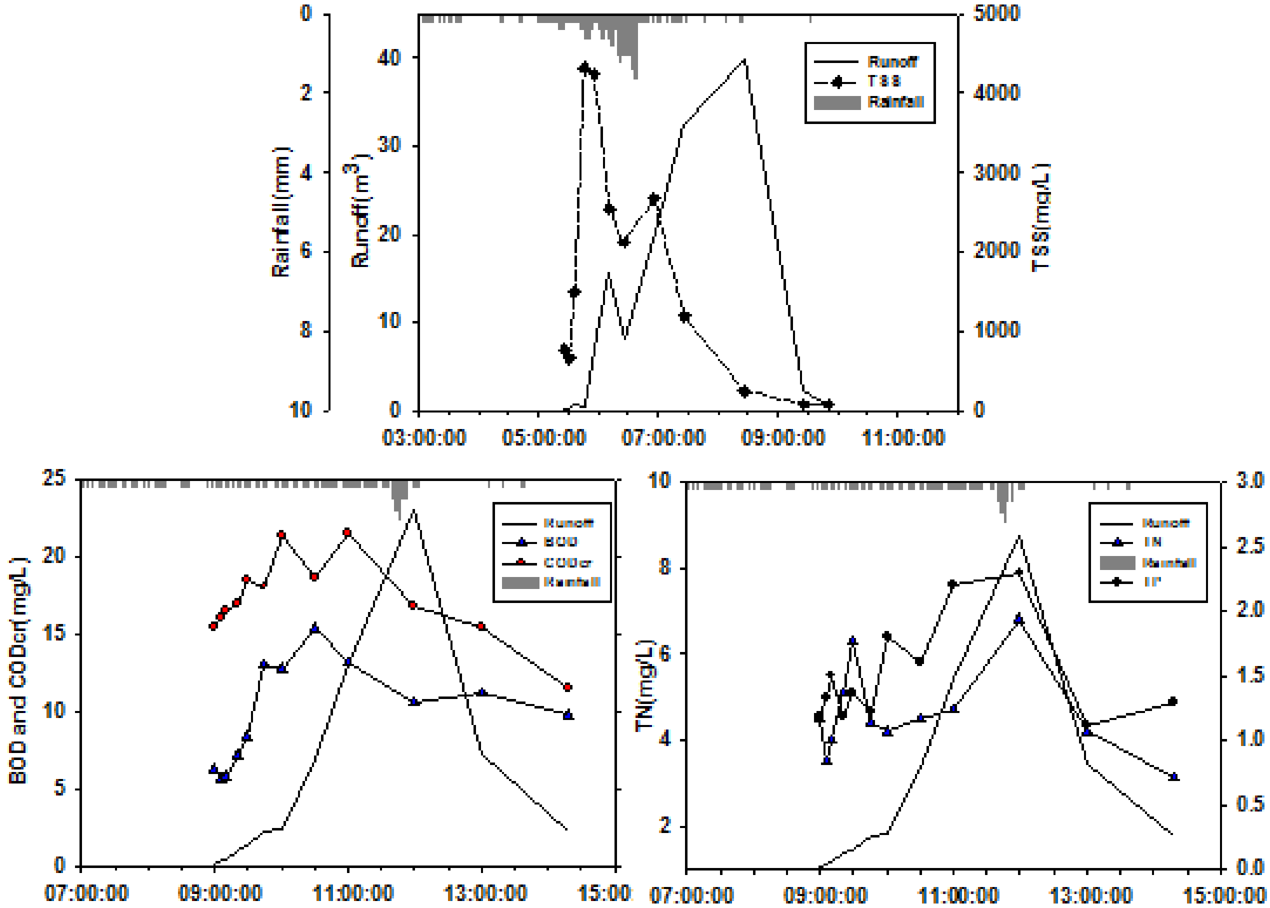


Fig. 2. Hydro and polluto graph (Event 9) Jeon et al.

earth and sand covered soil surface layer was washed off was discharged with stormwater runoff. Phenomenon like Fig. 2 is also well described in Fig. 3. As shown in Fig. 3, TSS was discharged as very high concentration immediately after occurrence of stormwater runoff. Also, it found that BOD and CODcr concentration increased with decrease of TSS concentration. And then, it was shown that TN and TP concentration started to increase with peak of stormwater runoff (BOD and CODcr concentration was already declining at this time). From these results, it is likely that outflow of pollutants generated from field covered with vinyl greenhouse during rainfall was discharged in order of particle material > organic material > nutrient salts.

3.3. Analysis of the first flush effect

To determine that the first flush effect of pollutants in stormwater runoff from catchment during rainfall, NCL-curve was used. NCL-curve is one of curve that can well show the runoff characteristics of rainfall. If pollutants concentration in stormwater runoff is the same by runoff interval, NCR-curve was demonstrated as straight line that slope value is 1, which angle of straight line is 45 degrees. If the slope value is greater than 1, it means to show the first flush effect that high concentration pollutants in the initial stage of stormwater runoff occurrence was discharged to rivers. And it means that the higher the slope of NCR-curve is 1, the stronger the first flush effect is. Therefore, in case of the slope is lower than 1, it means that an large amount of pollutants included in stormwater runoff is discharged in the middle and late stage of stormwater runoff occurrence [9]. The first flush effect graph on 32 event that the monitoring was conducted was shown in Fig. 4. The first flush effect of TSS was clearly shown. However, in other pollutants excepting TSS, some rainfall events showed the first flush effect, whereas others do not. The reason why the particle material clearly showed the first flush effect is as in the following. Most of catchment was consisted of impermeable by vinyl greenhouse. Therefore, it is likely that earth and sand, the body of plants and so on built up during dry weather was washed off by stormwater runoff gathered to the drain located between vinyl greenhouse and these was intensively discharged in the initial stage of stormwater runoff occurrence. The first flush effect of TSS was not shown in 5 events of total 32 events. Rainfall range of 5 events that the first flush effect was not shown was from 5 to 11 mm that the minimum rainfalls conducted the monitoring were. And average rainfall intensity of these rains was the range of 0.7 to 1 mm/h. Meanwhile, BOD, CODcr, TN and TP was determined that the slope of NCL-curve was close to 1. CODcr was analysed that the first flush effect was shown in higher rainfall intensity than 1.4 mm/h generally. The first flush effect of TN and TP was

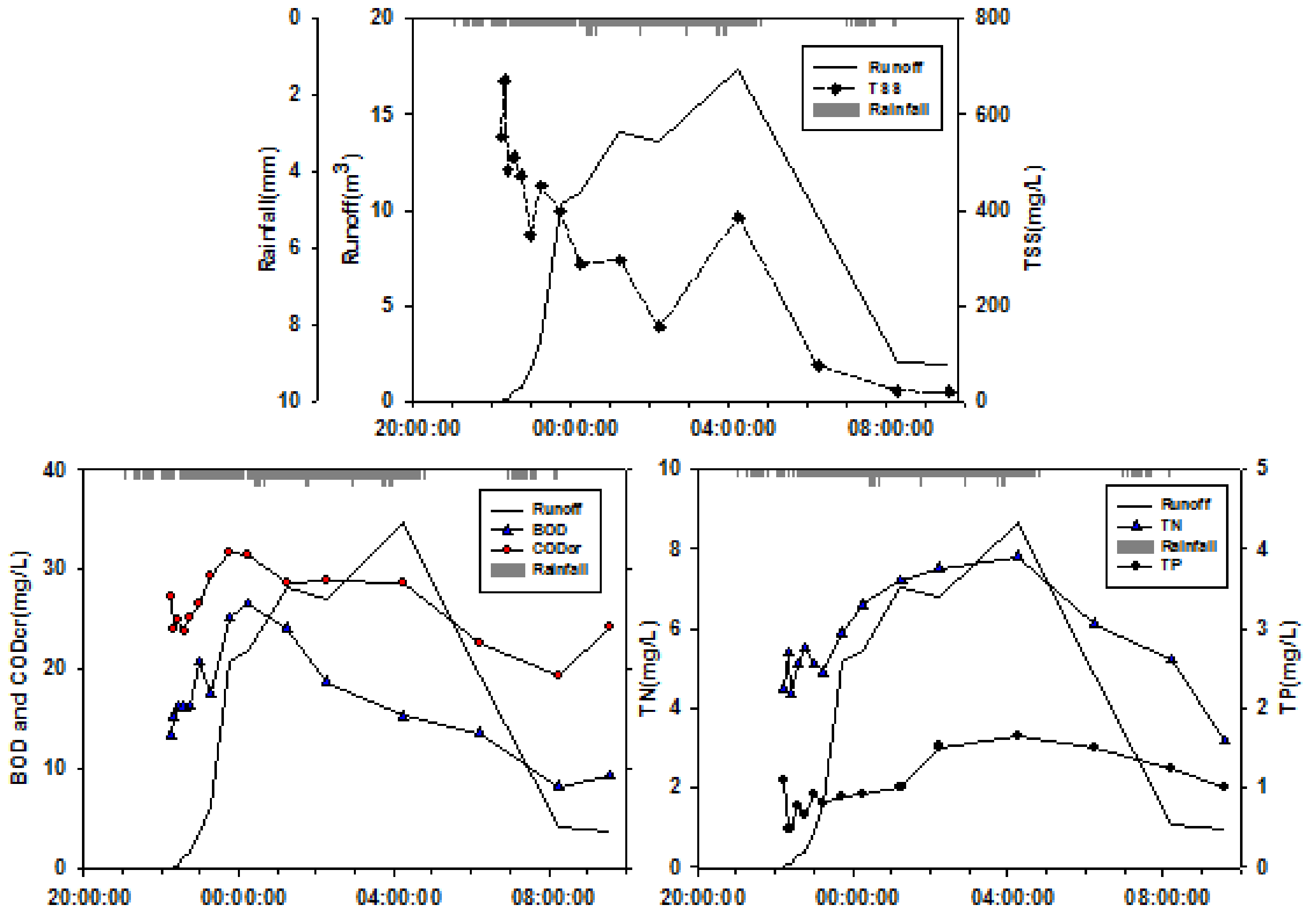


Fig. 3. Hydro and polluto graph(Event 12) Jeon et al.

shown in 2.2 mm/h of rainfall intensity that was stronger than that of CODcr. From the analysis results of NCR-curve as above, it found that the outflow characteristics of the first flush effect in the same catchment varied according to the rainfall intensity and the stronger rainfall intensity, it had a strong effect on the first flush effect of TN and TP. According to [10], conducting the study on permeable area, particle materials showed the strong first flush effect compared with other pollutants included dissolved solids, it is similar to the results of this study.

3.4. Variety of average concentration of pollutants by rainfall duration time

To research on runoff characteristics of pollutants thoroughly depending on the time that stormwater runoff was discharged, the results of statistical analysis using the concentration data of pollutants by the runoff time is shown in Fig. 5. Runoff concentration of TSS shown the peak between 5 and 10 min after stormwater runoff started to appear. At this point of time, average TSS concentration was analysed as the range of 405 to 599 mg/L. And then, TSS concentration was 462 mg/L after 30 min and 252 mg/L after 1 h. Meanwhile average TSS concentration was pretty decreased, after more than an hour. In contrast with TSS concentration, that of CODcr was increased between 30 and 60 after stormwater runoff occurrence. After that, it was again decreased. Average CODcr concentration showed the range of 17.8 to 18.5 mg/L during 10 min after stormwater runoff occurrence. After 30 min, it increased to 26.9 mg/L. And after 1 h, it showed 24.7 mg/L that was a little lower than that of 10 min after stormwater runoff occurrence. After 2 h, it was analysed as 14.7 mg/L of low concentration. Meanwhile, TN and TP determined peak concentration between 1 and 2 h after stormwater runoff occurrence. In the case of TN concentration, the range of 4.3 to 4.9 mg/L was analysed during 30 min after stormwater runoff occurrence. And the range of 5.1 to 5.9 mg/L was shown between 1 and 3 h. 2.7 mg/L during 30 min after stormwater runoff occurrence, and the TP concentration range of 2.2–3.3 mg/L was found between 1 and 3 h. Overall, the time when pollutants peak concentration was shown was as in the following. Particle materials was between 5 and 10 min, organic matters was between 30 and 60 min and nutrients salts was between 1 and 2 h after stormwater runoff occurrence.

3.5. Analysis of stormwater runoff rate

The outflow of pollutants during wet weather have strong interrelationship with stormwater runoff rate. Stormwater runoff rate can be defined as percentage of a total amount of stormwater runoff discharged to rivers on the volume of

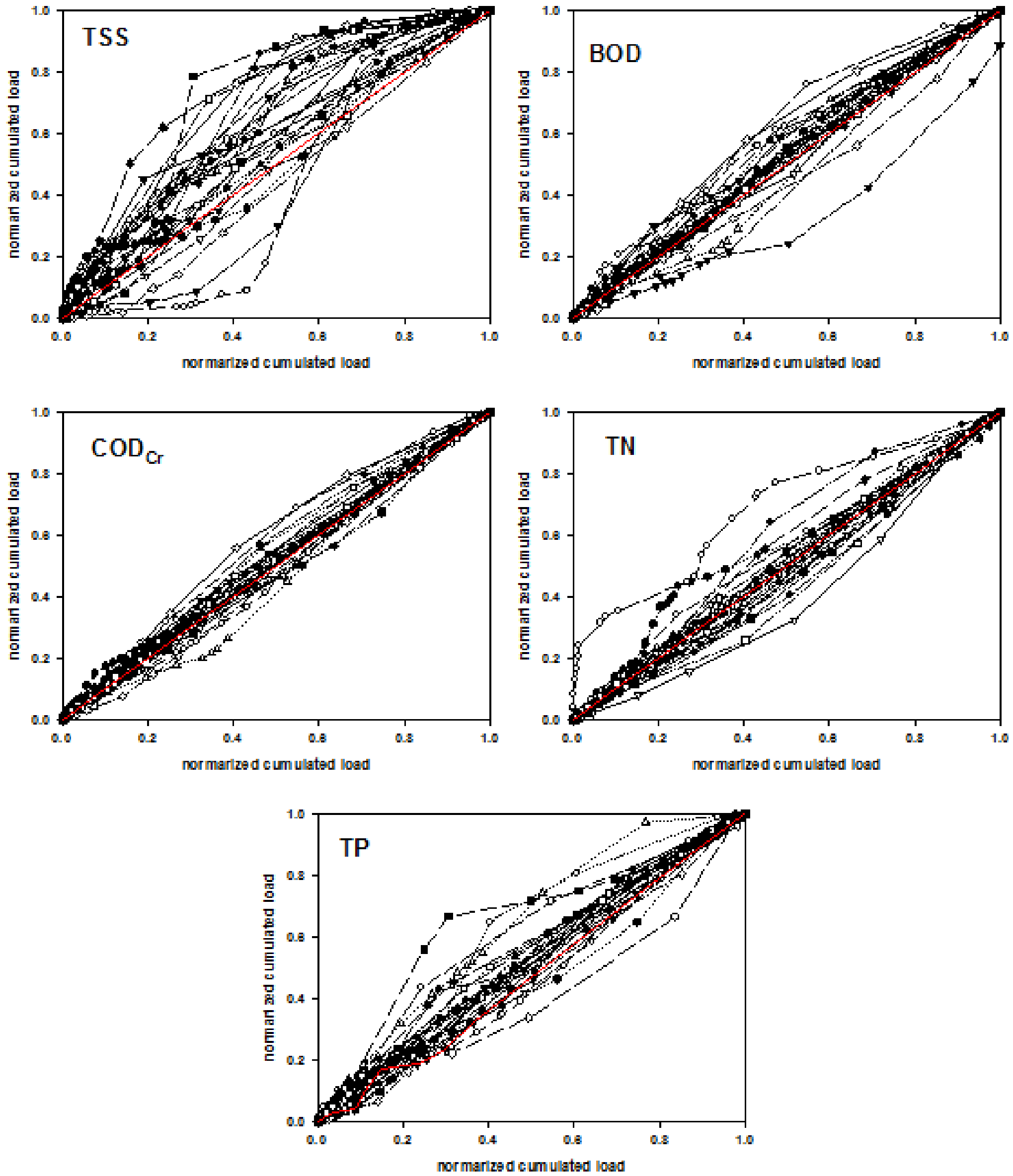


Fig. 4. NCL-curve of monitered rainfall event Jeon et al.

total rainfall in the catchment. It was calculated by using formula-1. The runoff height was calculated by dividing total runoff volume generated during wet weather into the catchment area.

$$\text{Runoff coefficient} = C = V_d / \sum_{N=1}^{M} R_m$$

$$\text{Runoff height (mm)} = V_d = V_i / A_w \quad (1)$$

$$V_i = / \sum_{i=l}^{M} Q_{ji} \bullet \Delta t$$

where, V_j is total rainfall volume (m^3) generated in the j area, Q_{ji} is ith flow rate (m^3/s) in the j area, Δt was measurement time, $\sum_{N=1}^{M} R_m$ is total rainfall (mm), Aw is catchment area (ha). In the case of impermeable area with high stormwater runoff such as road and bridge, pollutants built up during dry weather is more likely to be discharged with stormwater runoff. Although, a lots of pollutants during dry weather in soil that perviousness such as field is good, however, is accumulated, pollutants loads discharged to rivers during raining was considerably decreased because of low runoff rate. The analysis of runoff rate, therefore, is one of the major factors in characteristics of the NPS. The analysis of runoff rate of monitored event was conducted in this study. As a result, average runoff rate was 0.53 when average rainfall happens 32.8 mm (Fig. 6). The minimum runoff rate was 0.07 in the 7.2 mm rainfall and 1.2 mm/h rainfall intensity, the maximum runoff rate was 0.91 in the 72.6 mm and 4.6 mm/h rainfall intensity. Meanwhile, it was found that the results of runoff rate have the difference depending to rainfall. In under of 20 mm rainfall, the minimum runoff rate was 0.07 and the maximum runoff rate

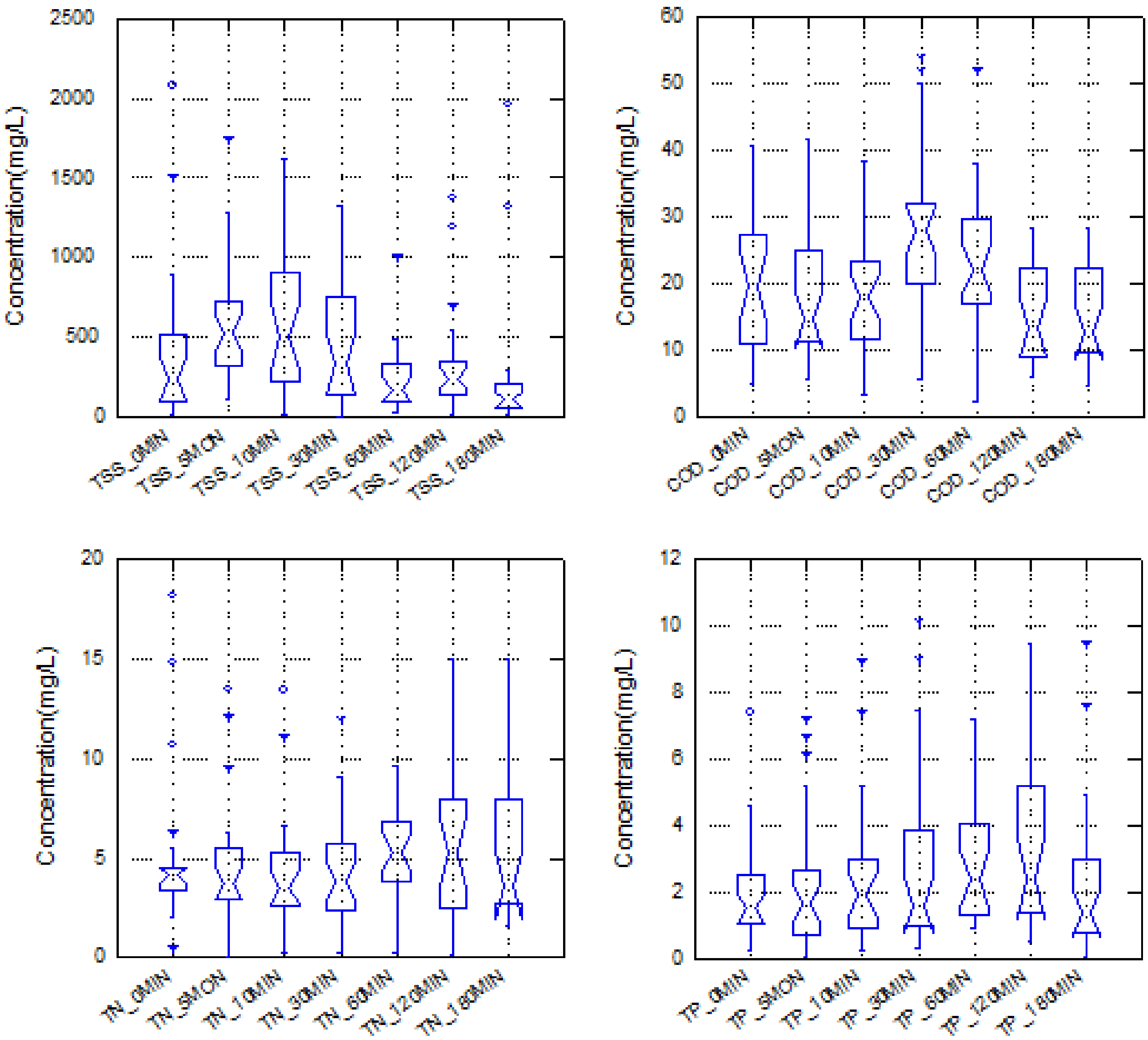


Fig. 5. Statistical range of pollutants by occurrence time of stormwater runoff Jeon et al.

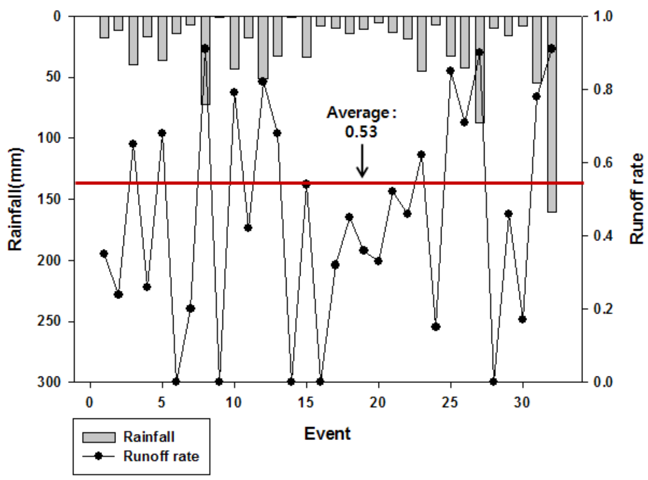


Fig. 6. Discharged ratio of stormwater runoff by rainfall Jeon et al.

was 0.52. And average runoff rate was 0.36. However, in over of 20 mm rainfall, the minimum runoff rate was 0.42, the maximum runoff rate was 0.91 and average runoff rate was 0.7. Runoff rate in 20 mm rainfall over was shown as around 1.5 times higher than that in 20 mm rainfall under.

Runoff rate of field where vinyl greenhouse was installed lower than that of road where have high impermeable area and higher than that of field where have high permeable area. Average stormwater runoff rate of highway conducted by [11] was 0.79. And according to the study of [8] conducted monitoring at vineyard have high permeable ratio, the range of runoff rate was from 0.38 to 0.43 under the range of 16.5–79.7 mm rainfall. High stormwater runoff rate means that it is very likely that pollutants accumulated in the catchment area during dry weather was discharged to waterbody with stormwater runoff generated during rainfall weather. Therefore, it is expected that field that greenhouse is installed than field that greenhouse don't be installed discharged more pollutants loads.

4. Conclusions

This study analysed the first flush effect of stormwater runoff discharge from tomato plantation in rural are to provide basic data for management NPS. The results is as below:

(1) Stormwater runoff from the field where vinyl greenhouse was installed occurred when about 15 mm rainfall was happened. This was time when the first rainfall started to drop and last about 2 to 4 h of time. Compared with stormwater runoff in field that greenhouse is not installed was occurred when rainfall dropped around 30 mm, that in vinyl greenhouse area needs less rainfall.

(2) In NCR-curve analysis to determine the first flush effect, the particle materials showed the strong first flush effect. And rainfall intensity influenced the first flush effect of pollutants, the stronger the intensity great influenced the runoff of nutrients salts.

(3) In the variety analysis of average pollutants concentration by rainfall duration time, TSS concentration showed the maximum value between 5 and 10 min after stormwater runoff occurrence, BOD and CODcr concentration was between 30 and 60 min. And TN and TP showed the maximum concentration between 1 and 2 h. Overall, peak concentration of pollutants appeared in order of particle materials, organic matters and nutrients salts.

(4) Minimum value of runoff rate generated from target area in this study during wet weather was 0.07 and maximum value was 0.91. And average runoff rate was 0.53. Runoff rate was difference depending on rainfall. Average runoff rate was 0.36 when under 20 mm rainfall happen, but it was 0.7 when above 20 mm rainfall dropped.

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