ISSN (Print) 1226-5268 ISSNS (Online) 2287-7169
The Journal of Engineering Geology, Vol.24, No.4, December, 2014, pp. 463-471
http://dx.doi.org/10.9720/kseg.2014.4.463

Monitoring of Non-point Source Pollutants Generated by a Flower Farm

Byoungwoo Choi and Meea Kang*
Dept. of Environmental Engineering, Andong National University, Andong, Korea

Received 13 November 2014; received in revised form 24 November 2014; accepted 28 November 2014

This paper considers the effect of rainfall on non-point source (NPS) pollutant loads. The impact of runoff on the occurrence of NPS pollutants was found to be influenced by rainfall amount, rainfall intensity, and the number of antecedent dry days (ADD), both independently and in combination. The close correlation ($R^2 = 0.9920$) between rainfall and runoff amounts was demonstrated at the study site (a flower farm) over the period between January 2011 and December 2013. The relationships among pollutant levels, runoff, and rainfall was not satisfactory results except for the Biochemical Oxygen Demand (BOD_5). The correlation coefficients between BOD_5, and both runoff and rainfall, were greater than 0.92. However, the relationships of other pollutants, such as Suspended Solid (SS), Chemical Oxygen Demand (COD_{Mn}), Total Nitrogen (TN), and Total Phosphorus (TP), with runoff and rainfall had correlation coefficients of less than 0.70. The roles of rainfall was different from rainfall categories on the occurrence of runoff. Instantaneous rainfall intensity was a principle factor on the occurrence of runoff following light rainfall events (total ≤ 30 mm). For rainfall of intermediate intensity (total precipitation 31-50 mm), the combined effect of both average rainfall intensity and ADD was found to influence runoff generation. We conclude that the control of NPS pollutants with the reflection of the climate change that makes the remarkable effect of amounts and forms on the rainfall and runoff.

Key words: NPS (non-point source), pollutant, runoff, rainfall

Introduction

Efforts to improve water quality in the watersheds have progressed well with respect to point source pollutants, but the management of NPS pollution remains a significant challenge. Water quality and pollutant loads in rainfall-derived runoff from cropland is not only influenced by climatic factors such as precipitation, rainfall intensity, and the number of preceding dry days, but also by agricultural factors such as the characteristics of the crops being cultivated (Oh et al., 2004; Shin et al., 2006; Kang et al., 2009; 2010a; 2010b; Ryu et al., 2011; Yoon et al., 2011; Kim et al., 2013; Choi and Kang., 2014). In addition, as a result of the recent increase in the frequency of droughts and flooding, it is be coming much more difficult to manage NPS pollutants in agricultural areas. It has been reported previously that the three major types of NPS pollutants in agricultural areas are sedimentation, nutrient salts, and pesticide runoff (Carpenter et al., 1998; Hunt et al., 1999; Schultz, 2004). The problems associated with increases in NPS pollutants from agricultural areas are also increasing overseas. In developing countries, the use of water is becoming more important because of thriving agricultural activities and health considerations, whereas in developed

---

*Corresponding author: wdream@andong.ac.kr

countries (Reddy and Behera, 2006), with the successful reduction of pollutants from point sources, NPS pollutants from agricultural areas are reported to contribute the highest proportion to total water pollution (Environmental Protection Agency, 2000). Rainfall-derived runoff from agricultural areas can contaminate surface water in various ways, and can be categorized into two types. One is direct runoff, through agricultural drainage into surface waters such as rivers, and the other is seeping underground, which creates cracks as source of water in the ground, or may directly affect the surface water contamination (Brian et al., 2008). Horan et al. (2002) attempted to develop an approach to managing both point source pollutants and NPS pollutants more economically, and proposed the combination ratio of the two pollutants as the most influential factor in efforts to meet planned water quality standards. In addition, they concluded that, because NPS only affect water quality in small watersheds, exchange programs between two (point and non-point)would be in effective. Although NPS pollutants are difficult to control because they are generated by runoff from rainfall that shows extreme temporal and spatial variations, it is widely accepted that they are the most significant factor in terms of achieving water quality improvements. This study aims to determine the impact of runoff from NPS on water pollution loads by identifying the major factors that affect the generation of rainfall-derived runoff. Rainfall data were obtained from monitoring conducted over the past three years at a floriculture site. We believe that our findings will contribute to the effective management of rainfall-derived runoff from NPS.

Methods

The flower farm used here as the monitoring site for NPS pollutants is typical agricultural land (Andong, South Korea: N36°32'37.8", E128°47'17.8"), and covers an area of 631.3 m^2 with a slope of 8.5%. A flower farm was selected as one of NPS in the classification scheme of the Ministry of Environment, Korea (2014a). Rainfall, runoff, and the pollutant load in the runoff were monitored at the farm between January 2011 and December 2013. Rainfall amounts and runoff rates were measured on a per-minute basis using a raingauge (Environdata weather station rain gauge, RG 20, Australia) and a flow meter (Flo-Tote3, USA), respectively, from the start of each rainfall event. However, for a very small amount of rainfall runoff where the measurement on per-minute basis was not possible, spills were taken into a beaker and runoff speed was calculated by dividing by the corresponding time. Runoff samples were collected by the National Institute for Environmental Research (NIER, 2012). The runoff samples were analyzed for SS, BOD_5, COD_{Mn}, TN and TP according to the procedures of the Ministry of Environment (2014b). The EMC (event mean concentration) and TPM (total pollutant mass) were calculated using the equations 1 and 2 (NIER, 2010, 2012).

$$EMC = \frac{M}{V} = \frac{\sum_{n=1}^{N}(Q_n \times \Delta t_n \times C_n)}{\sum_{n=1}^{N}(Q_n \times \Delta t_n)} \tag{1}$$

M : the total mass of pollutants over the entire event (g)
V : the total volume of flow over the entire event (m^3)
C : the concentration of pollutant (mg/L)
Q: the flow volume (m^3/min)
Δt : the time interval (min)
N : the number of measurements

$$TPM \text{ (total pollutant mass)} = EMC \times V \tag{2}$$

V : the total volume of flow over the entire event (m^3)

Results and discussion

Characteristics of precipitation

Over the monitoring period, rainfall fell a total of 310 times at the survey site, giving a total accumulation of 3279 mm. Rainfall data are shown in Table 1. Rainfall events of less than 10 mm accounted for 69.4% of all events, but only contributed 16.1% to the total rainfall accumulation, but it is difficult to identify any significant impact on the surface water from the classified data (Table 1). Thus, This suggests that the pollutants remain fixed within the farmland soil. As for the monitoring rate by rainfall class, 100% was performed in the range of ‘less

Table 1. Rainfall monitoring statistics.

Rainfall range (mm)	Rainfall occurrence			Rainfall events monitored	
	Rainfall (mm)	Frequency	Percentage (%)[a)]	Frequency	Percentage (%)[b)]
0 < rainfall ≤ 10	526.8	215	16.1	215	100.0
10 < rainfall ≤ 30	1176.5	66	35.9	12	18.2
30 < rainfall ≤ 50	745.0	18	22.7	5	27.8
50 < rainfall	830.5	11	25.3	5	45.5
Total	3278.8	310	100.0	237	76.5

*a : Rainfall amounts for each rainfall category/total rainfall amounts.

b : Number of rainfall events monitored for each rainfall category/total number of rainfall events for each rainfall category.

Table 2. Characteristics of rainfall events monitored.

Event No.	Date (YY/MM/DD)	Rainfall (mm)	ADD (day)	Average rainfall intensity (mm/hr)	Runoff duration (hr)	Runoff (m^3)
01	11/03/20	18.4	23	2.9	zero	zero
02	11/04/22	37.6	32	3.0	zero	zero
03	11/04/29	31.8	6	0.8	2.2	0.04
04	11/05/09	135.8	7	2.8	20.5	23.56
05	11/07/24	17.0	9	0.8	zero	zero
06	11/09/05	11.8	5	0.8	zero	zero
07	12/03/05	14.8	32	0.6	zero	zero
08	12/03/16	12.4	9	0.8	zero	zero
09	12/03/22	23.0	3	1.0	zero	zero
10	12/03/29	19.4	4	1.0	zero	zero
11	12/04/21	45.2	17	1.8	0.7	0.03
12	12/04/25	27.8	2	2.0	zero	zero
13	12/05/03	18.0	5	3.2	0.4	0.62
14	12/06/30	38.4	21	2.2	0.8	0.33
15	12/08/15	81.8	1	5.2	6.2	5.24
16	13/04/06	29.2	18	1.3	zero	zero
17	13/05/27	14.6	7	0.8	7.7	0.05
18	13/06/18	156.4	20	5.4	22.0	38.80
19	13/07/04	78.0	1	3.0	7.3	1.28
20	13/07/15	11.8	0.9	7.9	zero	zero
21	13/08/22	50.4	15	1.5	2.5	0.19
22	13/09/28	41.4	13	1.2	zero	zero

*Zero = no runoff.

than 10 mm', 18% in '10 to 30 mm', 28% in '30 to 50 mm', 45% in 'more than 50 mm'.

Rainfall characteristics influencing occurrence of runoffs

The characteristics of the monitored rainfall events are shown in Table 2 and Fig. 1. As rainfall in the < 10 mm category did not generate any runoff during the monitoring period, only the results for rainfall exceeding a total of 10 mm are shown in Table 2 and Fig. 1. In terms of monitored rainfall, there were 22 rainfall events exceeding 10 mm, with amounts of rainfall between 11.8 and 156.4 mm, and the number of antecedent dry days (ADD) was in the range 0.9 to 32 days. However, rainfall events in the ≤ 10

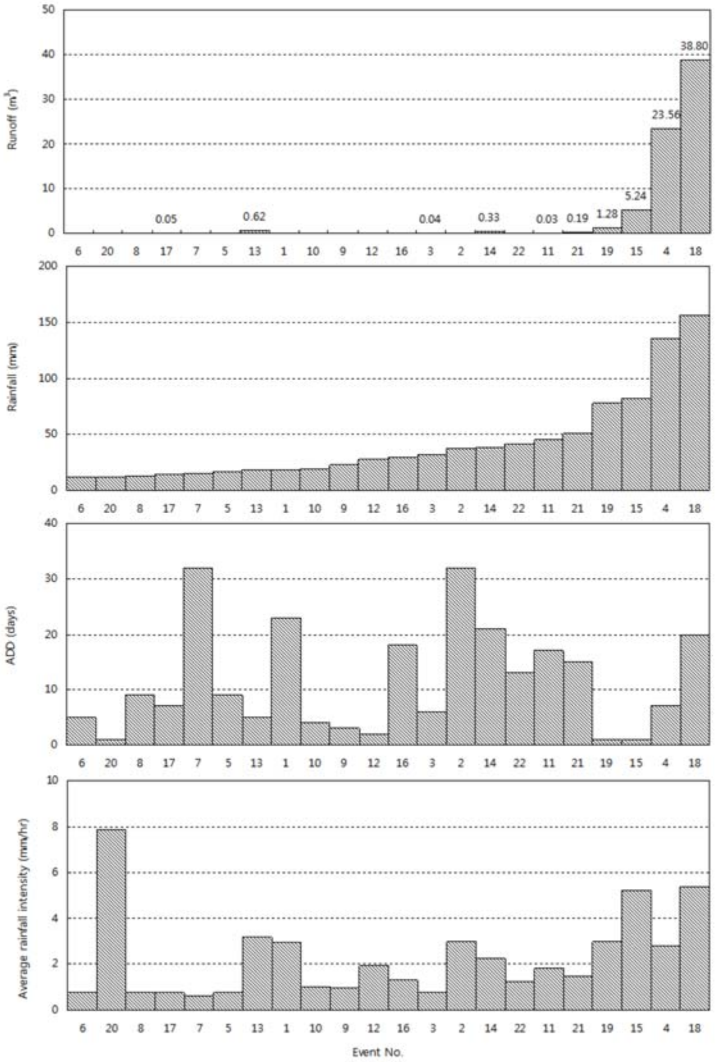

Fig. 1. Precipitation factors affecting runoff.

mm category were included in the count of dry days when calculating ADD.

For Event 20, 11.8 mm of rainfall, 0.9 days (22 hours) of ADD, and 7.9 mm of average rainfall intensity were recorded, and this was the shortest ADD and highest average rainfall intensity of all monitored rainfall events; however, no runoff was recorded. This suggests that rainfall was a more important control on the occurrence of runoff than average rainfall intensity or ADD. The correlation coefficient (R^2) between rainfall and runoff came out with avery significant value of 0.9920 for 10 of the rainfall

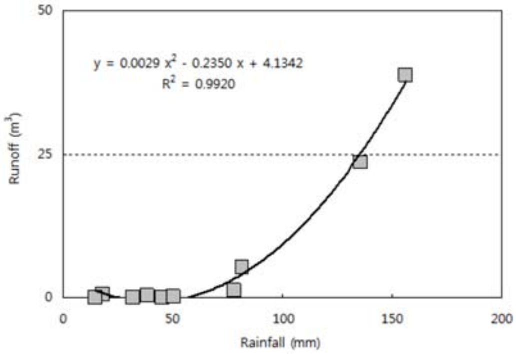

Fig. 2. Positive correlation between rainfall and runoff amounts.

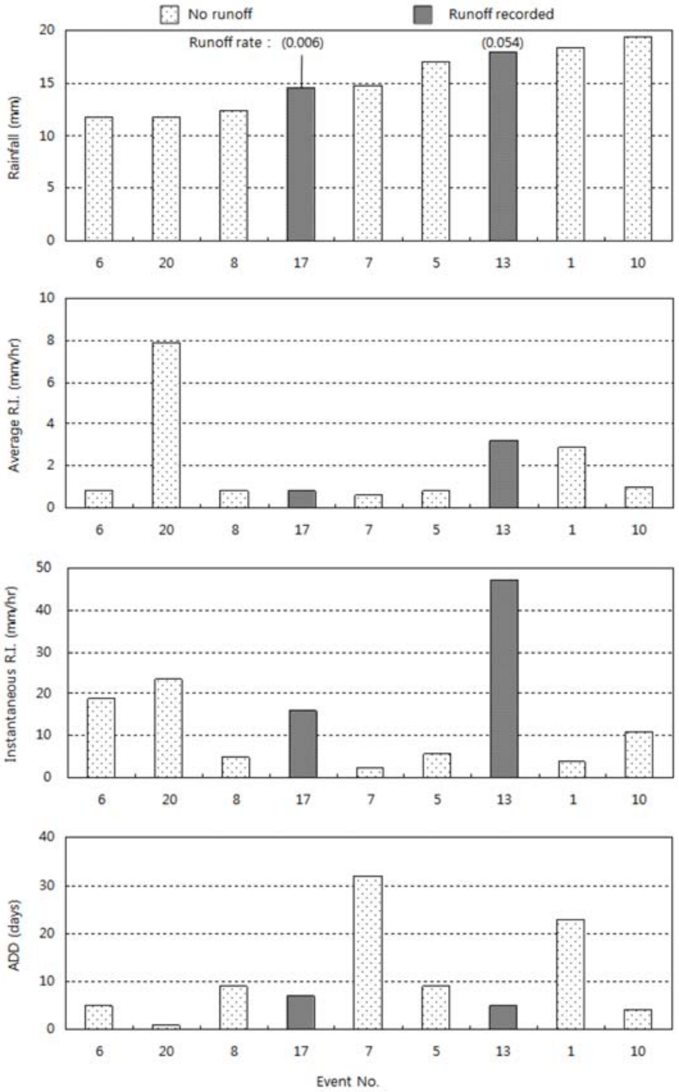

Fig. 3. Precipitation and runoff in the ≤ 20 mm category.
*Average R.I. : Average rainfall intensity during the event.
Instantaneous R.I. : Instantaneous maximum rainfall intensity during the event.

events where runoff occurred, and it can be seen that runoff also increases as rainfall increases (Fig. 2). On the other hand, the R^2 value between rainfall and runoff calculated from previous research at a potato farm was 0.6734 (Kang et al., 2009). The range of rainfall was less than 100 mm at this potato farm, and the correlation between rainfall and runoff was lower than that found here.

According to previous research by Kang et al. (2009, 2010b) on similar cropland close to the present study site, the average rainfall intensity is an important factor in the development of runoff for rainfall events in the ≤ 20 mm category. We recorded nine events in this ≤ 20 mm category (Fig. 3), but only two that generated runoff, namely Event 13 (rainfall total = 18.0 mm) and Event 17 (rainfall total = 14.6 mm). For Event 13, the average rainfall intensity was 3.2 mm/hr, but the instantaneous rainfall intensity was the highest in this category (≤ 20 mm) at 47.3 mm/hr. We interpret this to show that runoff occurred because of

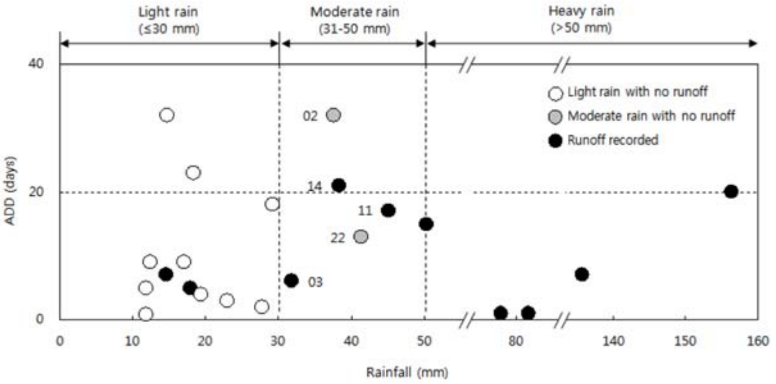

Fig. 4. Factors affecting runoff in each rainfall category.

the effect of the momentarily increased rainfall intensity. For Event 17, we also believe that the small amount of runoff (0.05 m^3) was generated by the relatively high instantaneous rainfall intensity (16.0 mm/hr), although the average rainfall intensity during this event was lower at 0.8 mm/hr. For Events 06 (rainfall total = 11.8 mm) and 20 (rainfall total = 11.8 mm), we believe that runoff did not occur because these events experienced the lowest rainfall totals in the ≤ 20 mm category, although the instantaneous rainfall intensities were 18.8 and 23.4 mm/hr, respectively. These observations suggest that instantaneous rainfall intensity is the most important control on the development of runoff for events in the ≤ 20 mm category.

For Events 02 and 22, runoff might have been expected to occur because rainfall totals were 37.6 and 41.4 mm, respectively; however, no runoff was recorded. For Event 02, the ADD was 32 days, the longest among all of the rainfall events monitored here, and this long ADD probably prevented runoff from occurring. For Event 22, we suggest that the lack of runoff was caused by the influence of the ADD (12 days) and average rainfall intensity (1.2 mm/hr). On the other hand, for Event 11 (rainfall total = 45.2 mm, ADD = 17 days) and Event 14 (rainfall total = 38.4 mm, ADD = 21 days), which were similar to Event 22, runoff was recorded. This is because the average rainfall intensity in Events 11 and 14 was higher than that of Event 22, at 1.8 and 2.2 mm/hr, respectively. Therefore, it can be seen that what influenced the occurrence of runoff in the 30-50 mm class was not a single factor, but the combined effect of multiple factors including average rainfall intensity and ADD (Fig. 4).

Events 15 (rainfall total = 81.8 mm, ADD = 1 day) and 19 (rainfall total = 78.0 mm, ADD = 1 day) showed a large differences in runoff with rates of 0.101 (runoff = 5.2 m^3) and 0.026 (runoff = 1.3 m^3), respectively, being recorded, although both events generated a similar amount of rainfall and had the same ADD value. Event 15 had higher average and instantaneous rainfall intensities than Event 19, with an average rainfall intensity of 5.2 mm/hr and an instantaneous rainfall intensity of 64.9 mm/hr, whereas Event 19 had an average rainfall intensity of 3.0 mm/hr and an instantaneous rainfall intensity of 9.5 mm/hr. Therefore, we suggest that the rate of runoff was higher in Event 15 because of the influence of the relatively higher average and instantaneous rainfall intensities. These results show that the amount of runoff was strongly affected by the average and instantaneous rainfall intensity. In addition, as runoff varied among events within the same rainfall class, depending on the correlation (R^2) between two parameters (runoff and rainfall), it can be seen that current NPS management methods used to estimate rainfall pollutant loads by classifying the rainfall events in terms of rainfall amounts have some limitations.

Pollutant runoff characteristics

The EMC values of the pollutants by rainfall event are shown in Table 3. The EMC of each pollutant was as follows: SS (6.31×10 mg/L ~ 1.27×10^4 mg/L), BOD$_5$ (2.87 mg/L ~ 9.98 mg/L), COD$_{Mn}$ (1.67×10 mg/L ~ 1.50×10^2 mg/L), TN (8.38×10^{-1} mg/L ~ 1.97×10 mg/L), TP (7.87

Table 3. EMC values of the pollutants (units: mg/L).

Event No.	SS	BOD_5	COD_{Mn}	TN	TP
03	1.27t N^{4}	7.49	1.00t N^{2}	1.97t N	8.41
04	5.93t N^{3}	4.09	1.10t N^{2}	1.26t N	6.26
11	7.92t N^{2}	3.53	1.67t N	4.16	2.29
13	8.42t N^{3}	9.98	1.50t N^{2}	1.85t N	1.06t N
14	1.08t N^{3}	2.87	4.35t N	3.22	1.72
15	3.32t N^{2}	5.41	2.43t N	8.38t N^{-1}	7.87t N^{-1}
17	1.23t N^{3}	6.55	4.25t N	3.74	2.39
18	3.98t N^{2}	3.68	1.84t N	2.38	9.09t N^{-1}
19	6.47t N^{2}	5.21	3.87t N	3.83	9.09t N^{-1}
21	6.31t N	4.15	2.42t N	1.63	2.25

*t N = × 10

Table 4. Pollutant load per event (units: g).

Event No.	SS	BOD_5	COD_{Mn}	TN	TP
03	5.69t N^{2}	3.35t N^{-1}	4.49	8.82t N^{-1}	3.77t N^{-1}
04	1.40t N^{5}	9.63t N	2.58t N^{3}	2.97t N^{2}	1.47t N^{2}
11	2.48t N	1.11t N^{-1}	5.23t N^{-1}	1.31t N^{-1}	7.22t N^{-2}
13	5.21t N^{3}	6.18	9.31t N	1.14t N	6.54
14	3.61t N^{2}	9.62t N^{-1}	1.46t N	1.08	5.76t N^{-1}
15	1.74t N^{3}	2.83t N	1.27t N^{2}	4.39	4.12
17	6.65t N	3.55t N^{-1}	2.30	2.03t N^{-1}	1.29t N^{-1}
18	1.55t N^{4}	1.43t N^{-2}	7.16t N^{2}	9.25t N	3.53t N
19	8.27t N^{2}	6.67	4.95t N	4.89	1.16
21	1.21t N	7.97t N^{-1}	4.65	3.12t N^{-1}	4.32t N^{-1}

*t N = × 10

$\times 10^{-1}$ mg/L ~ 1.06×10 mg/L). The pollutant with the largest range of EMC was SS, and the least variations in the concentration were shown in BOD_5.

As shown in Table 4, the pollutant loads by rainfall event were as follow: SS (1.21×10 g ~ 1.40×10^5 g), BOD_5 (1.11×10^{-1} g ~ 1.43×10^2 g), COD_{Mn} (5.23×10^{-1} g ~ 2.58×10^3 g), TN (1.31×10^{-1} g ~ 2.97×10^2 g), TP (7.22×10^{-2} g ~ 1.47×10^2 g). As for variation in the pollutant loads, SS, COD_{Mn} and TP were at the level of 10^4 while BOD_5 and TN were at the level of 10^3.

The correlation of the pollutant loads with rainfall and runoff are shown in Fig. 4. Rainfall and BOD_5 show the highest correlation (R = 0.92), followed by rainfall-TN (0.71), rainfall-COD_{Mn} (0.70), rainfall-TP (0.67), and rainfall-SS (0.58). For the relationship between runoff and pollutant loads, runoff-BOD_5 showed the highest correlation of 0.99, followed by runoff-TN (0.68), runoff-COD_{Mn} (0.66), runoff-TP (0.63), and runoff-SS (0.53).

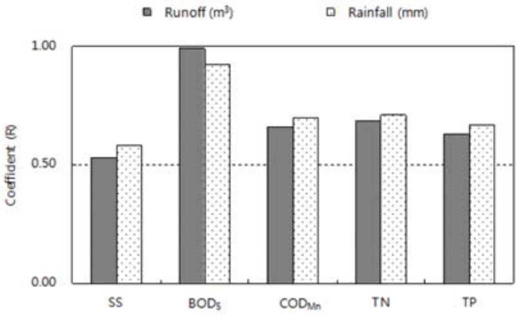

Fig. 5. Relationship among pollutant load, runoff and rainfall.

As correlation levels between rainfall and runoff and pollutant loads did not vary among the individual pollutants, a higher correlations were not observed in each pollutant except in BOD_5. In contrast, correlations between the pollution loads of SS and other pollution loads were shown higher with the SS-BOD_5 ($R = 0.57$), SS-COD_{Mn} (0.99), SS-TN (0.98), SS-TP (0.99). Therefore, when developing predictive models for NPS management of the agricultural area in the future, it is considered to be effective to establish a baseline by using the pollution loads of SS.

Conclusions

During the monitoring period, the highest rainfall total recorded was 156.4 mm, and this generated runoff of 38.80 m^3. The relationship between runoff (y) and the total amount of rainfall in an event (x) can be expressed by the equation $y = 0.0029x^2 - 0.2350x + 4.1342$ ($R^2 = 0.9920$). However, class-specific factors (i.e., related to the total amount of rainfall)were found to influence runoff, either singly or in combination. Looking at the factors affecting runoff by rainfall class, instantaneous rainfall intensity only played a role as a single factor in the lower rainfall range (≤ 30 mm), whereas the average rainfall intensity and ADD acted together at intermediate rainfall amounts (31-50 mm). In the higher range (> 50 mm), runoff occurred for all rainfall events. On the other hand, as a result of the influence of rainfall intensity, the rate of runoff varied considerably between similar levels of rainfall. Therefore, the current method of calculating NPS pollutant loads on the basis of a single factor classified by rainfall class has proven to be very limited in its effectiveness.

Variations in the concentration of pollutants in runoff are experiencing dynamic changing process, with SS on the level of 10^3 and others on the level of 10^2 while correlation is shown higher with more than 0.98 in loads of SS and those of BOD_5, COD_{Mn}, TN and TP (except 0.57 in the BOD_5). Therefore, it is expected that the pollution level in rainfall-generated runoff can be reduced through the management of soil effluents causing the increase in SS.

Acknowledgements

This research was supported by the project entitled *Research on NPS integrated monitoring and Management* funded by the Nakdong Basin Management Committee (No.07hwan-4-2011~2013).

References

Brian, M. D., Daniel, P., and Huertos, M. L., 2008, Agricultural nonpoint source water pollution policy: The case of California's Central Coast, Agriculture, Ecosystems and Environment, 128, 151-161.

Carpenter, S. R., Caraco, N. R., Correll, D. L., Howarth, R. W., Sharpley, A. N., and Smith, V. H., 1998, Nonpoint pollution of surface waters with phosphorus and nitrogen, Ecological Applications, 8(3), 559-568.

Choi, B. and Kang, M., 2014, Monitoring pollutants occurred by non point sources - rainfall runoff from cultivated lands for a sweet potato and a cherry tree -, Journal of Korean Society of Environmental Engineering, 36(1), 13-19 (in Korean with English abstract).

Environmental Protection Agency (EPA), 2000, Office of transportation and air quality, National Water Quality Inventory, EPA, Washington, DC.

Horan, R. D., Shortle, J. S., and Abler, D. G., 2002, Point-nonpoint nutrient trading in the Susquehanna river basin, Water Resources Research, 38(5), **8**-1-12

Hunt, J. W., Anderson, B. S., Phillips, B. A., Tjeerdema, R. S., Puckett, H. M., and deVlaming, V., 1999, Patterns of aquatic toxicity in an agriculturally dominated coastal watershed in California, Agriculture, Ecosystems and the Environment, 75(11), 75-91.

Kang, M., Choi, B., and Lee, J. K., 2010a, Correlation analysis on the runoff pollutants from a small plot unit in an agricultural area, Environmental Engineering Research, 15(4), 191-195.

Kang, M., Choi, B., and Yu, J. J., 2010b, Loading characteristics of non-point source pollutants by rainfall - case study with cherry tree plot-, Journal of Engineering Geology, 20(4), 401-407 (in Korean with English abstract).

Kang, M., Jo, S. H., Choi, B., Yoon, Y. S., and Lee, J. K., 2009, Loading characteristics of non-point source pollutants by rainfall -case study with sweet potato plot-, Journal of Engineering Geology, 19(2), 365-371(in Korean with English abstract).

Kim, J. Y., Hwang, J. Y., Ji, Y. D., Park, S. Y., Kim, D. H., and Lee, Y. J., 2013, Analysis of first flushing effects and event mean concentration of non-point pollutants from golf course during rainfall, Journal of Water Treatment, 21(3), 31-38 (in Korean with English abstract).

Ministry of Environment, 2014a, Environmental geographic information system, Report, Retrieved from http://egis.me.go.kr/ba/grdCoverIntroPage.do?mode=2 (in Korean).

Ministry of Environment, 2014b, Korean water analysis method, Notification No. 2014-163 of the Ministry of Environment, 1203p (in Korean).

National Institute of Environmental Research (NIER), 2010, A long-term monitoring for the non-point source discharge, Report, 561p (in Korean).

National Institute of Environmental Research (NIER), 2012, Stormwater monitoring, Guideline, 12p (in Korean).

Oh, Y. T., Park, J. C., Kim, D. S., and Rhyu, J. K., 2004, Pollutant characteristics of nonpoint source runoff in okcheon stream, Journal of Korean Society on Water Quality, 10(6), 657-663 (in Korean with English abstract).

Reddy, V. R. and Behera, B., 2006, Impact of water pollution on rural communities: An economic analysis, Ecological Economics, 58, 520-537.

Ryu, K., Lee, G., Seong, J., Kim, D., and Park, J., 2011, Runoff characteristics of non-point pollutant sources in an agricultural area watershed, Journal of Korean Society of Limnology, 44(2), 178-186 (in Korean with English abstract).

Schultz, R., 2004, Field studies on exposure, effects and risk mitigation of aquatic nonpoint-source insecticide pollution: a review, Journal of Environmental Quality, 33(2), 419-448.

Shin, Y., Lyou, C., Choi, Y. H., Lim, K. J., and Choi, J., 2006, Pollutant load characteristics by baseflow in a small agricultural watershed, Journal of Korean Society on Water Quality, 22(2), 244-249 (in Korean with English abstract).

Yoon, Y. S., Kwon, H. G., Lee, J. W., Yu, J. J., and Lee, J. K., 2011, Analysis of first flushing effects for the vineyard storm runoff, Journal of Environmental Science International, 20(8), 977-986 (in Korean with English abstract).

Byoungwoo Choi
Dept. of Environmental Engineering
Andong National University
1375 Gyeongdong-ro, Andong,
Gyeongbuk 760-749, Korea
Tel: 054-820-7881
E-mail: luki21@hanmail.net

Meea Kang
Dept. of Environmental Engineering
Andong National University
1375 Gyeongdong-ro, Andong,
Gyeongbuk 760-749, Korea
Tel: 054-820-6267
E-mail: wdream@andong.ac.kr