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Evaluation on the environmental effects of rain garden treating roof stormwater runoff

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지붕 강우유출수를 처리하는 빗물정원의 환경적 효과 평가

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Abstract

In this research, the environmental effects of rain garden when applied to a stormwater runoff originated from a rooftop were evaluated. The rain garden that was utilized as LID represents less than 1% of the catchment area that it drains. Storm event monitoring was conducted from March 2012 to August 2014 on a total of 19 storm events. In the 19 storm events that was monitored only 32% produced an outflow which has a mean rainfall characteristic of approximately 25 mm. With the application of rain garden, hydrologic improvement was observed as the facility exhibit a delay and reduction in the production of runoff and peak flows as the rainfall progresses. Furthermore, in terms of pollutant reduction, it was observe that the rain garden showed a generally satisfactory performance in reducing pollutants. In addition to this, the rain garden also has additional attributes that adds to the aesthetic appeal of the surrounding environment as well as in the lives of the people. The findings of this research will help in the further improvement and reinforcement of LID designs.

Key words : low impact development, pollutants, rain garden, roof runoff

요 약

빗물정원은 강우유출수를 현장에서 관리하는 LID 기술이며 보통 유역면적의 1% 이내의 면적에 적용된다. 본 연구는 지붕 강우유출수를 처리하는 빗물정원의 환경적 효과를 평가하기 위하여 수행되었으며, 강우시 모니터링은 2012년 3월부터 2014년 8월까지 총 19개의 강우사상에 대해 수행되었다. 19개의 강우사상 중에서 빗물정원에 유입된 강우유입수가 유출된 경우는 약 32%로 나타났으며, 이 경우 평균 강우량은 25mm으로 나타났다. 모니터링 결과 빗물정원은 강우시 첨두 유출율을 낮추고 지연시킴으로써 수문학적 물순환 특성을 개선시키는 것으로 나타났다. 또한 빗물정원은 강우량 25mm 이하의 강우유출수의 대부분을 저류 및 침투시킴으로써 지붕에서 유출되는 비점오염물질 저감에 크게 기여하는 것으로 평가되었다. 빗물정원은 물순환 및 비점오염물질 저감과 더불어 경관성을 제공함으로써 시민들의 심미적 효과에 기여하는 것으로 평가되었다. 본 연구에서 수행된 결과는 향후 빗물정원의 설계인자로 활용 가능하다.

핵심용어 : 저영향개발, 오염물질, 빗물정원, 지붕유출수

1. Introduction

Urbanization is the continuous development of urban areas that has long been perceived as one of the detrimental forces altering the natural hydrologic cycle and stream ecosystem (Hamel et al., 2013). Furthermore, urban areas also have been found to decrease low flows in streams as a result of less recharge of groundwater from precipitation (Ferguson and Suckling, 1990; Dietz and Clausen, 2005). Increase in peak runoff velocity and decrease in lag time due to urbanization were also noted by Leopold (1968). Urban areas also contribute pollutants to stormwater such as sediment, nitrogen phosphorus and heavy metals, impairing downstream habitat and water quality (Novotny and Olem, 1994).

A number of studies have indicated that rooftop runoff can be a major contributor of heavy metals to aquatic systems (Lye, 2009). According to Good (1993), runoff from sawmill rooftops along the coast of Washington in the northwestern United States characterized the runoff water as exceeding

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ambient water quality (USEPA, 1986) guidelines for copper, lead, zinc. Also, Simmons et al. (2001) investigated one-hundred and twenty-five domestic rooftop rainwater systems in Auckland districts for levels of heavy metals and found out that 14% of the systems exceeded New Zealand levels for lead in drinking water, 2% for copper levels and 1% exceeded zinc guidelines. Gromaire et al., (2001) studied runoff pollution at an experimental district in Paris, France and calculated that roof runoff contribute more than 80% of the cadmium, lead and zinc contamination during wet weather flow in the combined sewer system for the entire study site. Van Metre and Mahler (2003) also reported that rooftop runoff from buildings at Camp Mabry in Austin, Texas contributed as much as 55% of the heavy metal concentrations measures in the total watershed loads.

In response to this, low impact development (LID) technology is a sustainable development approach that aims to restore the flow regime closer to the pre-developed level and at the same time enhance the runoff quality (Bratieres et al., 2008). Moreover, LID technology incorporates infiltration, filtration, detention, retention, and evapotranspiration in order to enhance the stormwater quality and to preserve the natural hydrologic cycle (PGC, 1999). Rain garden commonly termed as bioretention are becoming a widely applied stormwater treatment system due to the system's flexibility in terms of design. The goal of the rain garden follows the overall basic LID site design principle which is to achieve stormwater management goals and to create a livable place to shop, relax and recreate (US DoD, 2004). Additionally, rain gardens lead to partial restoration of the pre-development hydrology of an impervious urban area. Therefore, this research was conducted in order to evaluate the environmental effects of rain garden facility managing roof stormwater runoff inside a university campus.

2. Materials and method

2.1 Description of LID site

The rain garden was located in Kongju National University Campus in Cheonan City, South Korea. The rain garden was developed to reduce stormwater runoff volume and pollutant concentration in an impervious roof deck with an area of 200 m^2 and a slope of 0.83%. The facility has a storage volume of 9.6 m^3 and has pre-settling tank, filtration, infiltration and evapotranspiration treatment mechanisms. Furthermore, the rain garden provides pollutant treatment by utilizing several processes such as adsorption, decomposition, ion exchange and volatilization (Prince's George County, 1993). The rain garden facility was made up of soil and filter media (i.e., sand, gravel and woodchip) which stores runoff in the void spaces of the aggregate material for filtration and adsorption of pollutants, and planted on the surface.

2.2 Sampling and Data analyses

Twelve (12) samples were gathered through manual sampling to effectively obtain the water quantity and quality of the runoff for every storm events. The six water samples were collected as soon as the runoff enters the facility with a time interval of 0, 5 10, 15, 30 and 60 minutes which corresponds to the "*first flush phenomenon*" of each storm

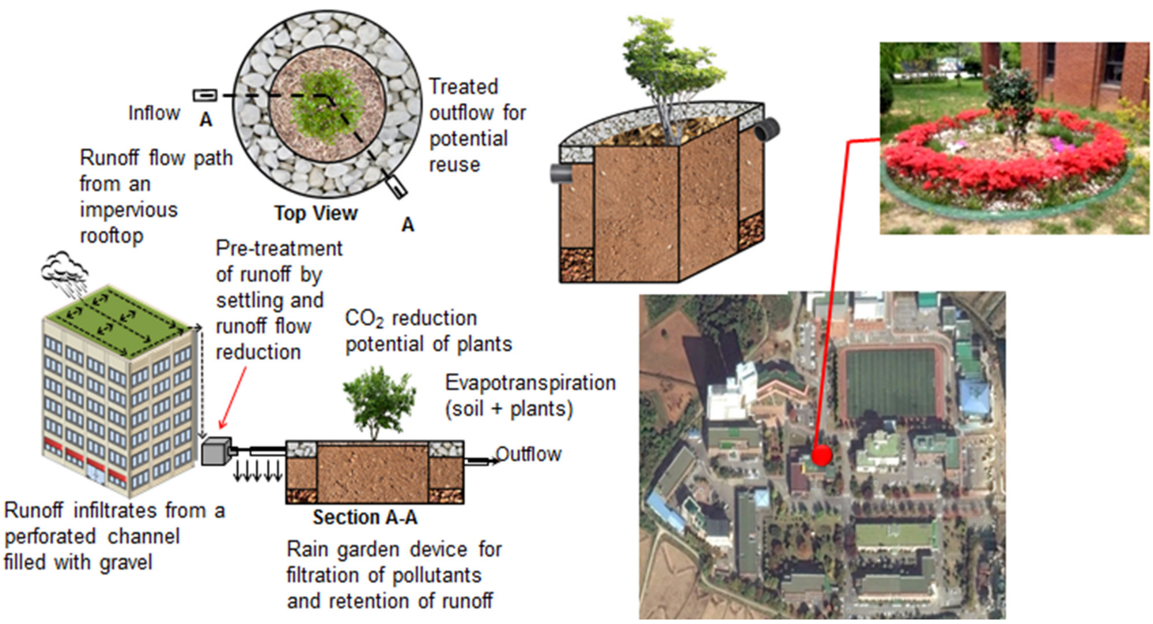

Fig. 1. Design, schematic and location of the rain garden facility.

event. Another six grab samples were gathered having a 1 hour time interval until the end of runoff. The mentioned sampling scheme was performed on both inflow and outflow of the rain garden and was based on the typical sampling scheme in Korea (Jung et al., 2008). However, for most of the shorter events, the scheme was modified by adjusting the number of samples until the runoff ended. In addition to the samples collected for water quality analysis, continuous flow measurements were performed and recorded using a 5-minute interval. The monitoring of storm events for the rain garden was conducted during a period of thirty (30) months from March 2012 to August 2014 with a total of 19 storm events. Other hydrologic parameters such as rainfall, rainfall intensity, antecedent dry day (ADD), etc. were obtained from Korea Meteorological Administration (KMA). Water quality parameters such as total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP) and heavy metal such as lead (Pb), copper (Cu), and zinc (Zn)were analyzed in accordance to the Standard Methods of Examination of Water and Wastewater.

3. Results and Discussion

3.1 Characteristics of monitored storm events

Table 1 shows the statistical summary of the monitored storm events in the rain garden facility. Among the 19 storm events monitored, only 6 events which are equal to 32% were able to produce an outflow for the rain garden caused by rainfall depth and runoff volume. The mean total rainfall that generated an outflow is 25.17mm with a rainfall duration of 4.90 hours which means that when the generated rainfall is more than 20mm, the facility will produce an outflow. Furthermore, it can be seen that during this condition, the antecedent dry day (ADD) has the highest mean value which can be said that ADD is directly proportional with the rainfall depth. According to Geronimo et al, (2013), the hydraulic retention time (HRT) in dependent on the rainfall duration wherein as the rainfall duration increases so as the HRT. Apparently, it was observe that the rainfall duration of 4.90 hours and a mean rainfall depth of 25.17 exhibited an HRT of 7.86 hours. On the other hand, rain garden can achieve 100% volume reduction when the mean rainfall depth is less than or equal to 5mm and when the runoff duration has a mean value of approximately 2.83 hours.

3.2 Hydraulic condition before and after rain garden application

The summary of the hydraulic condition before and after the application of rain garden is shown in Table 2. It was observed that the rain garden acquired a mean runoff volume of 1.26 m^3 and discharged a 0.14 m^3 of runoff in all storm events monitored which indicates an approximately 89% volume reduction after the application of rain garden facility. On average, it can be seen that the peak flow is four times greater than the average flows before rain garden. Furthermore, it was clearly shown that the average and peak flow rates were reduced by 83% and 75%, respectively. On the other hand, it was monitored that in order to produce an outflow in the rain garden facility the runoff volume should be greater than or equal to 2.94 m^3. However, the rain garden achieved 100% volume reduction when the runoff volume is less than or equal 0.48 m^3. The storm events that generated an outflow exhibit a peak flow rates eight times greater than the average peak flow rates compared

Table 1. Summary of monitored storm events

Condition	N storm events*	ADD (day)	Rainfall depth (mm)	HRT** (hr)	Rainfall duration (hr)	Runoff duration (hr)
Total storm events	19 (100%)	6.63	11.55	2.48	4.26	3.36
No outflow	13 (68%)	4.45	5.27	-	3.97	2.834
With outflow	6 (32%)	11.3	25.17	7.86	4.90	4.52

* N=number of storm events and values in parentheses denotes proportion to the total storm events
** HRT=hydraulic retention time

Table 2. Hydraulic condition before and after the application of rain garden.

Condition	N storm events*	Volume		Average flow rate		Peak flow rate	
		Before RG (m^3)	After RG (m^3)	Before RG (m^3)	After RG (m^3)	Before RG (m^3)	After RG (m^3)
Total	19 (100%)	1.26	0.14	0.006	0.001	0.028	0.007
No outflow	13 (68%)	0.48	-	0.006	-	0.017	-
With outflow	6 (32%)	2.94	0.43	0.009	0.003	0.052	0.024

*N=number of storm events and values in parentheses denotes proportion to the total storm events to the no outflow condition with peak flow three times the average flow rates. Apparently, the storm events that produced an outflow reduced the volume, average and peak flow rates by 85%, 67% and 54%, respectively indicating that the runoff was partially reduced upon the application of rain garden facility.

The linear regression plots displaying the relationship between the runoff volume and average flow rates before and after the application of rain garden are shown in Figure 2. The figure only analyzed the storm events that generated an outflow to prevent partiality in the data analysis. The runoff volume reduced by the facility was due to the combined mechanisms of infiltration, evapo-transpiration, and retention in the rain garden. It was observed that the amount of volume reduced is bigger than the discharged runoff by the facility. Furthermore, the percentage of volume discharge increases with the corresponding increase in the runoff volume generated in the facility. Same with the average flows before and after rain garden, a satisfactory decrease in the amount of average flows was observed upon the application of rain garden. In addition, the trendline fall below the 1:1 line suggesting the hydrologic improvement contributed upon the application of rain garden.

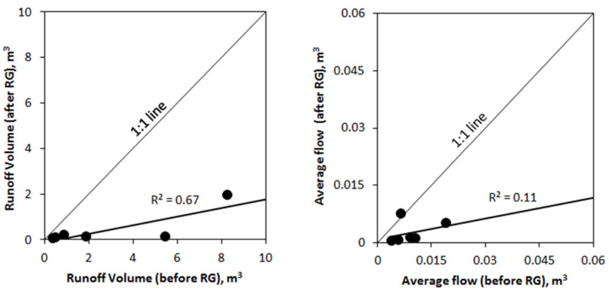

Fig. 2. Volume and average flows before and after rain garden application.

3.3 Pollutant concentration before and after rain garden application

Figure 3 shows the average inflow and outflow concentration with respect to sample collection time. All the figures shown started in the zero hour in order to directly compare the changes in the concentration of pollutants; however, in actual conditions, the inflow and outflow didn't happen all at the same time. Before the outflow occurred, the runoff underwent the process of retention inside the facility wherein it was stored for an average length of time before it was discharged.

The data included are the 32% of the storm events that produces an outflow. It was observed that the rooftop has a low concentration of pollutants since it is not exposed to vehicular activities and other various sources that can cause additional concentration of pollutants. Furthermore, the rain garden exhibited an average removal efficiency of 79% for all pollutants except total suspended solids (TSS) and total iron (total Fe). Based on the analysis it was found out that all pollutants have been effectively reduced by the rain garden wherein it can be said that the facility generally performed a satisfactory performance in reducing the

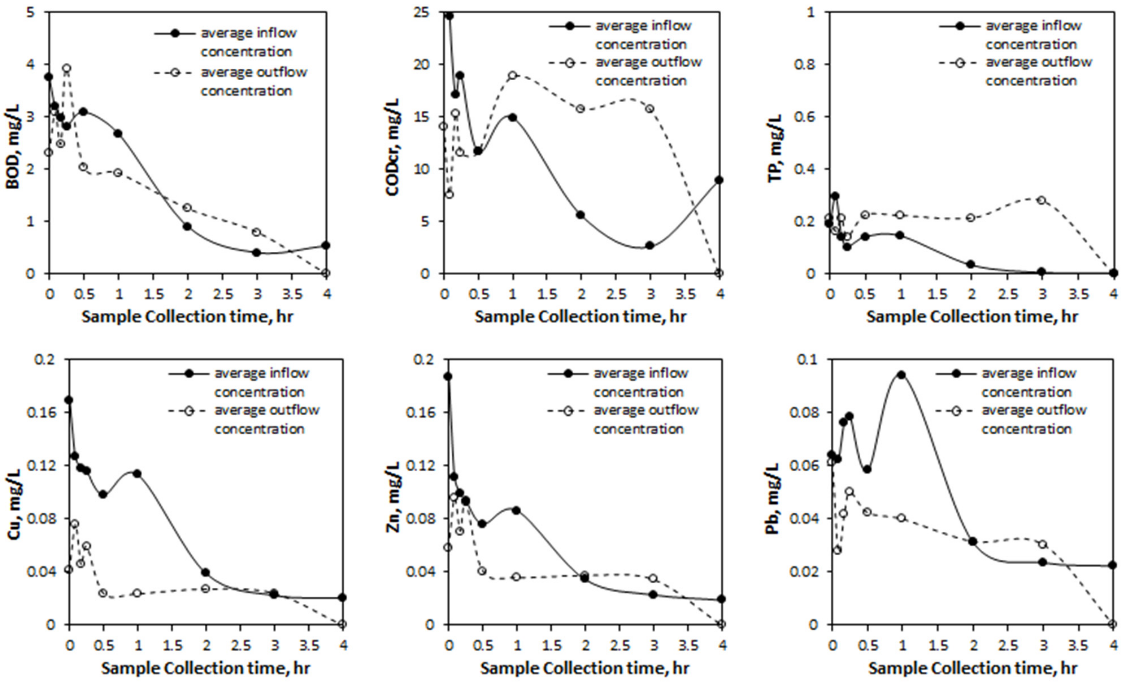

Fig. 3. Average inflow and outflow pollutant concentration in the rain garden facility.

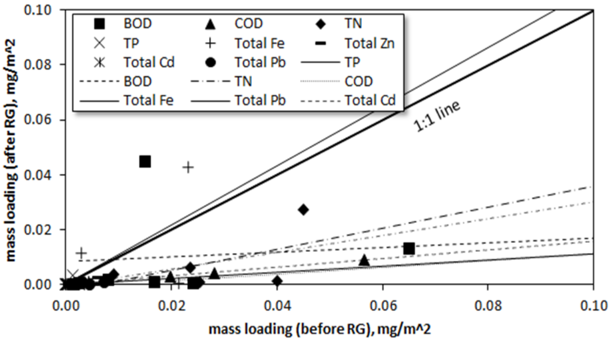

Fig. 4. Pollutant mass loading before and after LID application.

Table 3. Load ratio of the pollutant pollutants before and after LID application.

	BOD	COD	TN	TP	Total Zn	Total Cd	Total Pb
Load ratio	0.39	0.87	0.74	0.07	0.84	0.86	0.93

pollutants in stormwater runoff. However, the observed increase in the concentration of TSS after the application of rain garden was assumed to be due to the disturbance of the soil due to the introduction of runoff inside the facility.

Figure 4 and Table 3 shows the ratio of runoff and discharge pollutant loads. For the organics, the mass load ratio before and after the application of LID has an approximate value of 0.37 signifying that the facility exhibit a satisfactory performance in reducing BOD and COD. Moreover, for the nutrients, the mass load ratio range from 0.5 to 0.6. For the soluble metals, the figure showed a ratio of 0.14 signifying that 86% of the metal pollutants were reduced after passing through the rain garden facility. On the other hand, the particulate metals, except total Fe which falls to the 1:1 line, had a ratio of 0.12 that indicating a satisfactory performance of 88% in heavy metal reduction. These findings revealed that the rain garden is an effective LID facility in reducing pollutants from roof stormwater runoff.

4. Conclusion

Urbanization has long been contributing to the detrimental effects in the environment and a more feasible stormwater practice such as LID is needed to reduce if not eliminate these effects. In this research, evaluation on the environmental effects of rain garden was evaluated and the major findings are as follows:

- Based on the results, the rain garden moderately refurbished the pre-developed condition of an impervious area by preserving the natural hydrologic cycle and reduces nonpoint source pollution from urban areas.
- The rain garden can achieve 100% volume reduction when the rainfall depth and generated runoff volume is less than or equal 5mm and 0.48 m^3, respectively. Furthermore, when an outflow is produced, the rain garden can reduce the volume, average flow and peak flow rates by 85%, 67% and 54%, respectively. These results revealed that the rain garden can effectively reduce the amount of runoff and peak and average flow rates as the rainfall progresses.
- It was observed that the rooftop has a low concentration of pollutants since it is not exposed to vehicular activities and other various sources that can cause additional concentration of pollutants.
- The rain garden showed an average of 79% reduction for all pollutants and approximately 74% in terms of pollutant load indicating that the facility generally showed a satisfactory performance in terms of pollutant reduction since it effectively reduce the concentrations of organics and nutrients and particulate and soluble heavy metals.
- With the combined processes of infiltration, filtration and evapo-transpiration that were provided by the rain garden facility, the runoff was partially reduced and a significant decrease in concentration has been observed.
- The results and findings of this research will help facilitate and improve LID design for further application.

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