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Characteristics of heavy metals in soil in infiltration splash blocks and rain gardens for management of roof runoff from apartment buildings

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ABSTRACT

An increase in impermeable surfaces due to burgeoning urbanization is creating problems of non-point source, deterioration of urban amenities and the urban water cycle. Therefore, stormwater management with natural drainage has been attempted in Korea as a countermeasure. Objectives of this study are analysis of impact on heavy metals and distribution characteristics of the heavy metals in soil in infiltration splash blocks and rain gardens for management of roof runoff from apartment buildings. In this study, infiltration splash blocks and rain gardens were constructed to hold and infiltrate runoff from an apartment building roof. The distribution of heavy metals in soil in infiltration splash blocks and rain gardens was analyzed. There is a common feature that heavy metals were detected more in soil from the infiltration devices than in the surrounding soil in the order of Cu>Cd>Zn>As>Pb. The levels of these heavy metals are significantly lower than the Korea soil pollution standards. However, the distribution characteristics of Cu, Cd, Zn, As, and Pb in the splash blocks and rain gardens soil show that these heavy metals are influenced by roof runoff. This means that roof runoff could also be a non-point source.

Keywords: Decentralized rainwater management; Source control; End-of-pipe; LID; Non-point source

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1. Introduction

We have been managing heavy rainfall by quickly and forcibly draining large amounts of stormwater for flood prevention. However, owing to the increase in urban floods, pollution problems, and many other problems from runoff, an alternative measure for rainwater management needs to be found.

Rainwater management is classified into two types: traditional end-of-pipe drainage management and source control. European cities with traditional drainage systems have continuing concerns over

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stormwater pollution. This has led to the application of source-control technology in many European cities. Rainwater management at the source can be classified into structural methods and non-structural methods. The structural methods are divided into: (a) small-scale *in situ* management, (b) local management throughout the surrounding area, and (c) end-of-pipe measures. Rainwater infiltration, retention, and harvesting facilities and systems are classified as structural source-control technologies [1]. In particular, Germany has been promoting decentralized rainwater retention and infiltration as a sustainable and cost-efficient countermeasure for urban stormwater control since the early 1980s. Germany has required on-site rainwater retention, infiltration, and harvesting for new development projects as an alternative to the end-of-pipe method flowing directly into surface water. This is because pollutants and nutrients included in runoff can be hazardous for soil, underground water, and watersheds [2].

It has been known that about 8,320,000 out of the total 14,220,000 householders in Korea, or 58.5%, are in multi-family housing units such as apartments, row houses, and multiplex houses. Apartment buildings, which account for 6,628,993 households, comprise the largest portion followed by multiplex houses (1,168,481 households) and row houses (526,948 households). In particular, apartment buildings include half of the total households in Korea [3]. The building-to-land ratio (building floor area per site area) of apartment complexes is 17.36% on average. The green space rate of apartment complexes is 34.86%, which means that approximately 65% of the remaining area is impermeable [4]. Since half of all residential dwellings in Korea are in apartment buildings, people are becoming more and more interested in the installation of rainwater management facilities for source control of storm water and analytical studies on the effects of such installations in apartment complexes. Decentralized rainwater management and LID (low impact development) as a source control method have also been studied recently in Korea as a countermeasure for reducing flood and non-point pollutant, and restoring the water cycle [5–7]. Only about 3% of the total area of apartment complexes under the influence of the Korea Standard for Construction of Apartment Housing is natural soil, indicating that most of the green areas have been created on artificial ground. Due to the increase in apartment complexes, the water cycle has been affected, so an increase of runoff, non-point source load, and other phenomena have been created.

Solid contaminants mostly include pollutants from urban runoff, and precipitation in runoff storage tanks have been reported as a useful method for handling these contaminants [8]. The results of some studies have shown that roofs can also be non-point sources [9]. In addition, many cities throughout the world have been experiencing water supply problems due to the increase in population and drought. Usage of roof runoff must be examined in order to solve this problem, and the analysis of atmospheric deposition is also needed since it influences the water quality in a rainwater harvesting tank [10]. Atmospheric pollutants such as particles, colloids, organic substances, and heavy metals accumulate on roofs and other surfaces. These depositions degrade the quality of runoff water from rainfall. Roof runoff could be important because the volume of roof runoff has been estimated to be half of the runoff from impermeable surfaces in urban areas of industrialized countries. The water quality of roof runoff is influenced by the properties of the roof material and intrinsic rainfall quality. It usually shows a high level of contaminant concentration at the initial flush stage, and the level decreases as the rainfall continues. Catchment surface materials such as copper and lead can also be sources of pollutants. A study reported that metallic materials should be avoided on roof surfaces because metal roof surfaces can create pollution from heavy metals such as copper and zinc. In addition, some studies have asserted that metallic and PVC materials should be prohibited, and that characteristics of local atmospheric pollution should be examined [11–13].

Objectives of this study are analysis of impact on heavy metals and distribution characteristics of the heavy metals in soil in infiltration splash blocks and rain gardens for management of roof runoff from apartment buildings. Studies of heavy metals from soil in infiltration splash blocks and rain gardens have been carried out, and the results are presented here. The long-term effects of heavy metals from runoff including the first flush of an apartment building roof were analyzed in soil from storm water management systems. The distribution characteristics of heavy metals in soil in these systems were also examined.

2. Materials and methods

An infiltration splash block and rain garden were constructed in the 6th complex of H village in Bundang, Gyeonggi-Do, Korea, in order to control roof runoff. Approximately 18 years have passed since the completion of its construction. This is a large-scale rental housing apartment complex of 50 years constructed in the early 1990s with 1,489 households. In order to reduce initial pollutants and runoff from

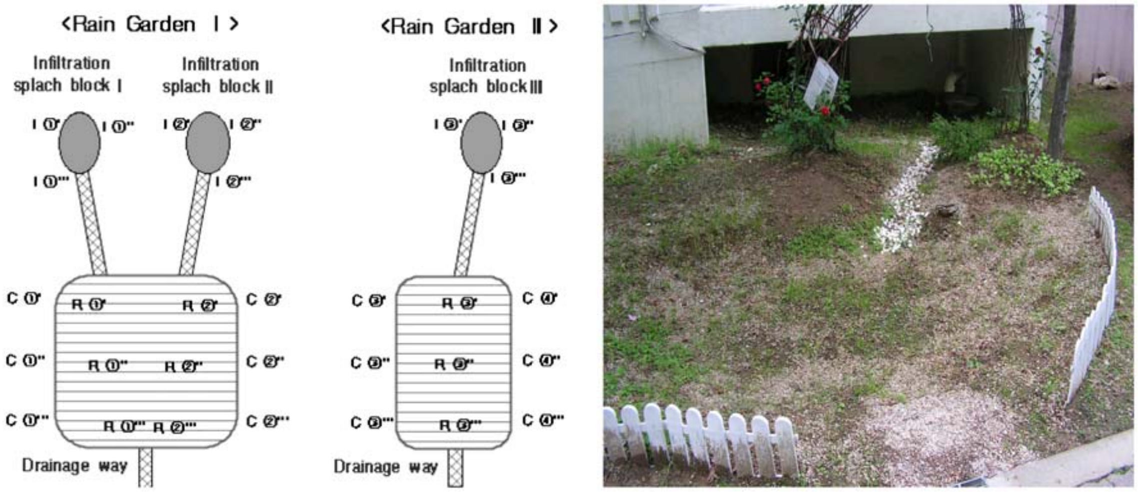

Fig. 1. Drawing and photograph of infiltration splash block and rain garden in a green area of the Bundang H apartment complex.

the apartment building roofs by retention and infiltration, two infiltration rain gardens, two gullies, and three infiltration splash blocks were installed.

Roof runoff flows into the infiltration rain garden through an infiltration splash block. The circular infiltration splash block is 300 mm in diameter and is approximately 300 mm in height. After installing an infiltration splash block, 500 mm in circumference and approximately 350 mm in depth recessed into the soil, 30–40-mm-diameter rubbles were placed inside, outside, and under the splash block so that roof runoff could be held and infiltrated. Round gravels, 3–4 cm in size, were placed in gullies connecting the infiltration splash block and rain garden. The rain garden has the capacity to trap the stormwater at a rate of 10 mm/h on 112 m^2 of the roof area (rain garden area: 9 m^2, detention water depth: 12.5 cm) without runoff. For infiltration at the rain garden, after digging a 400-mm-deep rain garden, a 100-mm-thick layer of 30–40-mm-diameter rubble, was installed and covered with a permeation sheet. In addition, a 100-mm-thick soil layer was packed on top of the permeation sheet and covered with 5–8-mm-diameter pea gravels. Roof runoff was first trapped and infiltrated into the splash block and then passed through the gullies to the rain gardens.

A study to examine the effects of heavy metal from roof runoff on the infiltration splash block and the infiltration rain garden was carried out for about 3.5 years from June 2005 to February 2009. The heavy metals in the soil were analyzed in February 2008 (after operating for 32 months), December 2008 (after operating for 42 months), and February 2009.

Soil analysis was carried out in 10 categories, excluding materials which can be created in any industrial complex, by considering the location of the infiltration facilities of the apartment complex. The soil analysis was carried out on soil collected from the infiltration splash blocks and the rain gardens where roof runoff flowed in, and the surrounding soil was selected as a control.

A total of 10 soil specimens of 500 g each were analyzed after collecting and mixing the surface soil of 15 cm deep from 3 different places in 10 locations. Analysis of soil contamination was carried out according to the analysis method for soil contamination in Korea. Cd (cadmium), Cu (cuprum), Pb (plumbum), Zn (zinc), Ni (nickel), As (arsenic), Hg (hydrargyrum) and Cr^{6+} (hexavalent chromium) were measured.

With the analysis data from three sampling times (February 2008, December 2008, and February 2009), an analysis of variance (ANOVA) was carried out to examine the differences in heavy metal concentration at each soil location depending on the sampling sites (Fig. 1).

3. Results and discussion

Heavy metals detected in soil from the rain garden and the infiltration splash block were in slightly higher concentrations compared to the surrounding soil. However, the levels of these heavy metals were significantly lower than the soil pollution standard, and organic phosphorous and cyanogen were not detected. The control was the green area in the apartment complex.

Table 1
Average concentration of heavy metals in the infiltration splash block, rain garden and control (garden soils) (Feb. 2008)

	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Heavy metal standard in soil in residential area (Korea)	4	150	200	300
Infiltration splash blocks ($n = 3$)	0.11	12.62	4.48	119.82
Rain gardens ($n = 3$)	0.14	10.12	4.28	129.60
Control (garden soils) ($n = 4$)	0.08	5.13	3.74	93.40
	Ni (mg/kg)	As (mg/kg)	Hg (mg/kg)	Cr^{6+} (mg/kg)
Heavy metal standard in soil in residential area (Korea)	100	25	4	5
Infiltration splash blocks ($n = 3$)	24.73	0.73	0.08	0.36
Rain gardens ($n = 3$)	20.84	0.64	0.06	0.22
Control (garden soils) ($n = 4$)	20.39	0.51	0.13	0.34

Table 2
Average concentration of heavy metals in the infiltration splash block, rain garden, and control (garden soils) (Dec. 2008)

	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Heavy metal standard in soil in residential area (Korea)	4	150	200	300
Infiltration splash blocks ($n = 3$)	0.08	20.77	4.76	143.14
Rain gardens ($n = 3$)	0.11	10.29	3.76	137.43
Control (garden soils) ($n = 4$)	0.05	4.55	3.45	93.75
	Ni (mg/kg)	As (mg/kg)	Hg (mg/kg)	Cr^{6+} (mg/kg)
Heavy metal standard in soil in residential area (Korea)	100	25	4	5
Infiltration splash blocks ($n = 3$)	22.43	0.44	0.012	0.24
Rain gardens ($n = 3$)	20.22	0.37	0.012	0.18
Control (garden soils) ($n = 4$)	18.23	0.31	0.027	0.20

The analysis results for heavy metals in the soil from the infiltration splash block and rain garden, which were operated for approximately 32 months with roof runoff, are shown in Table 1. Based on the average of heavy metals from the control green area in the apartment complex, the average level of each heavy metal from the infiltration splash block and rain garden was determined. Cr^{6+} was detected 1.06 times higher in the splash block than the surrounding soil, but it was detected 0.65 times lower in rain garden than the surrounding soil. In comparison with the surrounding soil (control), heavy metals were detected in the order of Cu>Cd>Zn, As>Pb>Ni>Cr^{6+}. There was no significant difference in the concentration of heavy metals between the infiltration splash block and the rain garden, but higher levels of heavy metals were detected from the splash block which contained the highest level of Cu.

This is because the splash block had the highest number of initial roof runoff receptions and the largest detention and infiltration amount of the runoff, and the roof runoff flowed into the rain garden after detention and infiltration by the splash block. However, Cd and Zn were detected more in the rain garden than in the surrounding soil.

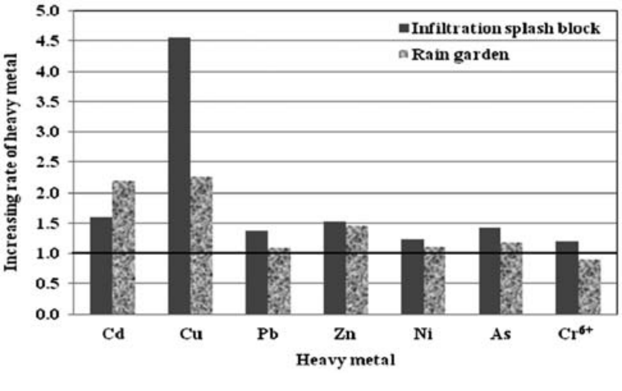

Fig. 2. Ratio between the splash block and rain garden to garden soil concentration of heavy metals (Dec. 2008).

The analysis results of heavy metals in soil from the infiltration splash block and rain garden, which were operated for approximately 42 months with roof runoff, are shown in Table 2. Cu was detected most particularly from the splash block. Like the preceding results of our analysis, the average level of concentration of the various heavy metals was higher in the rain garden and the infiltration splash block than in the surrounding soil as the control. Cr^{6+} was also detected 1.20 times higher in the splash block than in the surrounding soil, but it was also detected 0.90 times lower in the rain garden than in the surrounding soil.

In comparison with the surrounding soil as the control, heavy metals were detected in the order of Cu>Cd>Zn>As>Pb>Ni>Cr^{6+}. This is the order of heavy metal accumulation as seen in Table 1. Also,

Table 3
Average concentration of heavy metals in the infiltration splash block, rain garden, and control (garden soils) (Feb. 2009)

	Cd (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Heavy metal standard in soil in residential area (Korea)	4	150	200	300
Infiltration splash blocks ($n = 3$)	0.06	12.02	3.23	165.17
Rain gardens ($n = 3$)	0.06	6.78	2.67	158.16
Control (garden soils) ($n = 4$)	0.04	3.97	2.47	113.02
	Ni (mg/kg)	As (mg/kg)	Hg (mg/kg)	Cr^{6+} (mg/kg)
Heavy metal standard in soil in residential area (Korea)	100	25	4	5
Infiltration splash blocks ($n = 3$)	28.78	0.45	0.011	ND
Rain gardens ($n = 3$)	23.89	0.24	0.013	ND
Control (garden soils) ($n = 4$)	22.85	0.35	0.010	ND

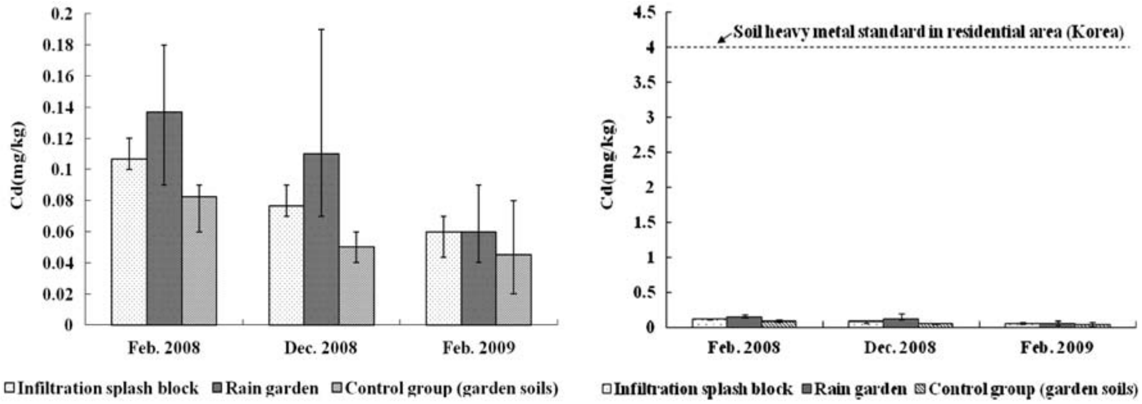

Fig. 3. Average concentration of Cd in the infiltration splash block, rain garden, and control (garden soils).

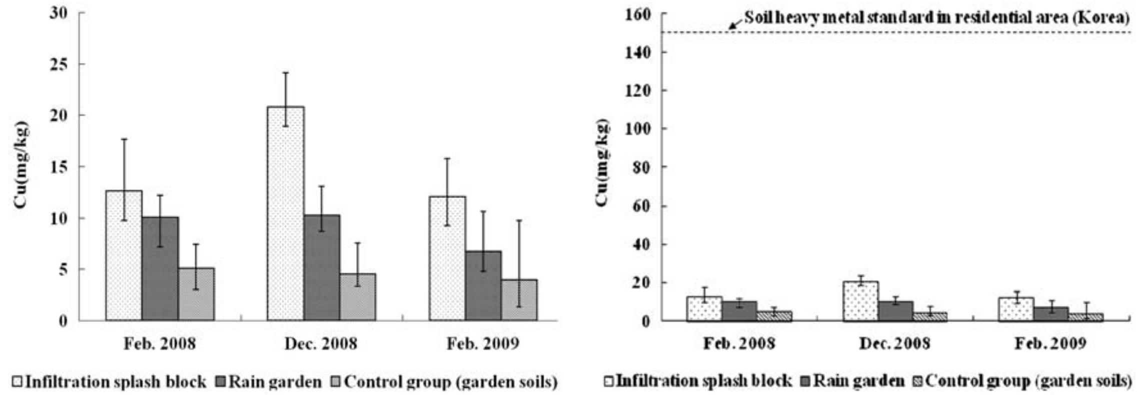

Fig. 4. Average concentration of Cu in the infiltration splash block, rain garden, and control (garden soils).

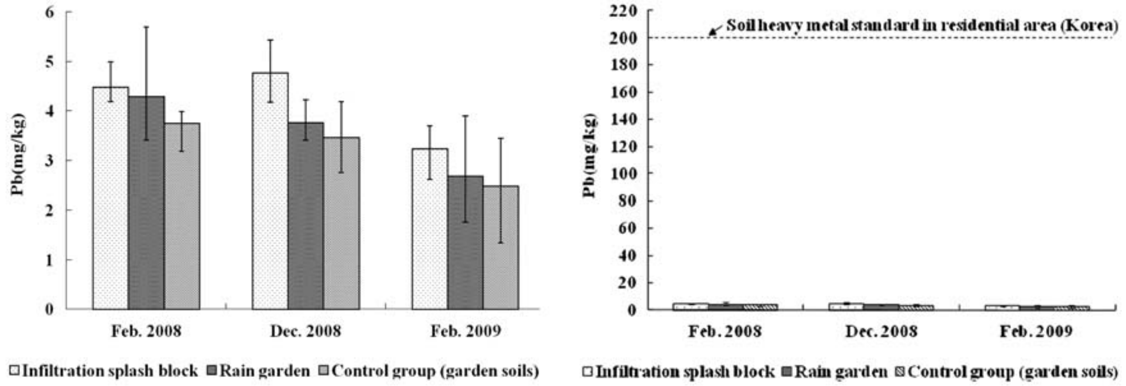

Fig. 5. Average concentration of Pb in the infiltration splash block, rain garden, and control (garden soils).

more heavy metals were detected in the splash block; particularly Cu, Pb, and As were detected at higher concentrations in the splash block. This is also because the splash block had the highest number of initial roof runoff receptions and the largest detention and infiltration amount of roof runoff. However, Cd was detected more in the rain garden than in the splash block. As Tables 1 and 2 show, Hg was detected at lower levels in both the splash block and the rain garden than in the surrounding soil. Cr^{6+} was detected at

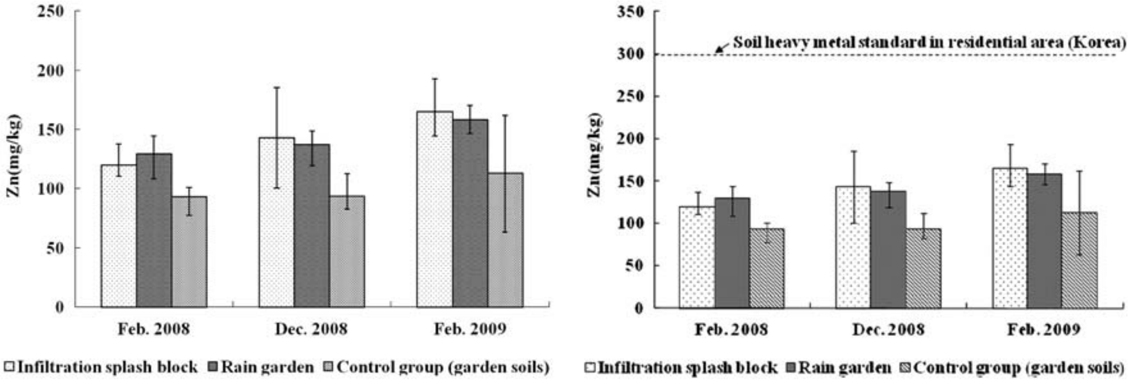

Fig. 6. Average concentration of Zn in the infiltration splash block, rain garden, and control (garden soils).

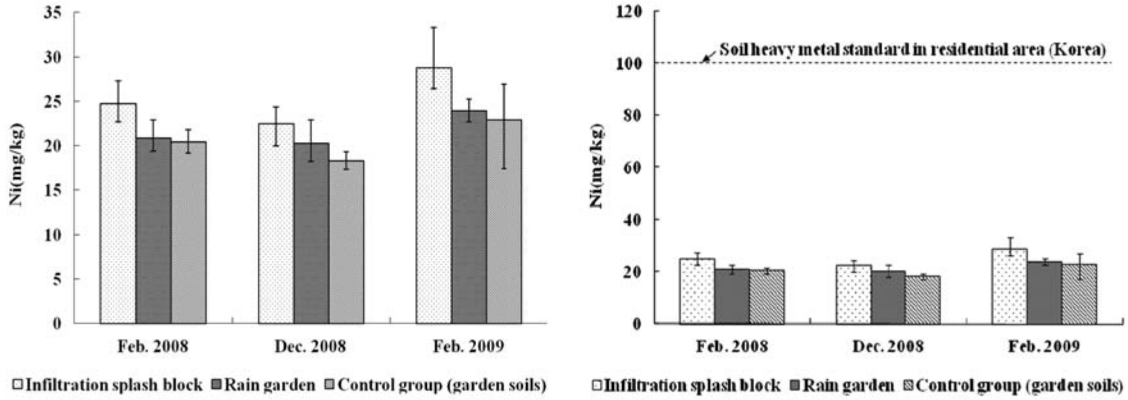

Fig. 7. Average concentration of Ni in the infiltration splash block, rain garden, and control (garden soils).

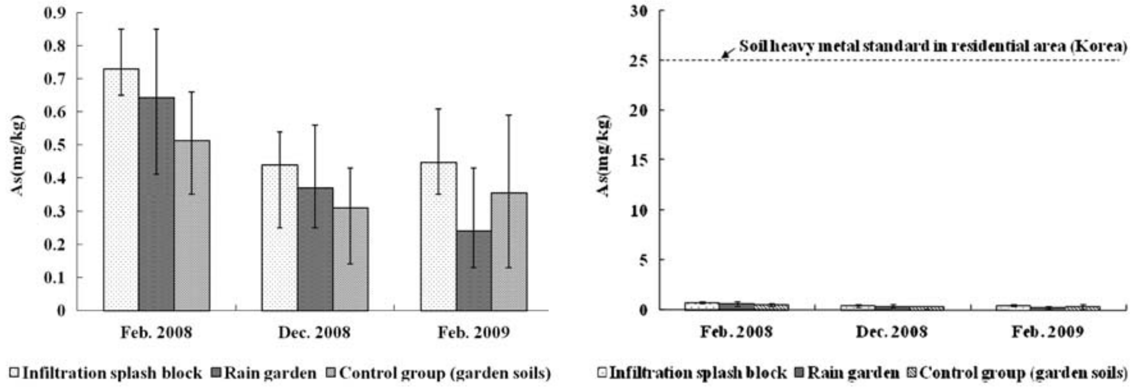

Fig. 8. Average concentration of As in the infiltration splash block, rain garden, and control (garden soils).

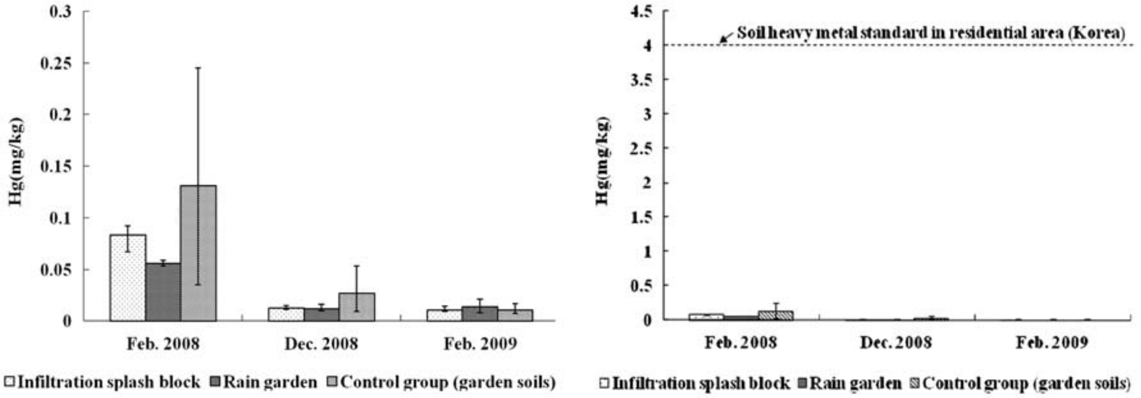

Fig. 9. Average concentration of Hg in the infiltration splash block, rain garden, and control (garden soils).

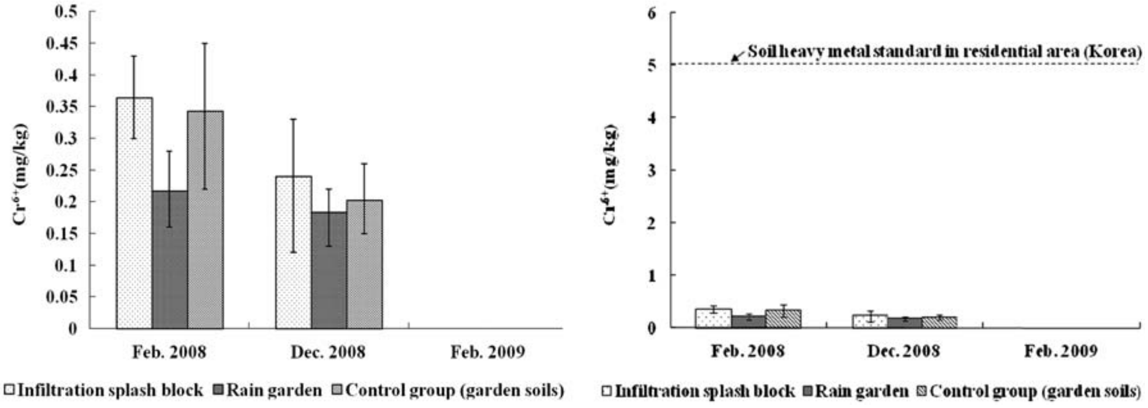

Fig. 10. Average concentration of Cr^{6+} in the infiltration splash block, rain garden, and control (garden soils).

a lower level only in the rain garden compared to the surrounding garden soil as the control. The rain garden was established by digging in the garden soil to a depth of 40 cm, piling up rubble and soil layer of 10 cm each, and then spreading pea gravel. According to these installation conditions, a lower level of Hg in the splash block and rain garden than in the surrounding soil means that there was no effect on Hg accumulation by roof runoff, as seen in Tables 1 and 2.

Table 4
Analysis of variance of the average concentration of heavy metals in the analysis data from three time periods (Feb. 2008, Dec. 2008, and Feb. 2009)

	Comparison	Difference between means	Simultaneous 95% confidence limits		
Cd	Rain gardens and control (garden soils)	0.04298	0.00428	0.08168	☆
Cu	Infiltration splash blocks and rain gardens	6.132	1.854	10.410	☆
	Infiltration splash blocks and garden soils	10.394	6.392	14.395	☆
	Rain gardens and garden soils	4.261	0.260	8.263	☆
Zn	Infiltration splash blocks and garden soils	42.65	14.36	70.95	☆
	Rain gardens and garden soils	41.68	13.38	69.97	☆
Ni	Infiltration splash blocks and rain gardens	3.660	0.044	7.277	☆
	Infiltration splash blocks and garden soils	4.818	1.436	8.201	☆

*Comparisons significant at the 0.05 level are indicated by ☆.

It was unclear whether the accumulation of heavy metal is serious in infiltration facilities that were operated for about 3.5 years, because the levels of this accumulation were significantly lower than the soil pollution standards. There is a common feature that heavy metals are detected more from the infiltration facilities than the surrounding soil in the order of Cu>Cd>Zn>As>Pb.

The accumulation of Cu, Cd, Zn, As, and Pb in the splash block and rain garden soil showed that these heavy metals are influenced by roof runoff to a degree. Particularly, Cu was detected at a significantly higher level than other heavy metals. Cu seems to have the greatest effect on heavy metal accumulation in soil. (Table 3, Figs. 2–10).

The Tukey test was used for the analysis. The results of the Tukey test showed that Cd, Cu, Zn and Ni had variances depending on the sampling sites. The Cu concentration at each sampling site was different between the infiltration splash block and the rain garden, between the infiltration splash block and the control (garden soils), and between the rain garden and the control. In other words, the environmental effect on each soil by Cu from roof runoff was relatively clear, according to the drainage course of roof runoff (infiltration splash block → rain garden).

Zn showed a difference in concentration between the control (garden soils) and the infiltration splash block, and between the control and the rain garden. The Ni concentration was different between the control and the infiltration splash block, and between the infiltration splash block and the rain garden. The Cd concentration was only different between the control and the rain garden.

The heavy metals that were detected in the rooftop runoff were Cu, Zn, and Ni. These results implied that the rooftop runoff had an effect on the soil in rainwater management facilities for the rooftop runoff management such as rain gardens. Among the heavy metals, Cu, Zn, and Ni showed the greatest differences in concentration in the infiltration splash block, the rain garden, and the control group, which implied that they had relatively greater effects than any other metals. Further measurement and analysis may be required with respect to Cd (Table 4).

4. Conclusions

Heavy metal elements were detected more in the rain garden and the infiltration splash block than in the surrounding soils (control), in the order of Cu>Cd>Zn>As>Pb>Ni>Cr^{6+} due to atmospheric deposition on the roofs. Heavy metals were detected more from the splash block that received roof runoff first and most. The concentration of Hg was lower or similar in the splash block and rain garden to surrounding soils, indicating that there was no Hg effect from roof runoff. However, Cu, Cd, Zn, As, and Pb seemed to be somewhat affected by roof runoff. In particular, roof runoff from apartment buildings seemed to have the greatest effect on Cu concentration in soil. These data indicate the impact of roof runoff on heavy metals in the soil of a residential complex, and continuous measurement and analysis are required. This means that roof runoff could also be a non-point source.

The combination of the infiltration devices including infiltration splash blocks and rain gardens would be a useful method for non-point source management and water cycle restoration in apartment complexes.

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References

[1] E. Chouli, E. Aftias, J.-C. Deutsch, Applying storm water management in Greek cities: learning from the European experience, Desalination 210 (2007) 61–68.

[2] E. Nolde, Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces, Desalination 215 (2007) 1–11.

[3] Korea National Housing Corporation, 2007 Year Book of Housing & Urban Statistics, 2007.

[4] Korea National Housing Corporation, 2006 site planning analysis, 2007.

[5] K.-H. Hyun, J.-I. Oh, S.-S. Ahn, J.-J. Choi, Effect of a decentralized rainwater management system in Korea apartment complex. Water Practice Technol. 3(2) (2008).

[6] J.-M. Lee, K.-H. Hyun, J.-S. Choi, Y.-J. Yoon, F.K.F. Geronimo, Flood reduction analysis on watershed of LID design demonstration district using SWMM5, Desalin. Water Treat. 38 (2012) 326–332.

[7] S.J. Chung, H.K. Ahn, J.M. Oh, I.S. Choi, S.H. Chun, Y.K. Choung, I.S. Song, K.H. Hyun, Comparative analysis on reduction of agricultural non-point pollution by riparian buffer strips in the Paldang watershed, Korea. Desalin. Water Treat. 16 (2010) 1–16.

[8] A. Saget, G. Chebbo, M. Desbordes, Urban discharges during wet weather: what volumes have to be treated? Water Sci. Technol. 32(1) (1995) 225–232.

[9] M. Chang, M.W. McBroom, R.S. Beasley, Roofing as a source of nonpoint water pollution, J. Environ. Manage. 73 (2004) 307–315.

[10] R. Huston, Y.C. Chan, T. Gardner, G. Shaw, H. Chapman, Characterisation of atmospheric deposition as a source of contaminants in urban rainwater tanks, Water Res. 43 (2009) 1630–1640.

[11] J. Főster, Patterns of roof runoff contamination and their potential implications on practice and regulation of treatment and local infiltration, Water Sci. Technol. 33(6) (1996) 39–48.

[12] J. Főster, Variability of roof runoff quality, Water Sci. Technol. 39(5) (1999) 137–144.

[13] R.-H. Kim, S. Lee, J.-O. Kim, Application of a metal membrane for rainwater utilization: filtration characteristics and membrane fouling, Desalination 177 (2005) 121–132.