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Comparative assessment of urban stormwater low impact strategies equipped with pre-treatment zones

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침강지 시설이 조성된 LID 시설의 환경적 영향평가

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Abstract

Recently, Low impact development techniques, a form of nature-based solutions (NBS), were seen cost-efficient alternatives that can be utilized as alternatives for conventional stormwater management practices. This study evaluated the effectiveness of an infiltration trench (IT) and a small constructed wetland (SCW) in treating urban stormwater runoff. Long-term monitoring data were observed to assess the seasonal performance and cite the advantages and disadvantages of utilizing the facilities. Analyses revealed that the IT has reduced performance during the summer season due to higher runoff volumes that exceeded the facility's storage volume capacity and caused the facility to overflow. On the other hand, the pollutant removal efficiency of the SCW was impacted by the winter season as a result of dormant biological activities. Sediment data also indicated that fine and medium sand particles mostly constituted the trapped sediments in the pretreatment and media zones. Sediments in SCW exhibited a lower COD and TN load due to the phytoremediation and microbiological degradation capabilities of the system. . This study presented brief comparison LID facilities equipped with pre-treatment zones. The identified factors that can potentially affect the performance of the systems were also beneficial in establishing metrics on the utilization of similar types of nature-based stormwater management practices.

Key words : Constructed Wetland; Infiltration Trench; LID; NBS; Stormwater

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요 약

최근 강우유출수를 비용효율적으로 관리하기 위해 저영향개발 (Low Impact Development, LID)과 자연기반해법 (Nature-based solution, NBS)를 도입하고 있다. 본 연구에서는 LID 시설 중 도심지 내 적용가능하고 유입부에 침강지가 조성된 침투도랑(IT)과 소규모 인공습지(SCW) 등 2개의 시설에 대해 효율성을 평가하였다. 효율성 평가는 장기간의 모니터링을 통한 자료를 이용하여 수행하였다. 분석결과 하절기 기간은 식생의 흡입 등의 생물학적 활동으로 인하여 SCW의 효율이 더 높았으나, 동절기 기간에는 식물의 고사로 인하여 IT의 효율이 더 높은것으로 분석되었다. 침강지 내 퇴적물의 분석결과 SCW 침강지 내 식생에 의한 정화작용 및 미생물등의 생물학적 처리기작으로 인하여 COD와 TN의 저감효율이 높은것으로 분석되었다. 본 연구에서는 침강지 시설을 조성한 LID 시설에 대해 비교하였으며, 자연과 유사한 자연기반해법을 LID 시설에 적용할 경우 기존 시설보다 처리효율이 우수한것으로 나타났다.

핵심용어 : 인공습지, 침투도랑, 저영향개발, 자연기반해법, 강우유출수

1. Introduction

Land conversion played an integral part in shaping the modern-day society. Urban development has been a global trend that impacted the ecosystem services and its components. Some of the effects of urbanization include increased water demand, upsurge in wastewater and solid waste generation, and environmental degradation as a result of high pollutant loadings (Liu et al., 2014). Rural-to-urban land conversion was also characterized by increase in impervious areas. Reduced infiltration rates disturb the natural flow path of water, and often lead to increased surface runoff and pollutant discharge to natural streams. Moreover, accumulated pollutants on paved surfaces are mobilized during storm events (Kim et al., 2010). Untreated urban stormwater runoff from urbanized areas washes-off various pollutants from anthropogenic, animal, and

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natural origins (Sidhu et al., 2013).

At present, the aim to revitalize ecosystem services was made possible by land restoration and rehabilitation (Keesstra et al., 2018). Nature-based solutions (NBS) are sustainable management techniques that focus on making the environment adaptive to modern-day challenges by maintaining biodiversity and promoting human well-being (IUCN, 2018). One of the applications of NBS in stormwater management can be achieved through the use low impact development (LID) strategies. LID facilities were designed to replicate the predevelopment hydrology of an area to reduce peak runoff volumes and pollutant concentrations in stormwater in a cost-efficient manner as compared to conventional treatment schemes (Houle et al., 2013). In an urban area, LID facilities can be applied to treat runoff from impervious areas such as parking lots, road sides, and rooftops, among others.

One of the most commonly-used LID facilities in treating urban stormwater is the infiltration trench (IT). ITs are rectangular excavations designed to filter and attenuate flood flow in an urban area by providing storage volume and enhancing the runoff infiltration (Guo & Gao, 2016). Due to its small and functional design, ITs are advantageous to roadside operations where there are limited spaces for complex stormwater management facilities. The utilization of small constructed wetlands (SCW) also received a positive response in terms of stormwater management. SCWs incorporate vegetation, coupled with sedimentation and filtration mechanisms, to enhance pollutant removal efficiency in the stormwater (Mangangka et al., 2015). In order to minimize the effect of urbanization and non-point sources (NPS) of pollution, performance evaluation of LID facilities should be considered (Choi et al., 2019). This study evaluated the effectiveness of IT and SCW in treating urban stormwater runoff. Vegetated and non-vegetated LID facilities were compared to evaluate their respective pollutant removal performances in relation to climatologic variations. Ultimately, this study posed the advantages and disadvantages of utilizing SCWs and ITs in nature-based stormwater management practices.

2. Materials and Methods

2.1 Study Area and Facility Design

The stormwater IT and SCW located at the Kongju National University (KNU), Cheonan City, Chungnam Province, South Korea were exhibited in Figure 1. The facilities were subdivided into three distinct zones, namely: pre-treatment zone, media zone, and effluent zone. The IT and SCW were designed with sedimentation tanks capable of accommodating 1 m^3 and 0.41 m^3 of runoff in the pre-treatment zone, respectively. IT's sedimentation tank was composed of sand and gravel sublayers overlain by geotextile, whereas SCW's sedimentation tank was underlain by wood chip layers. The IT has vertical media layers consisted of geotextile, wood chips, zeolite, and sand, respectively as compared with SCW with wood chip layers only. Woods chip and zeolite were incorporated in the design to enhance the particulates removal moisture retention mechanisms of the facility. Most LID facilities in South Korea incorporate natural types of filters to treat stormwater runoff (Segismundo et al., 2016). Filter media in IT and SCW's filtration zone were mainly composed of sand and gravel, with additional layers of wood chip pebbles integrated in the IT design.

Despite the distinct similarities in the treatment mechanisms, one profound difference between the two facilities is the presence of plants in SCW. *Acorus calamus*, commonly known as Russian iris, was specifically planted in the SCW due to its high phytoremediation and heavy metal hyper accumulation potential and high adaptability to the environment (Jeelani et al., 2017; Alihan et al., 2018). Constructed wetlands utilize physical (i.e. sedimentation, filtration, adsorption, etc.) and biological processes (i.e. decomposition and plant uptake) in stormwater treatment (Gill et al., 2014). On the other hand,

Table 1. Facility design and catchment area characteristics

Parameter	Unit	Low impact strategy	
		Infiltration trench (IT)	Small constructed wetland (SCW)
		Characterization/Value	Characterization/Value
Location	-	KNU - Cheonan campus	KNU - Cheonan campus
Land use	-	Road	Road and parking lot
Imperviousness rate	%	100	100
Catchment area	m^2	520	457
Surface area to catchment area ratio (SA/CA ratio)	%	1.25	1.07
Storage volume of the facility	m^3	3.85	2.94
Design total rainfall of the facility	mm	25	5
Design HRT of the facility	hours	3	1.3
Aspect ratio (L:W:H) of the facility	m	5:1.3:1	7:0.7:1

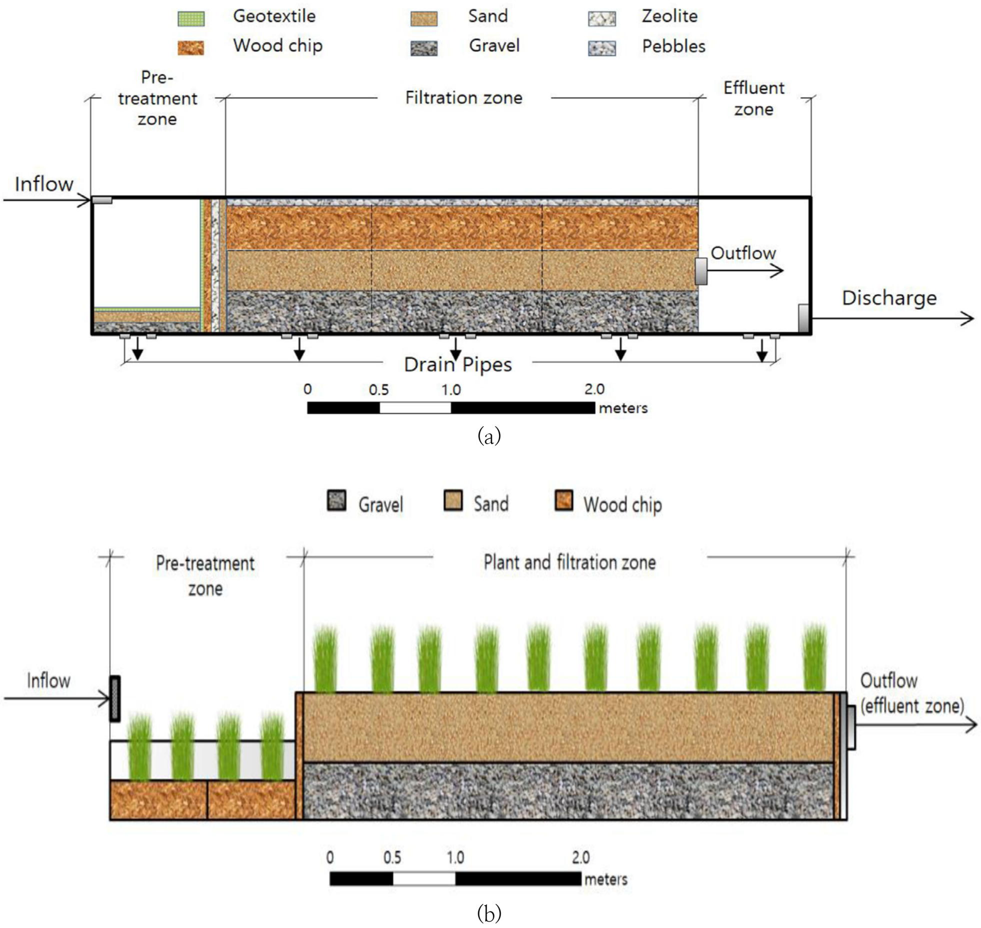


Fig. 1. Schematic diagram of the a) IT located and b) SCW located at Kongju National University

IT mainly relies on physical processes in stormwater treatment. This was evident in the more extensive use of various filter media in the IT as compared with SCW. The catchment area and characteristics of the two facilities were summarized in Table 1.

2.2 Data gathering and experiment procedure

A total of 40 rainfall events from May 2009 to September 2016 and 32 rainfall events from July 2010 to October 2015 were monitored to assess the long term performances of the IT and SCW, respectively. Samples were collected in the inflow and outflow ports by grab sampling as soon as the runoff started entering and leaving the facility, while additional samples were collected after 5, 10, 15, 30, and 60 minutes. Succeeding samples were collected at a one-hour interval throughout the duration of rainfall. Inflow and outflow rates were also measured every five minutes for the whole event duration. Standard methods for the examination of water and wastewater were employed to assess the water quality of the collected samples (APHA et al., 1992). Total suspended solids (TSS), turbidity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), and total phosphorus (TP) were among the water quality parameters examined. Moreover, the presence of total metals, including cadmium (Cd), chromium (Cr), iron (Fe), lead (Pb), nickel (Ni), and zinc (Zn), were also analyzed in the water samples. Sediment collection was done in the sedimentation tank and filter media succeeding facility maintenance operations. Particle size and sediment analyses were conducted following the soil sampling and methods of analysis proposed by Carter and Gregorich (Carter & Gregorich, 2006). Further evaluation was done to investigate the correlation between the pollutants contained in the sediments and the quality of stormwater runoff.

2.3 Data sources and statistical analyses

Primary hydrologic data such as antecedent dry days (ADD), precipitation depth, rainfall intensity, rainfall duration, and temperature were obtained from the Korea Meteorological Administration. By considering hydraulic components such as inflow and outflow volume, the pollutant removal efficiency (RE) of the systems was evaluated by calculating the pollutant load reduction in the influent stormwater. Equations 1 through 3 provide a detailed calculation procedure for determining the inflow pollutant load, outflow pollutant load, and mass removal efficiency, respectively.

$$\mathit{Inflow\ pollutant\ load(mg)} = \sum_{t=1}^{t=T} C_{in}(t)\, q_{in}(t) \qquad (1)$$

$$\mathit{Outflow\ pollutant\ load(mg)} = \sum_{t=1}^{t=T} C_{out}(t)\, q_{out}(t) \qquad (2)$$

$$\mathit{Mass\ removal\ efficiency(\%)} = \frac{\sum_{t=1}^{t=T} C_{in}(t)\, q_{in}(t) - \sum_{t=1}^{t=T} C_{out}(t)\, q_{ourt}(t)}{\sum_{t=1}^{t=T} C_{in}(t)\, q_{in}(t)} \qquad (3)$$

Where $C_{in}(t)$ and $C_{out}(t)$ denoted the pollutant concentrations of the influent and effluent, respectively, and $q_{in}(t)$ and $q_{out}(t)$ represented the inflow and outflow rates at time *t*, respectively.

Catchment physiography is one of the factors affecting the runoff water quality and quantity (Hamel et al. 2013). In order to account for the amount of pollutants washed-off per unit area of the catchment, the unit pollutant load (UPL) was calculated using Equation 4 (Li et al., 2015).

$$UPL(mg/m^2) = \frac{\sum C_t q_t \Delta t}{A} \qquad (4)$$

Where C_t is the pollutant concentration at time *t*, q_t represented the flow rate at time *t*, and A corresponded to the catchment area of the facilities. Moreover, statistical analyses were employed using Systat 12 and OriginPro 8 software to evaluate stormwater quality and other pertinent hydraulic and hydrologic variables relevant to the performance of the IT and SCW. The definition of the box plot used in this representation of data was illustrated in Figure 2.

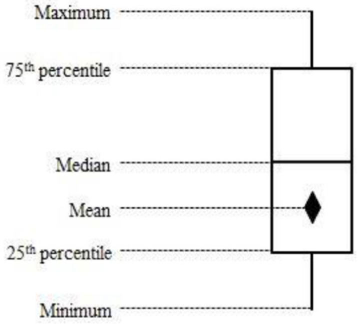


Fig. 2. Box plot definition.

3. Results and Discussion

3.1 Characteristics of monitored rainfall events

The statistical summary of the monitored rainfall events for IT and SCW were reported in Table 2. The monitored events for summer season constitute 37% and 50% of the total monitored rainfall events for the IT and SCW, respectively. Summer months in South Korea are characterized by warm temperatures and relatively-abundant rainfall. Rainy season usually begins in late spring season, extending up to the summer season from June to August. The longest ADD (34 days) was recorded during the winter season, whereas greater values of average rainfall intensity (5 mm/h) and shorter mean ADDs (7 days) were observed on summer season. Both facilities exhibited runoff volume reduction capabilities ranging from 1.91% to 100%, but the IT exhibited greater runoff volume attenuation. In the case of IT, 20% of the monitored events did not produce any outflow as compared with SCW in which only 3.85% of the monitored events achieved complete runoff volume reduction. This can be attributed to the larger total rainfall (25 mm) and storage volume capacity (3.85 m^3) of the IT design. It was noted that complete runoff attenuation was observed on rainfall depths not exceeding 5 mm.

3.2 Background pollutant concentration and removal efficiency

Due to combined natural and anthropogenic activities in the catchment area, urban stormwater runoff may contain various types of pollutant loads. The background pollutant

Table 2. Summary of monitored rainfall events

Parameter	Unit	IT					SCW				
		Min[a]	Max[b]	Mean	Med[c]	Std. dev[d]	Min[a]	Max[b]	Mean	Med[c]	Std. dev[d]
ADD	days	1.00	34.00	6.54	4.35	6.61	1.00	21.0	6.00	5.00	4.84
Total rainfall	mm	1.00	90.50	8.01	4.50	14.66	1.50	22.5	6.63	4.25	6.31
Rainfall duration	h	0.85	11.03	3.40	2.93	2.30	0.50	5.00	1.83	1.42	1.23
Rainfall intensity	mm/h	0.38	17.06	2.80	1.29	3.76	0.45	20.45	3.49	1.49	4.61
Total runoff duration	hr	0.42	6.00	2.34	2.00	1.58	0.50	5.00	1.83	1.42	1.23
Hydraulic retention time	hr	0.08	3.50	1.16	0.92	0.94	0.03	3.58	0.55	0.25	0.81
Total runoff volume before LID	m^3	0.02	14.82	2.26	1.19	3.35	0.01	9.92	1.63	0.52	2.50
Total runoff volume after LID	m^3	0.00	12.58	1.21	0.15	2.46	0.00	7.39	1.36	0.37	2.24
Total runoff reduction	%	7.99	100	69.22	78.61	31.80	1.91	100	38.10	32.40	29.48
Peak flow reduction	%	3.02	100	54.99	67.52	35.95	3.85	90.70	39.82	28.68	25.68

[a] Minimum; [b] Maximum; [c] Median; [d] Standard deviation

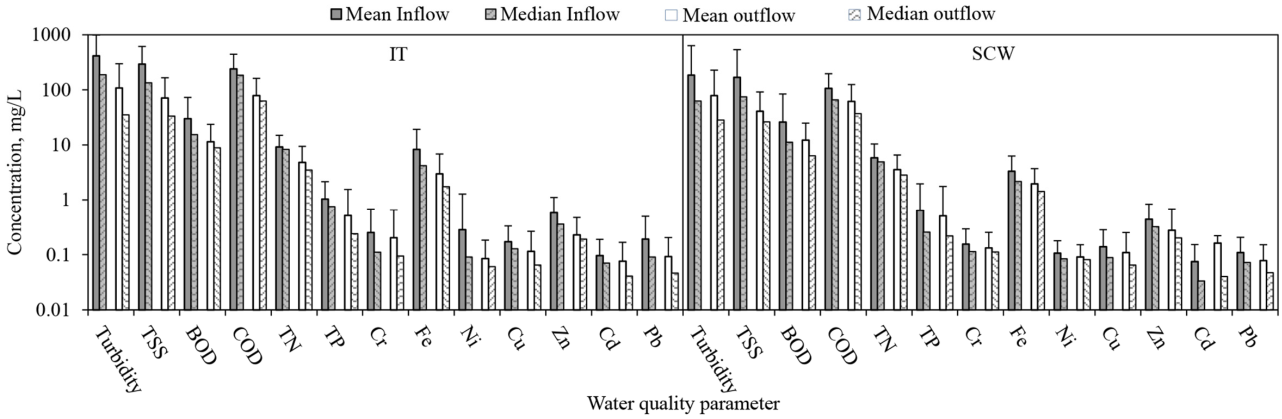


Fig. 3. Background inflow and outflow pollutant concentrations in the IT and SCW.

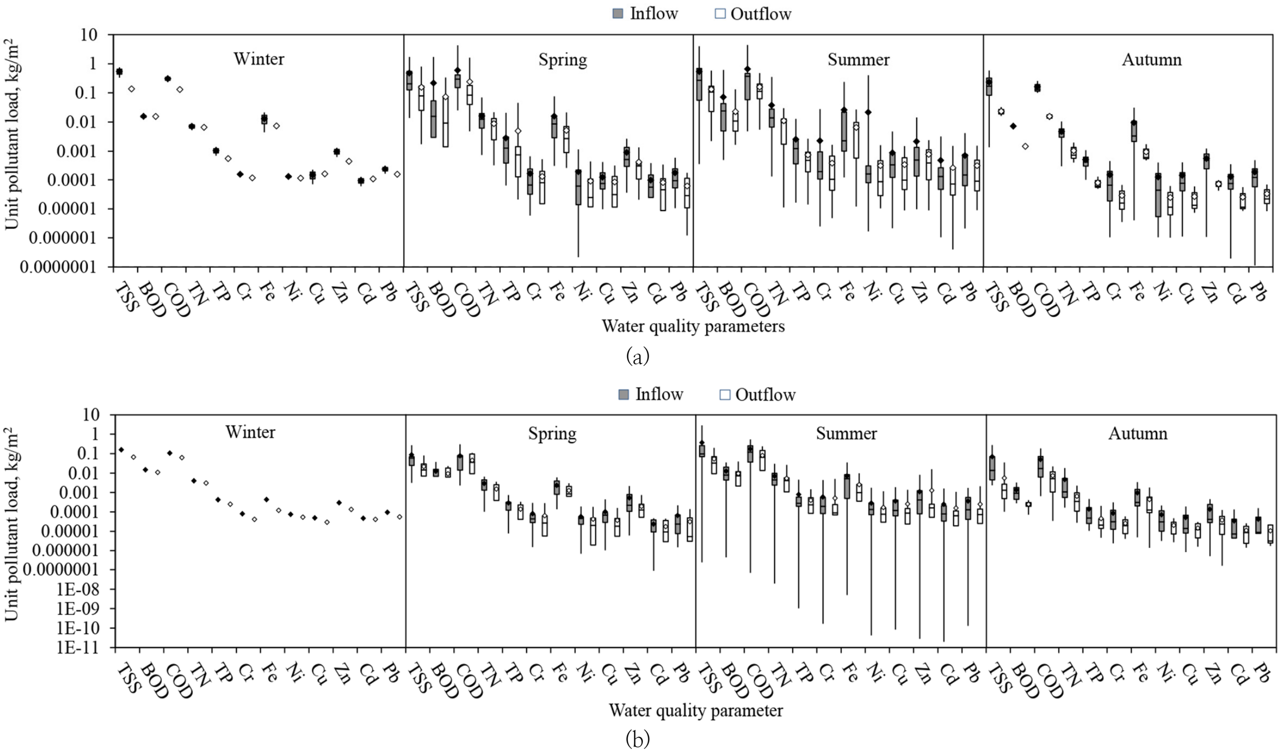
concentrations of inflow and outflow water samples collected from the IT and SCW were illustrated in Figure 3. Influent concentration of TSS in the IT was found to be 42% higher than SCW's influent. Moreover, influent BOD, COD, TN, TP, and total heavy metal in the IT exhibited 13% to 63% higher concentrations as compared with the influent in SCW. Since most pollutants in urban areas are particulate or sediment-bound, increase in pollutant concentration can be associated alongside with an increase in TSS concentration (Li et al., 2017). Various factors may also affect the concentration of pollutants in stormwater. Due to a relatively-bigger area (12%), deposition of pollutants in the IT's catchment can be of greater extent than the pollutant-accumulation rate in SCW's catchment. Moreover, the average rainfall depth and influent volume of the monitored events in the IT were 17% and 28% greater, respectively, than the monitored events for SCW. Larger rainfall depths and runoff volumes can also trigger the displacement of sediments in the catchment area, thereby increasing the pollutant concentrations in stormwater (Alias et al., 2014).

The mean values are generally greater than the median values, implying that majority of the observed pollutant concentrations have low values. In terms of pollutant reduction, the IT significantly reduced particulates and nutrients ($p<0.05$), whereas SCW effectively treated COD, TN, and Fe ($p<0.05$) in the runoff. The pre-treatment mechanism installed in the IT facilitated the removal of sediments in the stormwater runoff. Since majority of the pollutants were particulate-bound, preliminary reduction of particulates in the system led to significant reduction of other pollutants in the stormwater. The effective COD reduction of constructed wetlands can be attributed to the impact of microorganisms. The role of plants in the nitrification and denitrification process also contributed to the significant reduction of TN in the influent (Zhu et al., 2014). Moreover, the phytoextraction mechanism contributed by the plants can also be considered as the primary cause of heavy metal concentrations in the stormwater runoff (Chibuike & Oibora, 2014). Generally, vegetation provides mechanisms that allow LID facilities to treat organics, nutrients, and some heavy metals effectively as compared to non-vegetated systems. On the other hand, a non-vegetated facility was more efficient in removing particulates in the stormwater due to the extensive filtering structures incorporated in the system.

3.3 Effects of seasonal variability on the pollutant removal performance

Climatologic and hydrologic regime is an important aspect of LID facility design. Unlike other conventional stormwater management techniques, LID approach is more susceptible to climate variabilities since the primary components of the facilities are nature based. Figure 4 provides a graphical summary of the inflow and outflow unit pollutant loads in the IT and SCW as influenced by seasonal changes. The highest mean seasonal pollutant loads for organics (7.44 kg/m^2 to 390.96 kg/m^2), nutrients (0.38 kg/m^2 to 20.32 kg/m^2), and heavy metals (0.236 kg/m^2 to 146.96 kg/m^2) were recorded during summer for both facilities. For the summer season, the mean daily precipitation (2009-2016) amounted to 17.5 mm. This seasonal value was 489%, 114%, and 88% greater than the mean daily precipitation experienced during winter, spring, and autumn seasons, respectively. Increased amount of runoff during the summer season facilitated the transport of pollutants into the system. Pollutants accumulated on surfaces were washed-off by the stormwater on rainfall events, thereby increasing pollutant loads in the runoff (Ma et al., 2016).

The IT exhibited a 10%, 8%, and 5% to 74% decrease in the mean RE for particulates, COD, and heavy metals, respectively during the summer season. Aside from the increased pollutant loadings entering the system, the diminished performance of the IT was attributed to the increased rainfall intensity, duration, and other hydrological factors in the catchment area. Moreover, the filtration mechanism of an infiltration trench can be highly affected by variations in



(a)

(b)

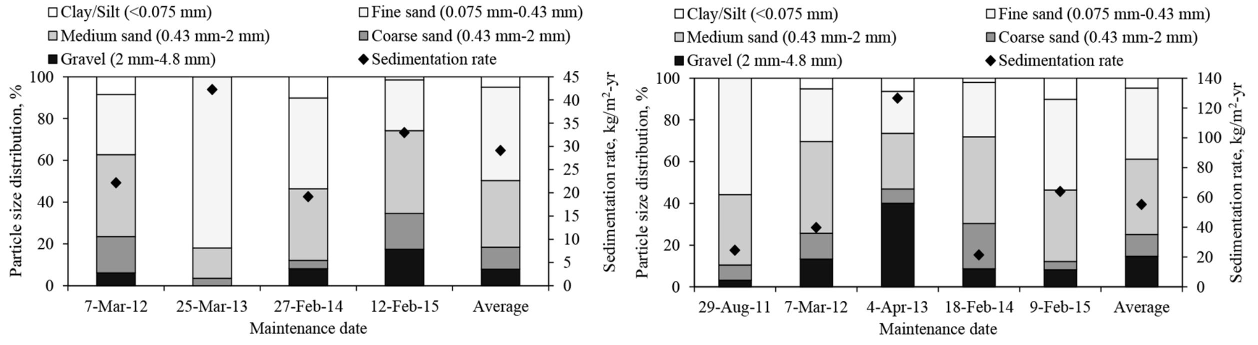
Fig. 4. Seasonal inflow and outflow unit pollutant loads in the a) IT and b) SCW.

hydrologic regimes (Guerra et al., 2018). Rainfall events exceeding the facility's design rainfall and storage volume caused the facility to overflow, thus bypassing the treatment zone. Winter season posed a greater impact on SCW as manifested by the 24%, 25%, and 21% to 70% decrease in the reduction of particulates, COD, and heavy metals, respectively. Plants are major components of a wetland system. Plants enable the SCW to uptake and detoxify pollutants through various mechanisms (Ali et al., 2013). Since plants become dormant during winter, the pollutant removal capabilities of the system had been reduced. Similar patterns were observed by Roseen et al, which led to a conclusion that vegetated and bioretention systems were greatly affected by seasonal variations compared to filtration and infiltration systems (Roseen et al., 2009).

3.4 Sediment analyses

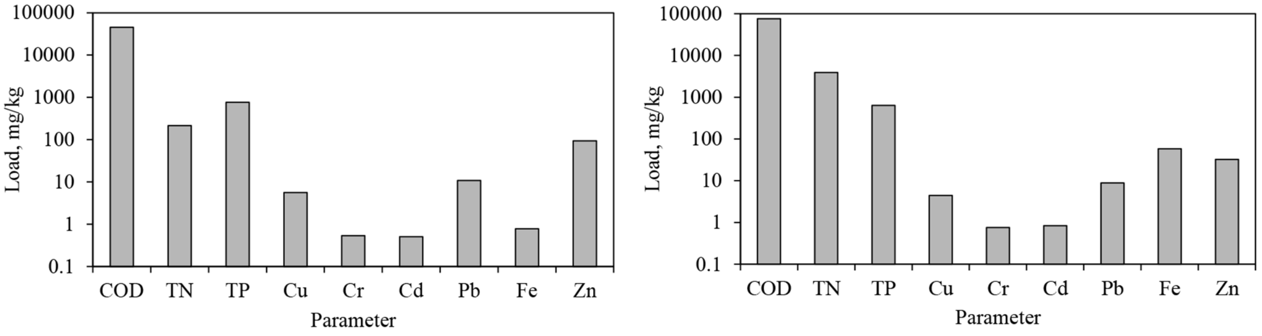
LID facilities are susceptible to ageing and performance degradation as a result of clogging. Regular maintenance of the IT and SCW were conducted to restore the filtering capability of the facilities. As illustrated in Figure 5, most of the sediments collected in the sedimentation tank and filter media of the SCW were mainly fine sands, constituting an average of 45%. A larger portion (36%) of the sediments collected in the IT was composed of medium sands. For facilities equipped with pre-treatment zone, gravitational settling is a major mechanism in the removal of particulates (Maniquiz 2012). Finer particles were basically unsettleable and can easily bypass the porous media layers, thus resulted to a lower percentage (2% to 10%) of sediment particle size (Yuan & Kim, 2018). The average sedimentation rate in the IT for the five-year collection period (2011 to 2015) amounted to 63.98 kg/m^2-yr, whereas an average of 32.97 kg/m^2-yr of sediments accumulated in the SCW from 2012 to 2015. Since the IT has 14% and 59% larger catchment area and sedimentation tank volume, respectively, as compared with the SCW, the washoff and sedimentation potential was also increased. Higher sedimentation rate in SCW corresponded to an increase in fine sand fraction, whereas increase in the gravel fraction was noted for greater sedimentation rate in the IT. Variations in the particles collected in the maintenance periods were due to the differences in characteristic sediment loadings in the catchment area. Changes in anthropogenic and natural particulate deposition patterns were seen to be the main cause of deviations in particle sizes washed-off by urban stormwater. Moreover, sediment accumulation can be influenced by several factors such as hydraulic loading, amount of sediments in the runoff, and particle sizes that can potentially fill the voids in the facility (Mercado et al., 2015).

Roadside sediment deposits contain inorganic and inorganic pollutants that can be transported or mobilized through stormwater runoff (Loganathan et al., 2013). The distribution of mean pollutant loads in the sediments collected in the IT and SCW was displayed in Figure 6. It can be observed that the COD (40%) and TN (95%) loadings in the SCW sediments



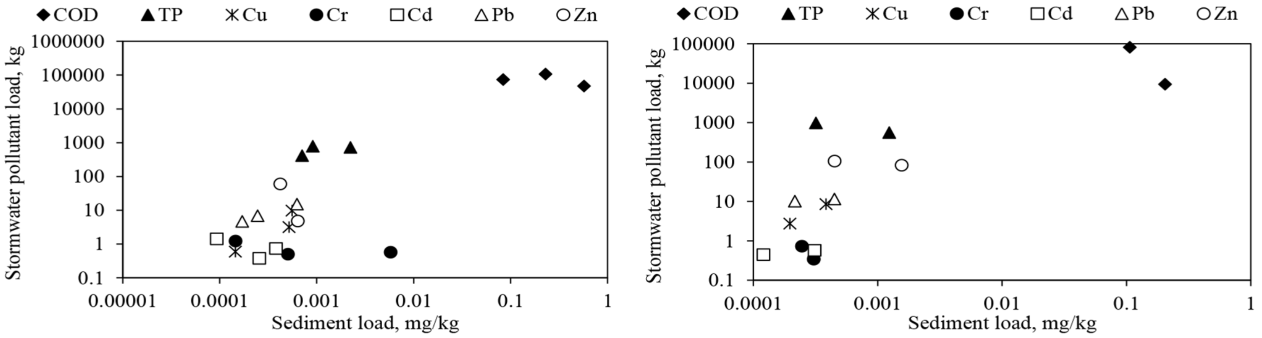
(a) (b)

Fig. 5. Particle size distribution and sedimentation rate in the a) IT and b) SCW.



(a) (b)

Fig. 6. Mean pollutant load distribution in the a) IT and b) SCW sediments



(a) (b)

Fig. 7. Comparison between mean sediment and influent stormwater pollutant loads in the a) IT and b) SCW

were relatively lower than IT's. Microbiological activities such as nitrification and denitrification and microbiological degradation of COD aided the removal of pollutants in the facility (Zhu et al., 2014). A wide range of variation was noted in the heavy metal concentrations in the facilities. Cu, Pb, and Zn loads in the SCW sediments were 26%, 22%, and 191% higher, respectively, than the IT sediments. A study conducted by Gill et al. also obtained the same trend of heavy metal accumulation in constructed wetland sediments. Portions of Cu, Pb and Zn on wetland sediments were especially observed to be highest on the first treatment zone of the system, and gradually decreased throughout the course of the facility (Gill et al., 2014). On the other hand, higher Cr (41%), Cd (65%), and Fe (7339%) loads were noted in the IT sediments. This variation can be explained by the differences in the mobility and partitioning of heavy metals in the solid phases of a particular unit (Kumar et al., 2013). Moreover, differences in landuse activities in the catchment area may also influence the type and abundance of heavy metal loading into the facilities.

Roadside deposits in urban areas contain pollutant-rich sediments than can be easily washed-off during rainfall events. Analysis of the collected sediments in the pretreatment and media zones and mean inflow pollutant loads in the stormwater runoff indicated that most stormwater pollutants in SCW exhibited high pollutant loads in conjunction with high sediment pollutant loads. Since most of the pollutants in stormwater were sediment-bound, there is a possibility that sediments impart a certain percentage of pollutant concentration in the influent stormwater (Wijesiri et al., 2016). However, despite the high pollutant loads in the IT sediments, influent stormwater pollutant loads in the IT did not exhibit the same properties. Particularly, some heavy metals found on sediments such as Cr, Cd, and Zn had negative correlations ($r=-0.5$ to $r=-1$) with the influent storm water quality. Heavy metals were typically affiliated with suspended particulates, which cannot be easily removed by gravitational settling (Maniquiz-Redillas & Kim, 2016). For this particular reason, the sediments collected in the pretreatment zone and media layers may not fully-correspond to the pollutant loads found in the influent storm water. A graphical summary of the relationship between the sediment and stormwater pollutant loads was presented in Figure 7.

3.5 Advantages and disadvantages of vegetated and non-vegetated LID facility

The utilization of LID facilities should be carefully-chosen depending on the treatment needs and site conditions. Non-vegetated facilities, such as the IT, use filtration as primary treatment mechanism of stormwater. One profound advantage of using filtration systems is the ability to replenish groundwater. On urban areas where the percentage of impermeable surface is extremely high, groundwater recharge potential was significantly reduced. ITs provide the opportunity of increasing groundwater recharge by means of percolation. For an infiltration type facility like the IT, larger flow volumes can be accommodated by the system. Additionally, larger sedimentation basins promote longer HRT, which can be beneficial in removing particles in stormwater. Considerable amounts of pollutants can also be removed from the influent due to the filter media incorporated in the design of IT. On the other hand, improper IT design may lead to groundwater contamination. According to the guidelines released by the United States Environmental Protection Agency (USEPA), a safe distance of 1.2 metres should be provided below the trench to avoid groundwater contamination (USEPA, 1999). Along with its compact design, ITs were also equipped with high water detention capabilities (Li, 2015). Engineered soils allow high infiltration and filtration rates of stormwater. However, a more frequent maintenance may be needed depending on the clogging condition of the filter media. Ultimately, clogged trenches result to higher hydraulic detention time, which can lead to ponding and potential breeding ground of insects and microorganisms.

Despite the lack of infiltration mechanism, SCW utilized biological processes in treating pollutants from stormwater. Incorporating vegetation in LID facilities induce phytoremediation mechanisms in to enhance pollutant treatment in urban stormwater. *Acorus calamus* is a type of hyperaccumulator plant that can uptake heavy metals and excessive nutrients present in the runoff (Sun et al., 2013; Zhao et al., 2009). A study conducted by Vymazal indicated that vegetated wetlands were more effective in nutrient removal as compared with other non-vegetated units (Vymazal, 2013). Ensuring the effectivity of SCWs requires precise selection of plant species and media types (Wu et al., 2015). Since filtration and adsorption were also employed in the treatment mechanism, SCWs also share the same advantages and disadvantages of an infiltration type LID facility. Additionally, treatment capabilities of vegetated systems can be seasonally affected (Farraji et al., 2016). Maintenance operations should also include the proper removal and/or replacement of plants, since decaying plant tissues can potentially contribute to the amount of pollutants present in the system. As compared to infiltration systems, vegetated facilities were more prone to microbial generation and insect breeding due to the presence of a warm and moist environment. Since plants constantly require a moist soil or media, SCWs are also excellent breeding ground for disease-carrying organisms

4. Conclusion

The application of NBS in stormwater management offers innovative solutions in reducing the volume and pollutant concentrations in urban stormwater runoff. Aside from being cost-efficient, NBS also provides a sustainable environment that is adaptable to the changing needs of the society. The IT and SCW are excellent examples of alternative stormwater management practices that provide significant peak flow reduction and water quality improvement schemes. Comparison of the two facilities revealed that both IT and SCW were affected by seasonal variations in climate. The pollutant removal performance of the IT was more sensitive during the summer season. Increased runoff volume resulted to a lower pollutant RE, especially on occasions where rainfall depths exceeded the facility's design capacity. On the other hand, SCW exhibited a lower pollutant RE during winter season as a result of plant and microbiological inactivity. Most of the sediments washed-off in the facility were composed of fine and medium sands. Since both IT and SCW were equipped with sedimentation tanks, larger sediments were trapped in in the pretreatment zone which also reduced the amount of sediments that can potentially clog the filter media. Assessment of the chemical properties indicated the COD and TN loads in SCW sediments were lower compared to IT's. This phenomenon demonstrated the organic and nutrient removal capabilities of the SCW as a function of phytoremediation and microbiological degradation. Moreover, the variations in the heavy metal loads in the sediments were found caused by the differences in landuse activities and mobilization of particulates in the catchment area.

Various advantages and disadvantages were deduced in comparing the facilities equipped with pre-treatment zones. Infiltration type facilities were effective in peak flow and pollutant management due to the presence of engineered soils that aid in percolation. However, improper design may lead to groundwater contamination. Moreover, media clogging was seen to be one of the most important factors affecting the performance of infiltration systems. Vegetated facilities utilize physical and biological mechanisms in stormwater treatment. However, the biological processes of vegetated systems were more susceptible so seasonal changes. This study presented brief comparison of LID facilities with pre-treatment mechanisms. The identified factors that can potentially affect the performance of the systems were also beneficial in establishing metrics on the utilization of similar types of nature-based stormwater management practices.

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