Understanding the mechanisms affecting the fate of organics and nutrients in a tree box filter treating parking lot runoff

Comprendre les mécanismes qui influent sur le devenir des matières organiques et des éléments nutritifs dans une boîte filtrante pour arbres qui traite les eaux de ruissellement d'un parking

Franz Kevin Geronimo[1], Marla Redillas[2], Hyeseon Choi[1], Heidi Guerra[3], Lee-Hyung Kim[1†]

[1]Dept. of Civil and Envi. Eng'g., Kongju National University, 1223-24 Cheonan-daero, Seobukgu, Cheonan city, Chungnam province, South Korea, 31080 ([†]Corresponding author's email: leehyung@kongju.ac.kr)
[2]Civil Eng'g. Dept., 2401 Taft Avenue, De La Salle University-Manila, Malate Manila, Philippines (marla.redillas@dlsu.edu.ph)
[3]Department of Environmental Engineering, Hanseo University, 46 Hanseo 1-ro Haemi-myun, Seosan-si, Chungcheongnam-do 356-706, Republic of Korea (heidiguerra@office.hanseo.ac.kr)

RÉSUMÉ

Cette étude a porté sur le comportement des matières organiques et des éléments nutritifs dans une boîte filtrante pour arbres de 8 ans qui traite les eaux de ruissellement d'un parking. D'après les résultats, on a constaté que les facteurs hydrologiques et hydrauliques, y compris le volume, le débit moyen, le débit de pointe, le temps de rétention hydraulique et la durée du ruissellement, ont eu une incidence importante sur l'efficacité de réduction des polluants du filtre de la boîte filtrante pour arbres, ce qui suggère que l'infiltration et la rétention dans l'installation jouent un rôle important pour réduire la charge organique et en nutriments du bassin versant du parking. Les analyses microbiennes des échantillons de sédiments prélevés dans le système ont révélé que le phylum microbien le plus commun dans les échantillons de sédiments était les protéobactéries, ce qui signifie que le filtre de la boîte filtrante pour arbres est sous conditions anaérobies suivi par d'autres bactéries fixatrices d'azote comme les actinobactéries, planctomycètes et bactériodètes. Ces résultats ont été utiles pour optimiser la conception et la performance des boîtes filtrantes pour arbres en tenant compte des mécanismes physiques, chimiques et biologiques d'élimination des polluants.

ABSTRACT

This study investigated the behaviour of organics and nutrients in an 8-year old tree box filter treating parking lot runoff. Based on the findings, it was found that hydrologic and hydraulic factors including volume, average flow, peak flow, HRT and runoff duration significantly affected the pollutant reduction efficiency of the tree box filter suggesting that infiltration and retention in the facility plays an important role in reducing the organic and nutrient loads from the parking lot catchment. Microbial analyses of sediment samples collected in the system revealed that the most common microbial phylum in the sediment samples was Proteobacteria implying that the tree box filter is under anaerobic condition followed by other nitrogen fixation bacteria including Actinobacteria, Planctomycetes and Bacteriodetes. These findings were useful in optimizing the design and performance of tree box filters considering physical, chemical and biological pollutant removal mechanisms.

KEYWORDS

Low impact development, microorganisms, treatment mechanisms, tree box filter, urban stormwater

1 INTRODUCTION

Strategies in addressing the water quality problems brought about by urban stormwater runoff has become an increasing concern due to non-point source pollutant accumulation in surface water thereby enhancing the further degradation of water bodies. Specifically, high nutrient concentration in water bodies lead to excessive algal growth and affects the level of organics since nitrogen (N) is essential to the production of plant and animal tissue while phosphorus (P) is vital for converting sunlight into usable energy and essential to cellular growth and reproduction. Management of urban drainage has become significantly complex over the past few decades, shifting from focused approaches to a multi-beneficial approach where several objectives drive the design and decision-making processes (Fletcher et al., 2015). Utilization of nature-based solutions including low impact development (LID) technologies, a multi-beneficial stormwater management approach that connects ecosystem with urban revitalization has been extensively practiced addressing the potential risks of mismanaged urban stormwater runoff. LID practices including decentralized technologies control stormwater from the source to mimic the pre-developed water cycle through mechanisms of microscale stormwater storage, increased infiltration and lengthening of flow path and runoff time (Damodaram et al., 2010). Understanding the mechanisms affecting the fate of organics and nutrients in a stormwater treatment system still needs investigation for optimum design and performance of stormwater treatment systems. As such, this study determined the mechanisms affecting the behaviour of organics and nutrients in an 8-year old tree box filter treating parking lot runoff.

2 MATERIALS AND METHODS

The tree box filter was constructed in 2010 inside Kongju National University, Cheonan city, South Korea to manage urban stormwater runoff from a 100% impervious parking lot. The aspect ratio (L: W:H) of the tree box filter was 1:0.67:0.87 with the design and catchment area shown in Figure 1. A total of 21 storm events were monitored from 2010 to 2016 with two maintenance procedures performed in between. Following the typical sampling scheme in South Korea, six grab samples were collected during the first hour when the stormwater runoff entered and was discharged by the tree box filter for the inflow and outflow water samples, respectively (Jung et al., 2008). The first grab sample was collected as soon as the runoff entered the tree box filter and after 5, 10, 15, 30 and 60 mins respectively. Sediment samples were also collected in the inflow and outflow part of the system and were analyzed for microorganism content. 16S rRNA gene sequence were conducted using Roche 454 pyrosequencing technology. PCR was performed to analyze the phylum and the count of the microorganisms.

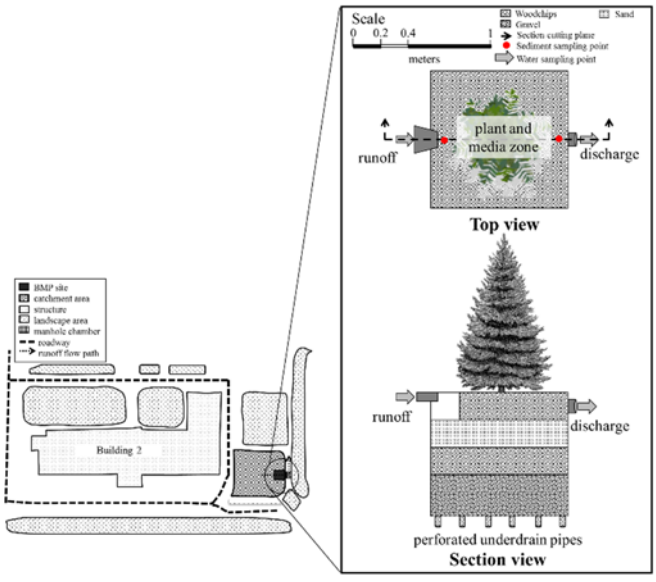

Figure 1: Schematic design of tree box filter and its catchment area

3 RESULTS AND DISCUSSION

3.1 Characteristics of monitored storm events

Cheonan city received an annual rainfall (mean ± standard deviation) from 2010 to 2016 amounting to 1176 ± 340 mm. The minimum and maximum rainfall depth monitored corresponded to 34% and 80% to 90%, respectively of the rainfall occurring in Cheonan city. These findings implied that the storm events monitored in the study objectively represented the rainfall depth occurring in Cheonan city. Among the 21 storm events monitored, only ten storm events were able to produce outflow wherein 40% of these occurred from June to August. The mean rainfall intensity of storm events that produced outflow was 34% greater than those which have no outflow. Excluding the storm events where the tree box filter has no discharge, the significant volume, average flow and peak flow reduction were 14% to 86%, 14% to 71% and 20% to 88%, respectively ($p < 0.001$). Rainfall depth was found to be negatively correlated with volume, average flow and peak flow reduction of the system implying that the increase in rainfall depth causes decreased hydraulic performance of the system ($r = -0.53$ to -0.59; $p < 0.01$). The hydraulic retention time (HRT) in the tree box filter was found to be significantly correlated with antecedent dry days (ADD) and runoff duration ($r = 0.55$ to 0.63; $p < 0.05$). This finding implied that the intermittent dry and wet condition affected by evapotranspiration mechanism of the tree box filter affected the system's hydraulic performance. Lastly, there was no correlation found between ADD and the system's hydraulic and pollutant reduction performance.

3.2 Stormwater quality characteristics

Figure 2 shows the inflow and outflow average ± standard deviation stormwater quality event mean concentrations (EMC) in the tree box filter. Considering the 10 storm events which produced outflow, only COD and TN was found to be significantly reduced from average ± standard deviation inflow EMC of 117.6 ± 116.6 mg/L and 6.1 ± 3 mg/L to average ± standard deviation outflow EMC of 61.8 ± 58.1 mg/L and 3.8 ± 3 mg/L, respectively. Average organics removal attained by the system were 50%, 66% and 35% for BOD, COD and DOC, respectively. On the other hand, average TN and TP removal were 73% and 63%, respectively. Reduction of runoff volume by 50% will result to organics and nutrients constituents' reduction ranging from 30% to 55% and 40% to 60%, respectively. Significant hydrologic and hydraulic factors including volume, average flow, peak flow, hydraulic retention time (HRT) and runoff duration affected the pollutant reduction efficiency of the tree box filter.

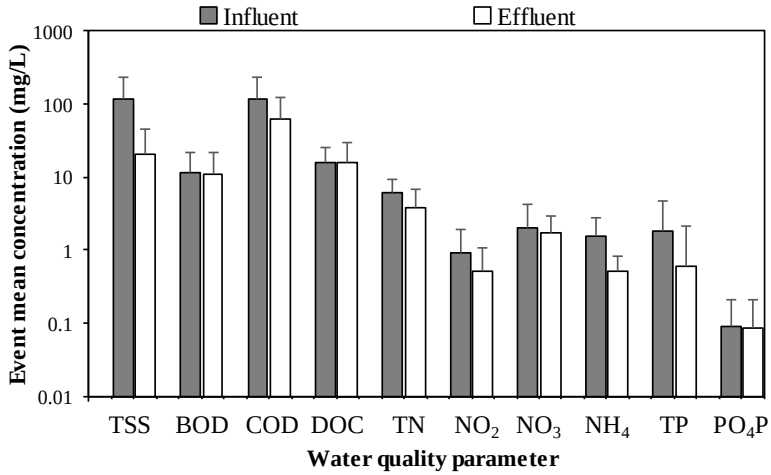

Figure 2: Average ± standard deviation values of influent and effluent event mean concentrations

3.3 Microbial analyses in the sediments collected from the tree box filter

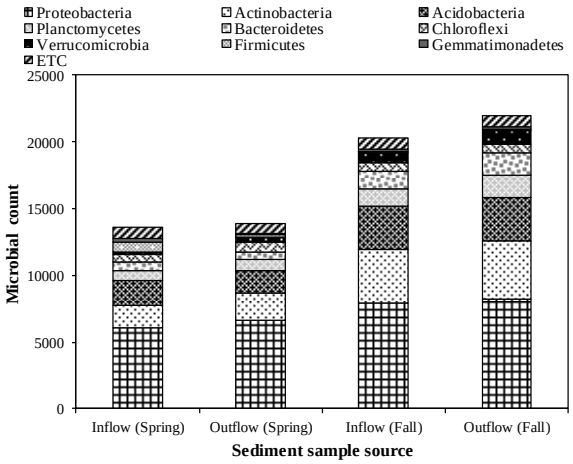

Figure 3: Microbial count in the sediments collected from the tree box filter

Exhibited in Figure 3 are the microbial count in the sediments collected from the inflow and outflow ports of the tree box filter. Apparently, the microbial count in the sediments collected during fall season is greater by 1.5 times than the sediments collected during spring season. Microbial analyses of sediment samples collected in the system revealed that the most common microbial phylum in the sediment samples was Proteobacteria implying that the tree box filter is under anaerobic condition followed by other nitrogen fixation bacteria including Actinobacteria, Planctomycetes and Bacteriodetes. These findings were especially useful in understanding the fate of organics and nutrients in the tree box filter.

4 CONCLUSIONS

In this study, a tree box filter developed to treat parking lot stormwater runoff was investigated to identify mechanisms affecting the removal of organics and nutrients. Mechanisms including adsorption, settling, microbial degradation, filtration and plant uptake were found to have affected the removal of organics and nutrients in the tree box filter. For similar tree box filter design and application, it is suggested that a small sedimentation basin be included to slow down clogging and for the ease of maintenance through coarse particle and debris removal. These findings were especially useful in applying similar tree box filter which may be designed by considering tree box filter surface area to catchment area of less than 1%.

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