Evaluation of pollutant dynamics and treatment efficiency of a small horizontal subsurface flow constructed wetland

Évaluation de la dynamique et du traitement des polluants dans un petit filtre planté de roseaux à écoulement horizontal

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RÉSUMÉ

En dépit des avancements dans le développement des installations à faible impact (DFI), plusieurs considérations doivent être prises en compte afin d'assurer un fonctionnement optimal et d'atteindre une réduction des polluants efficace. Cette étude évalue les caractéristiques des rejets de polluants dans les bassins urbains et l'efficacité des installations en zone humide souterraine à écoulement horizontal (SHSSF CW) dans leur traitement du ruissellement des eaux pluviales. 21 chutes de pluies entre 2010 et 2018 ont été suivies pour déterminer et quantifier les polluants présents dans les eaux pluviales. Le plus gros ruissellement de polluants fut observé lors de précipitations allant de 0.1 mm a 10 mm, tandis que des événements avec des quantités de pluie plus importantes ont montré des concentrations moins importantes, causées par un effet de dilution. Cependant, les constructions en zones humides ont manifesté de moins bonnes performances pour la supression des polluants, pour des quantités de pluie supérieures à 10 mm, causés par le dépassement des capacités d'évacuation d'eau de pluie des installations. Cette étude permet d'évaluer la dynamique du rejet de polluants et l'efficacité des installations DFI quand elles sont soumises à divers facteurs externes. Les résultats peuvent également servir de base à l'évaluation de la faisabilité de l'intégration de SHSSF CW dans un système intégré de gestion des eaux pluviales.

ABSTRACT

Despite the advancements in designing low impact development (LID) facilities, several considerations should be addressed to ensure optimum functionality and attainment of desired pollutant removal efficiency. This study evaluated the mass flushing characteristics of pollutants in an urban catchment and the efficiency of a small horizontal subsurface flow constructed wetland (SHSSF CW) in treating urban stormwater runoff. 21 rainfall events from 2010 to 2018 were monitored to determine and quantify stormwater pollutants. The highest pollutant washoff was observed on rainfall depths ranging from 0.1mm to 10mm, whereas events with greater rainfall depths exhibited lower pollutant concentrations due to dilution effect. However, the SHSSF CW manifested lower pollutant-removal performance on rainfall depths exceeding 10mm due to the exceedance of the facility's design rainfall. This study is beneficial in assessing the dynamics of pollutant washoff and efficiency of LID facilities subjected under various external factors. The findings can also serve as a baseline in assessing the feasibility of incorporating SHSSF CW in an integrated stormwater management system.

KEYWORDS

First flush, low impact development, nature-based solutions, small constructed wetland

1 INTRODUCTION

Non-point sources of pollution (NPS) from urban areas are one of the primary causes of water quality degradation among natural streams. Urban stormwater runoff may contain nutrients, organics, and heavy metals originating from anthropogenic and natural sources. Recent stormwater management techniques involve the use of nature-based solution (NBS) in runoff treatment to reduce the harmful effect of NPS in the environment. Low impact development (LID) is a type of NBS for stormwater management. LID technologies are economically-viable means of addressing the increased pollutant concentration and runoff volume of urban stormwater runoff. Despite the advancements in designing LID facilities, several considerations should be addressed to ensure optimum functionality and attainment of desired pollutant removal efficiency. This study evaluated a small horizontal subsurface flow constructed wetland (SHSSF CW) designed to treat urban stormwater runoff. Pollutant dynamics and mass flushing characteristics in an urban catchment were also investigated as a function of hydraulic and hydrologic factors.

2 MATERIALS AND METHODS

The SHSSF CW located at the Kongju National University, Cheonan City, Chungnam Province, South Korea utilized in the study was illustrated in Figure 1. The facility has an aspect ratio of 7m: 0.7m: 1m (L:W:H) and treats runoff from a 457-m^2 road catchment area. Inflow and outflow water samples were collected for water quality analyses on 21 rainfall events monitored from 2010 to 2018. Standard methods for water quality examination were conducted to determine total nitrogen (TN) and total phosphorus concentrations in the stormwater. Moreover, the presence of total heavy metals such as cadmium (Cd), chromium (Cr), and zinc (Zn) were investigated among the samples (APHA et al., 1992). Rainfall events were classified as low (0.1mm to 5mm), medium (5.1mm to 10mm), and high (>10mm) to assess the effect of hydraulic and hydrologic parameters on mass first flush (MFF) potential, unit pollutant loads (UPL), and pollutant removal efficiency of the SHSSF CW. Soil samples were also collected for analyses following maintenance operations in the facility.

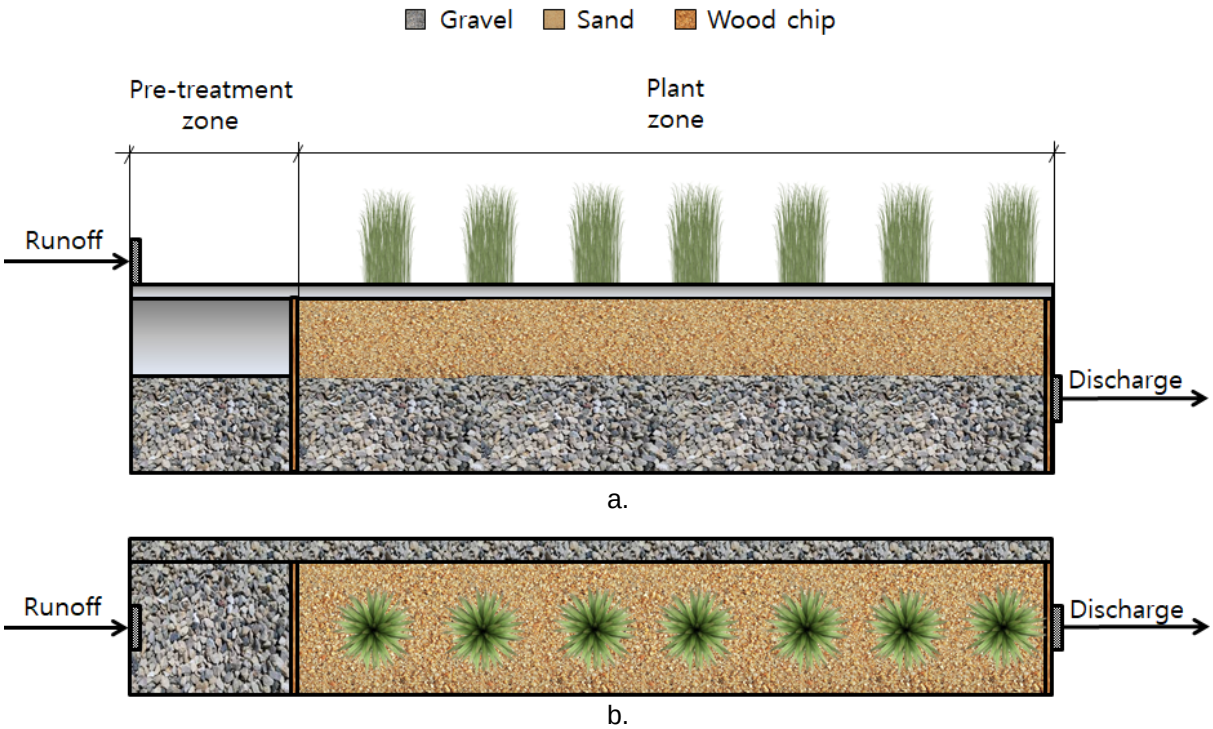

Figure 1. Schematic diagram of SHSSF CW: a) Side view b) Top view

3 RESULTS AND DISCUSSION

The plot of pollutant washoff characteristics as a function of rainfall depth and pollutant removal efficiency of the SHSSF CW with respect to UPL were exhibited in Figure 2. The highest nutrient UPL (0.019 kg/m^2 to 0.029 kg/m^2) were observed for rainfall depths ranging from 5.1mm to 10mm. Larger rainfall depths tend to dilute pollutants in stormwater, thereby reducing the amount of pollutants transported into the facility (Gong et al., 2016). Highest UPL for Cd, Cr, and Zn were observed on low rainfall events (0.1mm to 5mm) with values ranging from 0.072 kg/m^2 to 0.278 kg/m^2. Since heavy metals were bound to fine particles, small amounts of rainfall can easily mobilize fine-grained sediments (Li et al., 2015). The efficiency of the SHSSF CW was reduced by 18% to 40% in terms of nutrients and heavy metals removal for rainfall depths greater than 10mm. These events exceeded the SHSSF CW's design total rainfall of 5mm, thereby causing the facility to overflow. The average sediment accumulation rate in the SHSSF CW was 32.97 kg/m^2-yr. Moreover, 45% of the sediment deposits were mainly composed of fine sands.

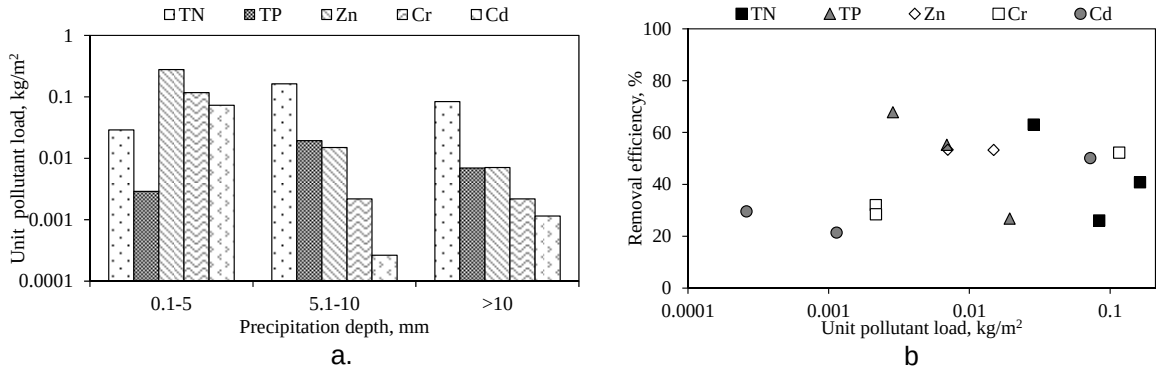

Figure 2. a) Pollutant washoff at varying rainfall depths b) Removal efficiency as a function of UPL

4 CONCLUSIONS

The dynamics of pollutant washoff is a complex process depending on various factors such as rainfall depth and intensity, runoff volume, and mass transport potential. In an urban catchment, mobilization of heavy metals was seen to be triggered even on low rainfall events. Since particulate-bound heavy metals can be easily transported by stormwater runoff, higher provisions should be incorporated on LID facilities in terms of heavy metal removal. On the other hand, high rainfall events tend to dilute pollutant concentrations on stormwater. However, the facility cannot accommodate higher runoff volumes, therefore resulting to a lower pollutant removal performance. Generally, design of LID facilities should incorporate the nature of pollutants, as well as the governing hydrologic regime in the catchment area. This study provided significant insights that can be useful in establishing design guidelines and factors to consider in LID facility optimization. The findings can also serve as a baseline in assessing the feasibility of utilizing SHSSF CW in an integrated stormwater management system

5 ACKNOWLEDGEMENT

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