Investigation on the factors affecting microorganism presence and survival in stormwater nature-based solutions

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Highlights

- Depending on the purpose of the application, a specific LID technology may be more suitable than the other.
- Depending on the target biogeochemical cycle, maintaining a good environment for a specific microbial phylum may be decided.
- Typical design using SA/CA ratio was found to be applicable to infiltration trenches and basins. On the other hand, using the traditional SA/CA ratio might result to error in designing bioretention and rain gardens instead, SV/SA ratio is recommended.

Introduction

Through the years, different terms have been associated with urban stormwater management. Most of these terms were from developed countries who identified the need to control NPS pollution to properly manage surface water quality and groundwater quality. Utilization of nature-based solutions including low impact development (LID) technologies, a multi-beneficial stormwater management approach that connects the ecosystem with urban revitalization has been extensively practiced addressing the potential risks of mismanaged urban stormwater runoff. As such, the 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.

Nature-based solutions (NBS) involved conservation or rehabilitation of natural ecosystems or the creation of natural processes in modified or artificial ecosystems to mimic natural processes for the improved management of water. By applying NBS, rehabilitation of ecosystem services can be ensured to improve nutrient management, reduce nutrient runoff, and infiltration to the ground especially for NPS from agricultural land uses. Microorganisms play an important role as decomposers, pathogens, and mutualist since it regulates the mass of ecological processes and biochemical cycling in soil. At present, studies about microorganisms have already revealed its function and roles in soil but it is still lacking in stormwater NBS. The function of soil microorganisms in regulating ecosystem function is still not fully understood which might eventually lead to poor prediction in soil biodiversity affecting ecosystem sustainability (Delgado-Baquerizo et al., 2020). Many studies have already been conducted to assess and fully understand the performance of different LID technologies. However, these LID technologies have been treated as a black box due to fluctuating flow and environmental conditions affecting its operation and treatment performance disregarding the contribution of soil microorganism to its overall performance. As such this study investigated the factors affecting the microorganism survival and presence and its implication in stormwater NBS.

Methodology

Eight different stormwater low impact development (LID) technologies were monitored from May 2009 to April 2018 with catchment and design characteristics summarized in Table 1. A total of 201 storm events were monitored in the eight LID technologies. These LID technologies were installed inside Kongju National

University, Cheonan City, South Korea to manage stormwater runoff from 100 % impervious road, roof, and parking lot areas. Initially, these LID technologies were designed to treat the first flush of storm events.

Table 1. Catchment, monitoring and design characteristics of stormwater green infrastructures.

LID Technology	Parameters						
	Runoff source	Catchment area, m^2	N storm events	Infiltration capability	Filter media	Facility aspect ratio (L:W:H)	Storage volume (SV), m^3
Infiltration Trench (IT)	Road	371	24	Yes	Sand, woodchip and gravel	1:0.2:0.26	3.54
Tree box filter (TBF)	Parking lot	379	26	Yes	Sand, woodchip and gravel	1:1:0.87	0.71
Hybrid constructed wetland 1 (HCW1)	Road and parking lot	323	21	No	Sand, woodchip and gravel	1:0.15:0.1	1.61
Hybrid constructed wetland 2 (HCW2)	Road and parking lot	425	22	No	Sand, bioceramic and gravel	1:0.14:0.1	1.56
Rain Garden 1 (RG1)	Roof	161	29	No	Sand, soil, woodchip, and gravel	2.47:1	6.26
Rain Garden 2 (RG 2)	Parking lot	481	20	Yes	Sand, woodchip and gravel	5:1:1	2.88
Bioretention 1 (BR1)	Parking lot	139	16	Yes	Sand, soil, bottom ash, and woodchip	2.5:1.08:1	2.32

Soil samples for microorganism analysis were collected at the initial 10 cm of the media part after the inlet and 10 cm of the media part before the outlet. This was conducted since the biological treatment mechanisms occurred in the media part of the low impact development technologies (LID) technologies (Hong, 2017). Although the runoff flow rate varies with the rainfall depth, generally it flows horizontally and vertically in the media part from the inlet to the outlet of each LID technologies. In addition, top and bottom layers of the media part have different properties including water content, temperature, and pollutant concentration. As such, soil sample collections for microorganism analysis were conducted at the top and bottom layers of the sample points near the inlet and outlet of the media part. In order to compare the soil microorganisms in the soil of the LID facilities, soil samples were also collected in the nearby landscape and subjected to microbial analysis which was referred to as in situ soil (IS) collected at least 1 m away from each LID technology.

Results and discussion

The comparative analysis of microbial count in LID technologies and IS was demonstrated in Figure 1. Proteobacteria remained as the most dominant microorganism for all LID technologies and IS comprising 34% to 45% and 23% to 31% of the total microorganism count, respectively. Higher abundance of Proteobacteria was also observed in LID technologies compared to IS. Proteobacteria comprises 40% of validly published prokaryotic bacteria and encompass a major proportion of traditional gram-negative bacteria since it shows extreme metabolic diversity (Kersters et al., 2006). On the other hand, the abundance of Acidobacteria in LID technologies were found to be 2.6% to 15.8% less than that of IS. Since LID technologies received stormwater runoff during storm events, more pollutants acting as substrate enter the technologies which obstruct its growth since Acidobacteria adapted to low substrate availabilities (Naether et al., 2012). Actinobacteria in LID technologies and IS comprised about 9 to 16% and 10 to 17%, respectively. The difference in Actinobacteria between LID and IS was affected by several factors such as its ability to resist

UV radiation, heat, and desiccation, ability to produce antibiotics excluding other bacteria, and survival in heavy metal contaminated soils. Chloroflexi abundance found in IS were greater by 1% to 9% compared to LID technologies. This finding was due to the abundance of Chloroflexi in low-nutrient soils and other oligotrophic ecosystems (Gou-Chun et al., 2013). The finding of this research, however, negated the findings that Chloroflexi abundance increased with increasing pollution level and are highly resistant to heavy metals. Except for TBF and RG2, the dominance of Planctomycetes in LID was greater by 0.1% to 2.3% compared to IS. These findings were attributed to the resistance of Planctomycetes to extremely high nitrate, nitrite, and ammonium concentration. Planctomycetes abundance in LID technologies was also found to be less than saline-alkali soil ranging from 12% to 20%. Bacteroidetes abundance in LID was found to be greater by 2% to 10.6% compared to IS which was supported by its resistance and richness in heavy metal-containing soils. On the other hand, Verrucomicrobia abundance in LID was lower by 0.2% to 3.61% in all LID technologies except for BR1 since Verrucomicrobia is negatively correlated with an increase in pollution level. Similarly, Gemmatimonadetes were also less by 1% to 3.7% in all LID except BR1 compared to IS which was due to the metal stress that severely affects rare and sensitive species leading to decreased competition ability. On the other hand, Verrucomicrobia abundance in LID was lower by 0.2% to 3.61% in all LID technologies except for BR1 since Verrucomicrobia is negatively correlated with an increase in pollution level. Similarly, Gemmatimonadetes were also less by 1% to 3.7% in all LID except BR1 compared to IS which was due to the metal stress that severely affects rare and sensitive species leading to decreased competition ability.

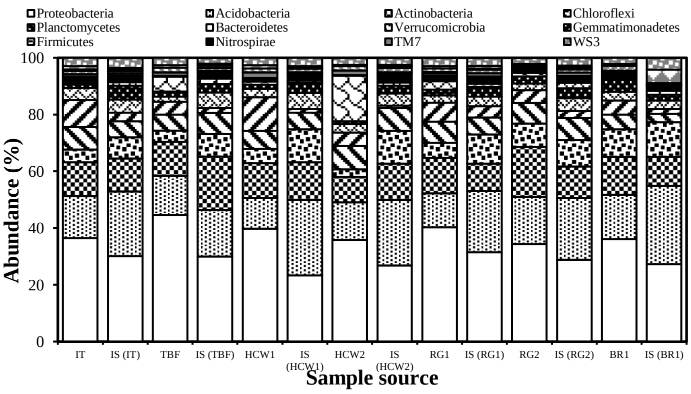

Figure 1. Comparison of microorganism phyla dominance in each stormwater green infrastructure and in situ soil.

Conclusions and future work

Microorganism count in LID technologies exhibited low count compared to those of IS. This finding is attributed to stormwater entering the LID technology during storm events which contained contaminants that might pose stress to the microbial community. However, it was found that more diverse microbial family and genus were observed in LID compared to IS which might have been affected by an intermittent change in pH during storm events. These findings are useful for designing LID technologies considering biological mechanisms.

References

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