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Life cycle greenhouse-gas emissions from urban area with low impact development (LID)

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Abstract. In this study, a comprehensive model developed to estimate greenhouse gas (GHG) emissions from urban area with low impact development (LID) and its integrated management practices (IMPs). The model was applied to the actual urban area in Asan Tangjeong district (ATD) as a case study. A rainwater tank (1200 ton) among various LID IMPs generated the highest amount of GHG emissions (3.77×10^5 $kgCO_2eq$) and led to the utmost reducing effect (1.49×10^3 $kgCO_2eq$/year). In the urban area with LID IMPs, annually 1.95×104 $kgCO_2eq$ of avoided GHG emissions were generated by a reducing effect (e.g., tap water substitution and vegetation CO_2 absorption) for a payback period of 162 years. A sensitivity analysis was carried out to quantitatively evaluate the significance of the factors on the overall GHG emissions in ATD, and suggested to plant alternative vegetation on LID IMPs.

Keywords: greenhouse gas emission; low impact development; green infrastructure; life cycle assessment; reduction effect; sensitivity analysis

1. Introduction

Greenhouse gas (GHG) emissions from water infrastructures have been recognized as a severe problem due to their high involvement with the environmental systems (Frijns 2012, Rothausen and Conway 2011). To reduce the emissions from water infrastructures, previous studies have suggested several innovative ways such as a decentralized system for the sustainable water infrastructures (Lienert *et al*. 2006). However, few researchers brought the benefits of the mitigation methods into question whether how much the methods could mitigate the environmental impacts on the ecosystem as well as a human society. To resolve the question, life cycle assessment (LCA) methodology has been widely applied to evaluate the mitigation methods whether they are truly beneficial on the environment or not (Angrill *et al*. 2012, Kyung *et al*. 2013, Lim *et al*. 2010, Lundie *et al*. 2004, Nessi *et al*. 2012, Pasqualino *et al*. 2011).

In recent years, a great deal of effort has been made on the low impact development (LID) and its integrated management practices (IMPs) as an effective decentralized stormwater management system, because it cost-effectively reduces the bulk loading of runoff and environmentally

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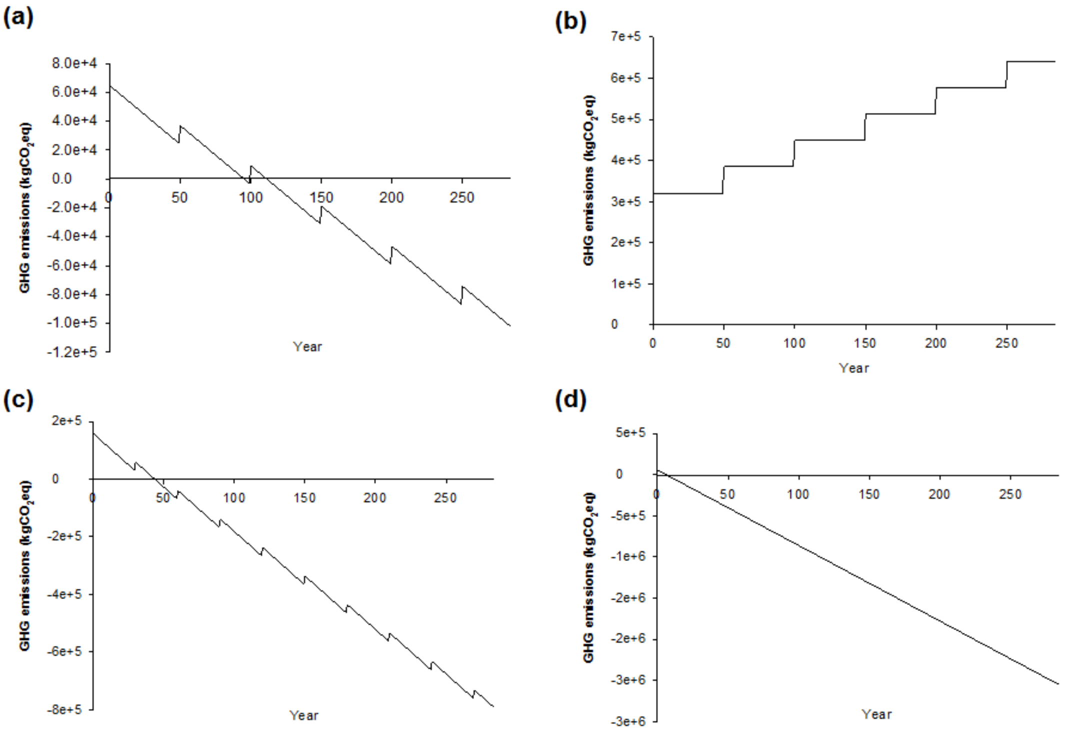

Fig. 3 Cumulative GHG emissions of IMPs: (a) constructed wetland; (b) lateral infiltration ditch; (c) vegetated swale; (d) infiltration swale at ATD; and (e) rainwater tanks (1200 and 600 ton)

infiltration swales (Figure 3 (d)), GHG emissions were 1.58×10^5 and 5.58×10^4 $kgCO_2eq$, and annual avoided emissions were 4.35×10^3 and 9.21×10^3 $kgCO_2eq$, respectively. In every 30 years, additional GHG was emitted from vegetated swales to maintain and replace perforated pipes under the swales. Their payback periods were 44 and 7 years, respectively.

For 1200 ton (2 units) and 600 ton (3 units) rainwater tanks installed in ATD, Fig. 3(e) shows that GHG emissions were respectively 7.72×10^5 and 6.18×10^5 $kgCO_2eq$, covering 75% of total GHG emission. Since the annual avoided emissions (2.96×10^3 and 2.21×10^3 $kgCO_2eq$/year) after tap water substitution were relatively small, rainwater tanks could not offset the GHG emissions and maintenance emissions over the years. These results implies that the rainwater tank constructed for the purpose of public interests (e.g., conservative toilet flush or gardening of parks in ATD) are expected to have a marginal reducing effect. Alternatively, reducing the consumption of concrete referring an environmental-friendly configuration (Angrill *et al.* 2012) and substituting concrete with other alternative materials (BlueScope 2004) should be primarily considered to mitigate GHG emissions.

GHG emissions of constructed wetland, lateral infiltration ditch, and rainwater tanks outweighed their avoided emissions during 100 years. Only vegetated and infiltration swales could alleviate their GHG emissions by their reducing effects. It implies that reducing effect was partial and slow to accrue the payback compared to the material consumption during the installation. Their reducing effects should be improved to be considered as one of the options to mitigate GHG emissions within the urban area. Additionally it is necessary to consider their other advantages such as hydrological improvement in infiltration, water retention, evapotranspiration, and mitigation of urban heat island effect (Spatari *et al*. 2011, USEPA 2009).

4.3 Comparison of conventional and LID urban plan in ATD

Cumulative GHG emissions of conventional and LID urban planning in ATD were compared and described in Fig. 4. Conventional urban planning emitted small amount of GHG (2.69×10^4 $kgCO_2eq$) from construction processes of water pollution control facilities (8 units) because the gravity-powered facilities did not consume energy or resources to treat rainwater runoff and maintenance activities which generates negligible amount of GHG emissions. In case of LID urban planning, vegetation CO_2 absorption and tap water substitution generated the avoided emissions (1.95×10^4 $kgCO_2eq/year$) over years and eventually exceeded GHG emissions (1.85×10^6 $kgCO_2eq$) of installation. These results indicates that the cumulative GHG emission of LID urban planning is less than that of conventional one after 160 years, although the initial GHG emission of conventional one was 72 times less than that of LID. The payback period of LID IMPs installed in ATD was 162 years. It implies that LID urban planning can contribute to GHG mitigation only in the long term perspective (> 150 years).

4.4 Sensitivity analysis

Sensitivity analysis was conducted as shown in Table 4 based on the functional year of 162 years identified as payback period of LID IMPs. The most significant factor on overall GHG emissions was NEE, covering 78.4%, due to wide vegetated area of LID IMPs. It indicated that type and area of vegetation have the largest effects on CO_2 absorption capacity. The reed vegetated on IMPs in ATD had relatively low NEE (2.72 $kgCO_2/m^2$-year), compared to that of alternative

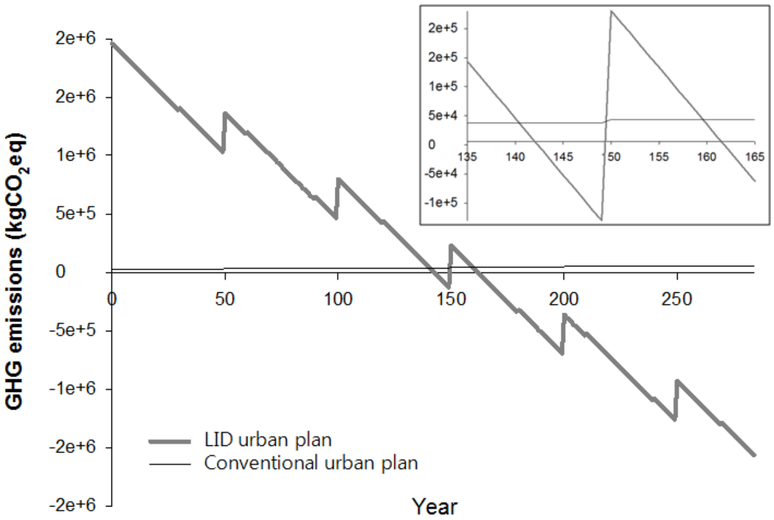

Fig. 4 Cumulative GHG emissions of conventional and LID urban planning in ATD

Table 4 Significant factors influencing cumulative GHG emissions in 162 years in ATD

	Significant factors (Contribution percentage to variance)
GHG emissions	EF of concrete (50.9%), Lifespans (32.6%), EF of reinforced steel (15.3%), EF of PVC pipe (0.9%), and EF of diesel (0.3%)
Avoided emissions	NEE (90.5%), Rainwater reuse (7.5%), and EF of Tap water production (2.0%)
Overall GHG emissions	NEE (78.4%), Rainwater reuse (7.0%), EF of concrete (6.4%), Lifespan (4.4%), EF of reinforced steel (1.9%), EF of tap water production (1.8%), and other 19 factors (0.1%)

vegetation such as sedum (sprunum, 3.1 $kgCO_2/m^2$-year), grass (kamtsch aticum, 5.7 $kgCO_2/m^2$-year), and shrub (azalea, 4.9 $kgCO_2/m^2$-year) (Kim *et al*. 2012). This indicated that planting alternative vegetation can effectively reduce GHG emissions over years by improving CO_2 absorption capacity. The second significant factor was rainwater reuse capacity (7.0%) which is highly correlated with average annual precipitation. The rainwater reuse capacity of this study was calculated based on weather statistics and assumed reuse rate. The rainwater modeling tool (e.g., Storm Water Management Model) should be utilized later to achieve more detail results with exact value of the reuse capacity than herein (Lee *et al*. 2012). The third significant factor was concrete usage, covering 6.4%. Substituting concrete with plastics for rainwater harvesting tanks (the biggest consumer) can be suggested as practical way to mitigate GHG emission of the tanks (BlueScope 2004). Indeed, plastic rainwater tanks for small volume (< 1 ton) have been widely applied to household rainwater harvesting system (Krishna 2005). Other factors including lifespan (4.4%), EF of reinforced steel (1.9%), EF of tap water production (1.8%), distance for material transportation (< 0.1%), fuel consumption for construction (< 0.1%), and electricity consumption for operation of rainwater tanks (< 0.1%) are relatively negligible.

As a result, regional and climatic characteristics such as average annual precipitation, rainwater runoff, and capacity of rainwater harvesting should be checked and analyzed to maximize their benefits of LID IMPs (Krishna 2005).

5. Conclusions

In this study, the model for quantifying GHG emissions and avoided emissions from LID IMPs was developed by applying LCA methodology. Its applicability was demonstrated by applying the model to LID urban area in ATD. The results indicated the avoided emissions caused by tap water substitution and vegetation CO_2 absorption effects are annual 2.01×10^4 $kgCO_2eq$ and its payback period to offset GHG emissions from LID IMPs in ATD is approximately 162 years. The significant factor influencing on overall GHG emissions was identified as NEE (78.4%) by sensitivity analysis. Planting alternative vegetation (e.g., grass or shrub) was suggested as the most effective strategy to reduce the emissions.

This model is the first study to quantify overall GHG emissions and evaluate the environmental benefits of LID IMPs at urban scale. It can be used for urban planner as a powerful tool by providing basic information of GHG emissions and alternative suggestions to design an LID applied area toward being sustainable infrastructures. Finally, it will be connected with models for other water infrastructures and advanced an integrated model to assess entire water system at the city scale in the near future.

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