https://doi.org/10.71573/k7tkqk27

Development of a Multi-Objective Optimal Design Framework for Integrated Green-Grey Infrastructure

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Abstract

Rapid urbanization and climate change have exposed the limitations of traditional grey infrastructure (e.g., UDN and DR), which often lack the resilience needed to address urban water management challenges. The integrated optimal design of green-grey infrastructure is a promising solution, with studies verifying the effectiveness of green infrastructure—such as Low Impact Development (LID)—in reducing runoff and enhancing sustainability, as well as the efficiency and flood mitigation benefits of grey infrastructure. However, previous methodologies have overlooked spatial constraints in integrating green and grey infrastructures, resulting in suboptimal site-specific designs. In this study, a multi-objective optimal design framework is proposed for the integrated green-grey infrastructure. The framework enhances efficiency by identifying feasible locations, narrowing the optimization space, and preventing overlaps. Based on GIS data (e.g., land use maps, slopes, and digital elevation model) and UDN information, the framework identifies potential installation locations for LID and DRs according to the UDN. Additionally, the framework prioritizes facilities based on flood reduction effectiveness to prevent overlaps and maximize efficiency. The results showed that the types of LID and the feasible installation locations for DR significantly decreased, while the design cost of UDN tended to increase further.

Highlights

- A multi-objective optimization framework is proposed for the green-grey infrastructures design.
- The effectiveness that shares suitability between each infrastructure was verified.
- The expanded Urban Drainage Network was the most effective in flood mitigation.

Introduction

The optimal design of Urban Drainage Systems (UDS) has become increasingly important as rapid urbanization and climate change have intensified runoff and flooding. To address these challenges, the integrated design of green–grey infrastructure—combining Low Impact Development (LID), Urban Drainage Networks (UDN), and Detention Reservoirs (DR)—has emerged as an effective strategy to mitigate flood risks and enhance urban resilience. Previous studies have demonstrated the benefits of such integration and applied multi-objective optimization techniques (Humaiqani & Ghamdi, 2023; Xiong et al., 2023; Wang et al., 2023). However, they have often overlooked spatial constraints when integrating green and grey infrastructure, resulting in suboptimal site-specific designs.

To address this gap, this study proposes an advanced multi-objective optimization framework that integrates the complementary roles of LID, UDN, and DR. The framework improves efficiency by identifying feasible locations, narrowing the optimization space, and preventing overlaps. Using detailed design information such as LID type and area and the capacity of UDN and DR, the framework supports more effective integrated designs. Results show that, while the number of LID types and feasible installation sites for DR decreased, the design cost of UDN tended to increase, reflecting trade-offs in the integrated design approach.

Methodology

Development of multi-objective optimization framework for integrated green-grey infrastructure

This study proposes a framework for the integrated optimization of green–grey infrastructure, emphasizing the coordinated design of UDN, DR, and LID. Potential locations for installing LID and DR are first identified using GIS data and hydraulic analysis, which narrows the optimization space and prevents overlaps. The framework is conducted in two stages: (1) the Suitability Assessment Stage, and (2) the Application of Multi-objective Optimization.

Suitability assessment for green-grey infrastructure

In the suitability assessment stage, DEM, land-use maps, slope data, and UDS data are used to identify potential installation sites for DR and LID (Step 1). Hydraulic analysis is then conducted to locate flooded nodes (Step 2), and the final potential locations for installation are determined (Step 3).

Application of multi-objective optimization

The multi-objective optimization stage starts by defining optimization decision variables, and constraints from the suitability assessment (Figure 1). At each iteration, newly generated designs are compared with existing designs of similar construction costs for each infrastructure type. Superior designs replace the old ones. For example, a new LID-focused design combines UDN and DR components from the best existing designs (excluding LID) and is compared with similar LID-cost designs. If superior, it replaces the existing design.

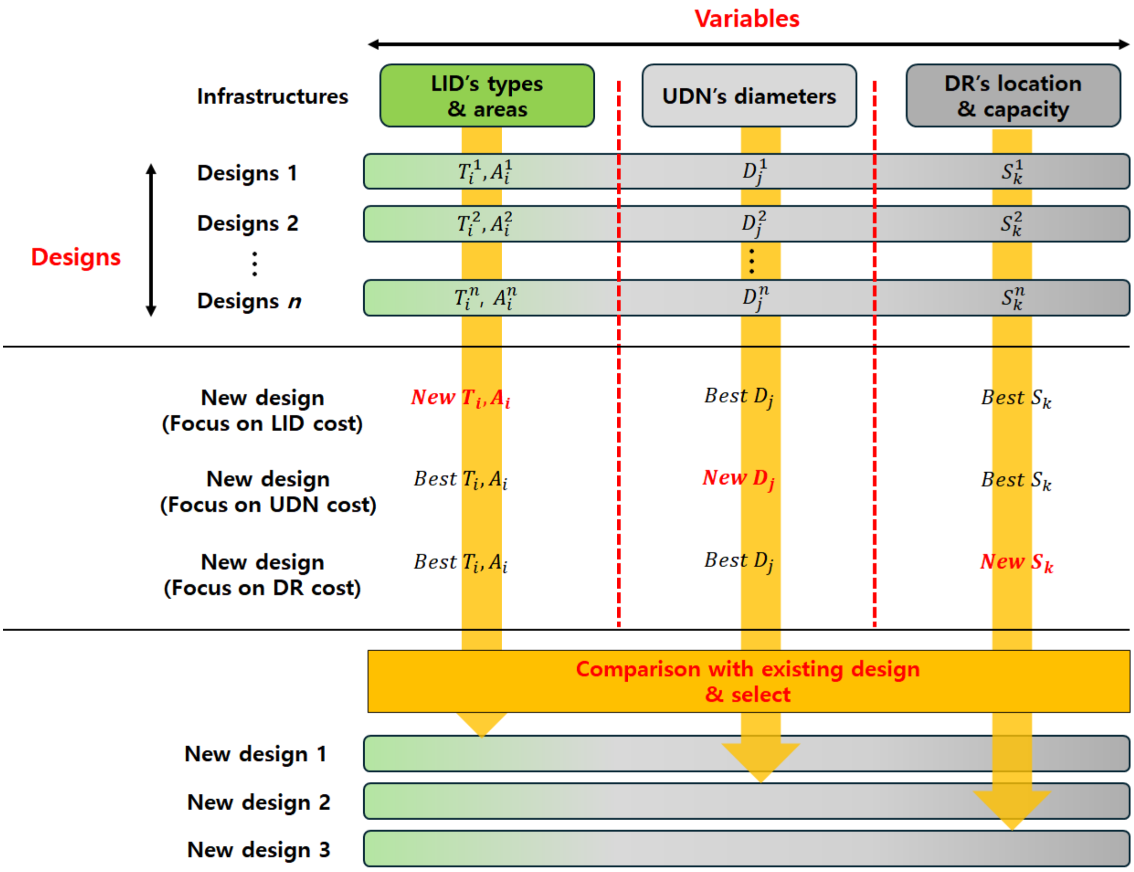

Figure 1. Framework for generating and selecting optimal designs of Green-Grey infrastructures

Case study

The study area is the A-UDS region in South Korea, which is predominantly residential with an average slope of 10% and is prone to frequent flooding (Figure 2). The existing UDN was originally designed for a 10- to 30-year return period, while the detention reservoirs were designed for a 30- to 50-year return period (Ministry of Environment, 2020).

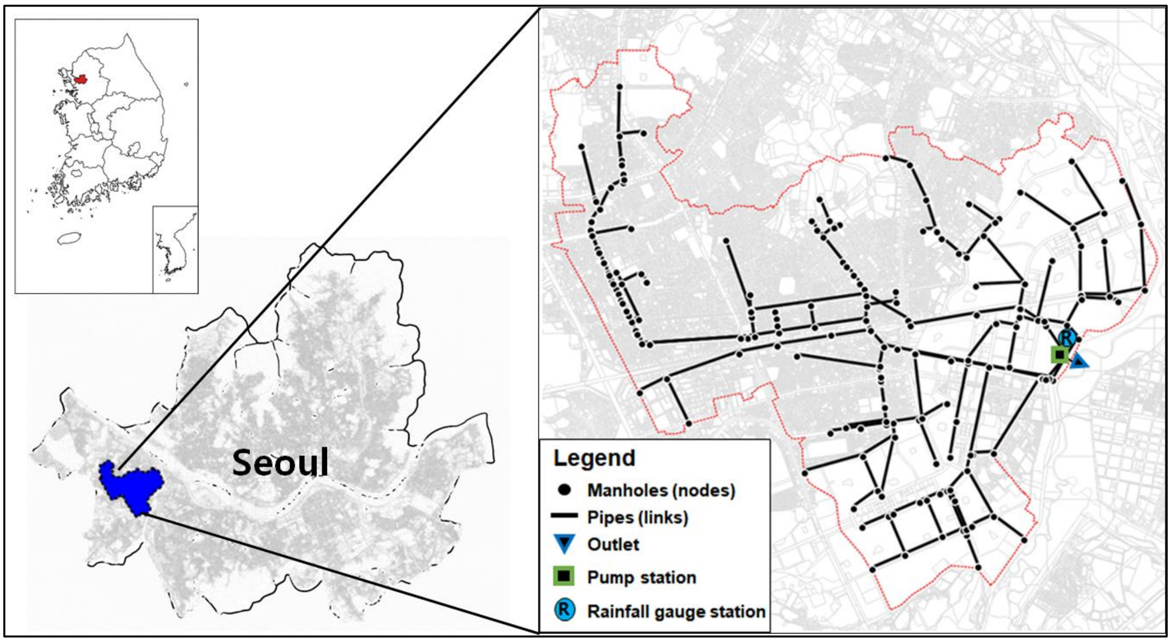

Figure 2. Study A-UDS

Results and discussion

To validate the proposed method, a comparison was made with the existing approach (non-suitability assessment & multi-objective optimization strategy). The results showed that the proposed method offered greater flood reduction effectiveness relative to cost. The design costs for LID decreased by 23.79% and for DR by 20.19%, while UDN's cost increased by 33.01%. This indicates that UDN was more effective in flood reduction than LID, and as UDN's design cost increased, DR's cost decreased.

Conclusions and future work

This study proposed a multi-objective optimization strategy for the optimal design of coupled green-grey infrastructure, including the suitability assessment of each infrastructure and a design strategy for their optimal integration. The proposed method was found to provide greater flood reduction effectiveness relative to cost compared to the existing approach, which used each infrastructure as a separate decision variable. Furthermore, UDN was identified as the most effective for flood reduction. However, more detailed considerations, such as long-term rainfall scenarios, validation across various urban areas and operation costs, should be incorporated into the design process of each infrastructure.

Acknowledgement

This work was supported by Korea Environmental Industry & Technology Institute (KEITI) through technology development project to optimize planning, operation, and maintenance of urban flood control facilities, funded by Korea Ministry of Environment (MOE)(RS-2024-00398012).

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