A novel framework for Low Impact Development (LID) planning and runoff control in urban watersheds

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Introduction

The lack of sustainable development in numerous cities has altered watersheds' permeability characteristics, leading to a higher risk of urban flooding (Yao et al. 2016). Besides, traditional grey urban drainage networks have been shown to be inefficient in terms of environmental protection and technical performance. Low Impact Development (LID) practices have been proposed by many researchers as a substitute, however, restoring urbanized watersheds to the desired hydrological conditions may impose excessive costs on decision-making organizations (Kim et al. 2017; Rezazadeh Helmi et al. 2019). Hence, the selection of LID combinations should be based on criteria such as cost-effectiveness and adaptation to the urban context.

Numerous studies have been conducted on optimizing and planning schemes for LID combinations to mitigate urban runoff and several models coupled with other tools have been investigated (Taghizadeh et al. 2021; Hassani et al. 2023). Some of the most popular LID types include green roofs, rain barrels, bio-retention cells, porous pavements, and vegetated swales (Liu et al. 2021). In this study, an integrated framework based on modeling, multi objective optimization and decision support tools have been proposed through a dynamic interaction between Storm Water Management Model (SWMM), System for Urban Stormwater Treatment and Integration (SUSTAIN), and Multi-Criteria Decision Making (MCDM) models. This method is capable of not only determining cost-effective solutions for a single scenario, but also prioritizing scenarios of various LID types based on technical and economic criteria that could help decision makers to select most suitable LID schemes for stormwater systems in urban watersheds.

Materials and methods

The proposed method was applied in a stormwater system located in the northern part of district 11, Tehran, Iran occupying a total area of 2.7 km^2. Six diverse LID schemes were defined as stormwater control scenarios considering land use and spatial limitations (Table 1). SWMM was used for rainfall-runoff modelling as well as simulating the hydrological processes of the drainage network during a 10-year return period storm event (USEPA, 2015). The SWMM output was imported to SUSTAIN model and cost-effectiveness analysis was conducted using the SUSTAIN built-in optimization module for each scenario (USEPA, 2009). In the next step, the optimized LID schemes were simulated through the SWMM LID module to analyze the stormwater system's performance under LID and Non-LID scenarios.

Table 1. LID scenarios for runoff mitigation.

Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Green Roof Bioretention Vegetated Swale	Rain Barrel Bioretention Vegetated Swale	Green Roof Porous Pavement Vegetated Swale	Rain Barrel Porous Pavement Vegetated Swale	Green Roof + Rain Barrel Bioretention + Porous Pavement Vegetated Swale	Scenario 5 + Dry Pond

The most superior solution of each scenario were investigated and ranked using TOPSIS multi-criteria decision making model based on four criteria including: 1) Runoff Volume Reduction, 2) Peak Discharge Reduction, 3) Reduction of Surcharged Conduits, and 4) Implementation Costs. The weights for each criterion were determined using AHP, Entropy and combined AHP-Entropy methods to make robust weightings. The flow chart for the proposed methodology has been demonstrated in Figure 1.

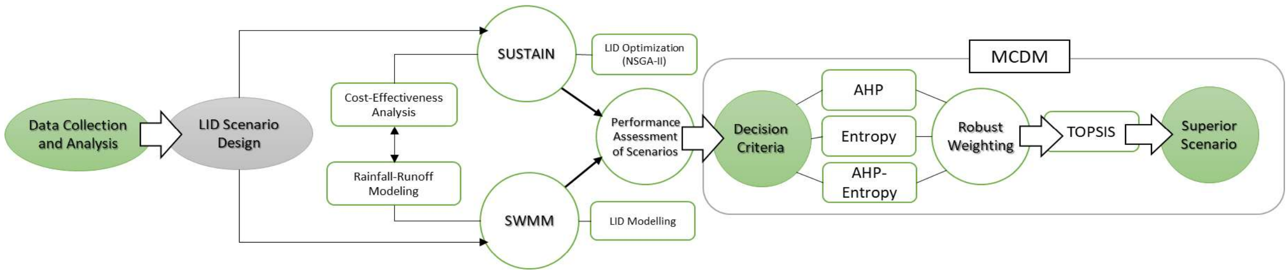

Figure 1. Research flowchart.

Results and concluding remarks

According to the summarized results in Table 2, the performance of each scenario has been shown based on four pre-defined criteria. All weighting methods including AHP, Entropy and AHP-Entropy represented the cost factor as the most contributing criterion in ranking the scenarios. Using TOPSIS method, Scenario 4 consisting of Rain Barrels, Porous Pavements, and Vegetated Swales was selected as the ideal scenario with 7.68 million dollars, reducing runoff volume, peak discharge, and the lengths of surcharged conduits by 20.77%, 19.2%, and 26.4%, respectively. Scenario 3 with a combination of Green Roofs, Porous Pavements, and Vegetated Swales ranked sixth despite the best performance comparing other scenarios due to the high implementation costs.

The proposed approach can help decision-makers and urban planners to determine the most suitable LID schemes, taking into account LID modelling, multi-objective optimization, and experts' attitudes through multi-criteria decision making. However, it is suggested that other criteria such as stormwater quality, social and aesthetics aspects be considered for future studies.

Table 2. Summarized results for the performance and ranking of LID scenarios.

Scenario	LID Coverage (m^2)	Total Cost (million $)	Peak Flow Reduction (%)	Runoff Reduction (%)	Reduction of Surcharged Conduits (%)	TOPSIS (Ranking)
Scenario 1	951354	196	51.3	59.44	52.8	5
Scenario 2	21160	3.25	4.3	15	5.1	2
Scenario 3	1147329	234.6	61.3	68.96	58.4	6
Scenario 4	*39699*	*7.68*	*19.2*	*20.77*	*26.4*	*1*
Scenario 5	630938	135.4	38.2	43.38	45.6	4
Scenario 6	626707	136.3	40.6	44.25	46.9	3

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