Journal of Environmental Studies

Vol. 48, No. 1, Spring 2022

Journal Homepage: www.Jes.ut.ac.ir
Print ISSN: 1025-8620 Online ISSN 2345-6922

Multi- Criteria Prioritization of Green Infrastructure Practices and Their Combinations to Control Runoff in Tehran Metropolitan

Document Type
Research Paper

Received
Desember 19, 2021

Accepted
March 27, 2021

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DOI: 10.22059/JES.2022.335865.1008264

Abstract

Urban green infrastructure (GI) development is a technique for reducing the consequences of urbanization on the hydrological cycle. This research aims to propose proper GI practices for urban areas of Tehran metropolitan using multi-criteria decision-making methods, including the Analytical Hierarchy Process (AHP) and TOPSIS. The framework of this research has seven main steps. Firstly, relevant criteria and sub-criteria were selected. Secondly, these criteria were weighted with a panel of nine experts with various fields related to the research from different viewpoints using AHP. A sensitivity analysis was conducted using PYSIS software to avoid possible bios. In the third step, all GI practices' suitability was evaluated and prioritized using the weight of selected criteria and sub-criteria. Finally, different scenarios for combining practices were defined, assessed, and prioritized. The results indicate that the porous pavement is the most suitable GI practice for Tehran, while green swale received the weakest. The results also revealed that infiltration trench, bio-retention bed, rainwater harvesting, retention pond, bio-retention pond, and green roof held the rank of second to seven of GI suitability. In terms of GI combination, ten essential GI combinations for the city of Tehran were proposed, including conveyance- detention, conveyance-restoration, conveyance-irrigation, detention- conveyance, detention- absorption, detention- irrigation, and absorption-irrigation. Finally, for each of the combination scenarios, GI combinations were proposed.

Keywords: Low impact development, Sustainable development, Urban hydrology, Analytical Hierarchy Process (AHP), TOPSIS

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Introduction

Urban development disturbs the natural infiltration of runoff by creating impermeable surfaces. With the increase of impermeable levels in the watersheds, the volume of runoff also increases, and cities will be exposed to waterlogging and floods in the rainy season. Therefore, the level of groundwater resources is expected to have lowered gradually. Today's main policy to face this problem centers on using traditional flood systems like concrete channelization to convey runoff which increases the problem of groundwater recharge. So, it seems that Green Infrastructure Development (GID) could play a crucial role in the restoration of the disrupted hydrological cycle, lowering the runoff problem, and moving toward urban sustainability.

Reviewing the scientific literature on the use of green infrastructure to reduce hydrological disturbance in Iranian Cities, it is clear that scattered studies have been conducted to provide a plan for GID. Recent studies mostly focused on the hydrological benefits of green infrastructure development, and other environmental, social, and economic factors affecting the development of green infrastructure have been ignored. If we are determined to use green infrastructure to improve the hydrological performance of the city, we must inevitably identify and weigh other contributing factors for a multi-objective selection. In addition, prioritizing individual practices of green infrastructure may not be sufficient, as green infrastructures are generally synergistic in combination. Therefore, the main aim of this study is to achieve a framework for prioritizing green infrastructure practices and a combination of them to control runoff in Tehran. In this regard, the following objectives have been defined to achieve the main aim:

- Achieving appropriate criteria for selecting and prioritizing types of green infrastructure
- The weighting of selected criteria and sub-criteria
- Considering the importance of combining different forms of green infrastructure
- Achieving the best combination of green infrastructure based on multi-criteria decision makin

Materials and methods

Study area

Tehran is a metropolitan area with about 730 km2 and more than 8.5 million people, located in the south part of the Alborz Mountains. The city is comprised of 22 districts. The middle districts and downtown areas are urbanized, while the other districts have more open spaces and untouched lands. The slope of most parts of the city is about 3-9 percent, mainly from the north to the south. There are seven natural rivers streaming the city. These natural valley-rivers play important roles in natural ventilation and runoff conveying. Tehran has a diverse Land use. Apart from big green patches dispersed in the northern parts and the urban fringe areas, all patches of the city are manmade and impermeable.

Tehran has faced rapid growth in the current decades. Rapid urbanization has worsened the natural hydrological cycle and jeopardized this megacity of waterlogging and floods. Flood risk is one of the second most important natural hazards in Tehran. The city is coated with impermeable surfaces like buildings, highways, roads, and parking lots. In rainy seasons rainfall rapidly turns into runoff flowing throughout the streets and finally leaves the urban watershed. Consequently, the level of groundwater supply is expected to have diminished.

Methods

The framework of this research has four steps.

1. Selection of relevant criteria and sub-criteria
2. Determining the weight of each criterion and sub-criteria
3. Reaching of decision matrix,
4. Prioritization of green infrastructure practices
5. Development of combination scenarios
6. Prioritization of combination scenarios

Each step is elaborated on below.

This step was done by reviewing scientific sources and interviewing experts and specialists. At this step, we tried to select criteria for multivariate decision models that are more repetitive in scientific texts and are by the study area's geographical, climatic conditions, and realities. Finally, the criteria in introducing green infrastructure in Tehran with the aim of runoff control includes five main criteria: runoff quantity control, runoff quality control, cost, compatibility with city structure, and adaptation to the climate of the city.

A combination of an expert panel and the Analytic Hierarchy Process (AHP) was used to weight the selected criteria. A questionnaire was first prepared by the standard structure of pairwise comparison, which is common in the hierarchical analysis method. Then, 15 faculty members, consulting engineers, and researchers in various fields related to the development of green infrastructure in urban areas were surveyed. Then the weight of criteria, sub-criteria, and inconsistency coefficients were calculated. Meanwhile, the responses of 6 participants had an inconsistency coefficient of more than one-tenth and were excluded. Therefore, nine experts participated in the weighting process of the criteria. Expert Choice was used to calculate the weight of criteria and incompatibility coefficients.

To compile the decision matrix and achieve the ability of the studied green infrastructure types, a review of scientific literature was performed. At this step, we referred to studies that examined the ability of green infrastructure about each of the criteria.

At this stage, the TOPSIS method was used to prioritize green infrastructure. TOPSIS is a multi-criteria decision-making method programmed based on the similarity of the solution to the ideal solution and the distance from the non-ideal solution. This technique can be used to rank, compare different options, select the best option and determine the distances between options. Different forms of green infrastructure were prioritized based on the final decision matrix and the weight of the studied criteria. R (package topsis) was used to prioritize the alternatives .

Sensitivity analysis is performed to ensure results and confirm that the weighting is non-biased. The method is that values are added or subtracted to each indicator, and the model will run again with the changes made, and the results will be compared. In this study, PYSIS software was used to analyze the sensitivity of the results of this study. To ensure that the scores and weights were non-biased, sensitivity analysis was done with a 30% change in weights for 10,000 repetitions.

To combine different forms of green infrastructure, five main functions of green infrastructure for runoff management were identified, including infiltration, storage, conveyance, irrigation, and rainwater collection. Based on these performances, different scenarios for the combination of GI practices were identified and scored .

Equation 1 was used for prioritizing the combination scenarios.

$A= (S1 \times D1)+(S2\times D2)$

Where A is the final score of each compound, S1 is the final score of the green infrastructure expressed in the row, D1 is the green infrastructure score expressed in the row in the runoff management process, S2 is the green infrastructure score expressed in the column, D2 is the green infrastructure score in the column in the runoff management process.

Discussion of Results

Results revealed that permeable pavement with a score of 0.756 is the most suitable, while green atmosphere with 0.342 points was selected as the most unsuitable form of green infrastructure for the city of Tehran. Infiltration trenches, rain beds, rainwater harvesting systems, detention ponds, bio-retention ponds, and green roofs were ranked second to seventh.

The sensitivity analysis results showed that with a 30% change in coefficients and 10,000 times of model implementation, we did not see much difference in the results of this research, and again permeable pavement has been introduced as the most appropriate option. The lack of change in the ranking of options in the sensitivity analysis indicated the low level of subjectivist bias.

In the next step, to achieve appropriate scenarios, a combination of different practices of green infrastructure from Formula 1 was used, and 112 possible combination scenarios were examined, scored, and ranked. Finally, three preferred scenarios for each combination based on the hydrological performance were proposed.

Conclusion

In this study, a framework was proposed to use multi-objective prioritization of different forms of green infrastructure to control runoff in Tehran. The results showed that the permeable pavement is the most suitable form of green infrastructure for Tehran, while the green swale is the most unsuitable. Infiltration trenches, rain gardens, rainwater collection reservoirs, ponds, biological ponds, and green roofs were ranked second to seventh. Also, to achieve the appropriate composition patterns of green infrastructure, the functions of different types of green infrastructure were divided into infiltration, storage, conveyance, irrigation, and rainwater collection and the combined scenarios of these Infrastructures were examined. This study proposed a suitable scenario of 30 green infrastructure combinations with different hydrological performances for development with other purposes.