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A fuzzy TOPSIS-based approach for prioritizing low-impact development methods in high-density residential areas

Milad Mehri, Sonia Sadeghi and Seied Mehdy Hashemy Shahdany*

Department of Water Engineering, Faculty of Agriculture Technology (Aburaihan), College of Agriculture and Natural Resources, University of Tehran, Tehran, Iran
*Corresponding author. E-mail: mehdi.hashemy@ut.ac.ir

MM, 0009-0009-3378-7851; SS, 0009-0008-6469-1185; SMHS, 0000-0001-9962-1437

ABSTRACT

The study successfully implemented six low-impact development (LID) methods to manage surface runoff in urban areas: green roof, infiltration trench, bio retention cell, rain barrel, green roof combined with infiltration trench, and rain barrel combined with bio-retention cell. Each method has unique benefits in mitigating surface runoff effects in urban environments. The following four indicators were used to evaluate the methods: runoff volume reduction, peak runoff flow rate reduction, economic sustainability, and social sustainability. The study, which lasted approximately 4 months, was conducted in an eastern Tehran metropolis residential area with a mix of old and new buildings. The SWMM model determined runoff volume and peak flow values, and a price analysis list determined the economic index. Local experts completed 25 questionnaires to evaluate the social index. Fuzzy TOPSIS multi-indicator decision criteria were used to prioritize LID methods, and the Rain barrel + Bio retention cell combined scenario emerged as the best option based on all four criteria. The method reduced peak runoff flow by 23.1–66.1% under rainfall with 10-year return periods. The green roof + infiltration trench method had the highest percentage reduction of 2,737 m^3, while the infiltration trench had the lowest reduction of 273 m^3.

Key words: decision-making, hydraulic simulation, LID, stormwater collecting system, urban water management

HIGHLIGHTS

- Successful implementation of LID methods enhances urban runoff management.
- Green roofs and rain barrels prove highly effective in diverse ways.
- Four-month field study evaluates LID methods based on runoff indicators and sustainability.
- Fuzzy TOPSIS analysis identifies Rain barrel + Bio retention cell as the best LID option.
- Green roof + infiltration trench method demonstrates the highest peak runoff flow reduction (66.1%).

1. INTRODUCTION

Urban flooding poses a significant threat to both urban infrastructure and residential areas. With the combined effects of urban development and climate change, the damage caused by flooding in cities has increased dramatically. This is due to the increase in impervious surfaces, resulting in a capacity shortage in the stormwater drainage network. When rainfall events exceed the capacity of the drainage network, the destructive effects of urban flooding are most pronounced (Wang *et al.* 2021). In this regard, several studies have shown that land-use changes due to urban development can have a significant impact on peak flood discharge and runoff amounts. For instance, Zope *et al.* (2017) found that in a metropolis in India, land-use changes from 16.64 to 44.08% caused an increase in peak flood discharge from 2.61 to 20.9% for rainfall with return periods of 2–200 years. Similarly, Shanableh *et al.* (2018) conducted a study in the U.A.E., which revealed that quadrupling of urban development from 1976 to 2016 resulted in an increase in runoff amount from 10 to 15 mm and an increase in runoff coefficient of about 0.15. In another study, Zhou *et al.* (2019) observed that rapid urbanization in a metropolis in northern China, from 1987 to 2018, led to an increase in annual surface runoff volume from 208 to 413%. Furthermore, Ren *et al.* (2020) demonstrated that by implementing urban renewal and reconstruction development plans, it is possible to reduce the depth of runoff during rainfall by increasing surface permeability from 25 to 36, 37, and 38 mm, respectively, resulting

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in a reduction of runoff depth from 21.2 to 10.7, 9.8, and 9.5 mm. In urban areas, the risk of flooding caused by intense and unpredictable rainfall events has increased due to inadequate drainage systems. As a result, effective stormwater management has become a major concern in metropolitan management to control these floods and minimize their impact. The management and control of surface runoff in urban areas is a critical issue that requires extensive study and investigation. One of the latest solutions used today in the management of surface runoff in urban areas is the implementation of low-impact development (LID) methods. The application of LID approaches has proven to be highly effective in achieving stormwater management objectives by restoring and maintaining natural hydrological conditions from a quantitative perspective, while simultaneously improving environmental conditions to meet qualitative objectives in urban basins, as noted by Shkaruba *et al.* (2021). By using these innovative techniques, many advantages can be gained, including the preservation of natural habitats and ecology, the prevention of impervious surface expansion, the reduction of surface runoff volume and speed, the maintenance of surface and subsurface water quality, the reduction of pollutants entering the runoff, and the improvement of the living environment in terms of aesthetics, social and cultural benefits, and more. LID systems have been widely used to achieve various economic, environmental, social, and technical objectives, such as infiltration trenches (ITs), porous pavement, rain barrels (RBs), bio-retention cells (BRCs), rain gardens, green roofs (GRs), and vegetative swales (Hamouz *et al.* 2020; Zeng *et al.* 2020; Meerow *et al.* 2021; Rio *et al.* 2021; Zaqout & Andradóttir 2021). Bai *et al.* (2018) studied the effects of LID scenarios on reducing stormwater effects on the drainage network of a metropolis in China under different rainfall patterns, using the EPA-SWMM model. The selected LIDs were chosen for their infiltration increase and water storage objectives. The simulation results showed that the combination of LIDs (infiltrationstorage) had the best performance in reducing peak flow and overflow volume by about 32.5 and 31.8%, respectively. Campisano *et al.* (2017) evaluated LID methods using the SWMM model in long-term and infrequent rainfalls. The simulation results showed that the accuracy of using this system is higher in long-term rainfalls.

In 2020, Kter *et al.* conducted a study in Bangladesh to examine the impact of RB's mass use on a metropolitan scale, particularly in minimizing the impact of frequent floods. The findings revealed that RB can reduce flood extent by 28.66%. In 2017, Wang *et al.* evaluated and modeled different tools for reducing runoff using the SWMM model. They used three scenarios: porous pavement, rainwater collection, and green roof. The results showed that porous pavement was the most effective tool in reducing the volume of runoff, reducing it by about 30%. In 2019, Randall *et al.* investigated the effect of using LID methods to manage urban runoff and rainwater retention in Beijing, China. Their goal was to store 80–85% of the rainwater. By implementing three scenarios – green roof, vegetative swales, and continuous porous pavement – and calculating the return period of 35 years of rainfall, they found that by implementing 30% green roof, 10% vegetative swales, and 35% continuous porous pavement, the amount of rainwater storage increased from 59.9 to 82.2% of the total area of the region.

In the realm of decision-making models, there exist two distinct categories- multi-objective models and multi-indicator models. While the former is effective for designing purposes, the latter is commonly utilized to determine the best possible option from a pool of choices. Multi-criteria models were first introduced in 1975 by Churchman, Acoff, and Arnoff as a means to tackle complex decision-making challenges (De Montis *et al.* 2000). Among the numerous studies conducted in this field, the work of Lagzian (2014) stands out. Lagzian identified and prioritized surface runoff management scenarios in Neyshabur, Iran, using a multi-criteria decision-making (MCDM) method. Five criteria, including social, economic, hydrological, technical, and environmental factors, were taken into account while weighing the different management scenarios. In light of the above, the present study introduces a novel practical-oriented configuration of the LIDs implementation in a densely constructed residential region, the Municipality number two territory of Tehran metropolis in Iran, considering the socio-economic criteria and technical concerns in taking action. In this regard, the LID's performance in flood mitigation has been evaluated, and the practical aspects of their implementation in an urban area were discussed. To achieve this objective, the SWMM model was used for surface runoff simulation in the study area and the effect of the LIDs configuration implemented on the volume and peak flow rate of runoff was investigated. In order to prioritize the LIDs configurations in the study area based on the selected criteria, a Fuzzy TOPSIS algorithm has been used, emphasizing economic and hydrological criteria. Finally, the best LIDs configuration has been introduced in the study area. MCDM models are effective tools to make appropriate decisions. One feature of this method can be pointed to the spectrum ranking of criteria associated with scoring by experts and interest groups that use a series of techniques, including total weighting or convergence analyses (Higgs 2006). MCDM can be divided into two broad categories multi-attribute decision-making (MADM) and multi-objective decision-making (MODM), as MADM is one of the most common growing methods during the last decade that has been widely used in real decision situations. This method is based on finding the best alternative among possible alternatives according to relevant weights, which are evaluated by several quantitative and qualitative indicators. MODM deals with selecting the best alternatives based on a series of more or less incompatible objectives. Several MADM methods have been developed to assess the weights of criteria available in a decision and choose a preferred alternative, including the entropy method, least weighted square, analytical hierarchy process (AHP), and TOPSIS. MADM methods are divided into two groups: methods that are based on ranking alternatives, which are known as ranking methods, including AHP and TOPSIS and methods that do not necessarily lead to the ranking of alternatives and are based on rank-priority relationships, which are referred to as outranking methods, including Electre and Prmothee. Among the eight compensatory multi-criteria evaluation methods, TOPSIS has the lowest deficit in the ranking of alternatives. In Iran, TOPSIS has been used from the early 1990s finitely with functional spectrums in the areas of feasibility, prioritization and performance appraisal. The theoretical foundation of TOPSIS has been provided in some studies, including Asgharpour (2006), Chena & Larbanib (2006), Chu & Lin (2003), Ghatee & Mohades (2009), Simonovic & Verma (2008), Tsou (2008), Wang *et al.* (2007), You & Ding (2005). A study was conducted to extend TOPSIS to group decision-makings. The results indicated that TOPSIS was much stronger and more effective than other models (Hsu-Shin Shin *et al.* 2007).

The available scientific resources on LID methods reveal that scattered studies have been conducted to reduce hydrological disturbances. However, recent researches have mainly focused on the hydrological benefits of these methods, while other crucial environmental, social, and economic factors that are effective in the use of these methods have been largely ignored. To effectively enhance Tehran's hydrological performance through LID methods, it is essential to identify and weigh other effective criteria to prioritize these forms. It is worth noting that prioritizing each form of these methods separately may not be effective since they generally have synergy in combination. Therefore, the main objective of the study is to develop a comprehensive framework for multi-criteria prioritization of different forms and combinations of LID techniques. Therefore, the present study offers a comprehensive investigation into the implementation of LID practices in a densely populated residential area located in the Municipality number two territory of Tehran metropolis, Iran. The novelty of the study is to introduce a practical LID configuration that considers both socio-economic criteria and technical concerns for effective flood mitigation. The study evaluates the performance of LIDs in flood mitigation and discusses their practical implementation in an urban area. The SWMM was used to simulate surface runoff in the study area, and the effect of the implemented LID configuration on the volume and peak flow rate of runoff was investigated. The study also employs the Fuzzy TOPSIS algorithm to prioritize LID configurations based on selected criteria, with a focus on economic and hydrological factors. Overall, the study provides valuable insights into the implementation of LID practices in densely populated urban areas and identifies the most effective LID configuration for flood mitigation in the study area. Based on the information mentioned above, the following are the sub-objectives that this study aims to accomplish:

1. Surface runoff simulation of the study area using the SWMM model
2. An extensive study was conducted to examine various methods for controlling urban runoff in cities. The study aimed to implement LID techniques either individually or in combination to effectively manage urban runoff. The primary objective of the study was to serve as an exemplary study providing an in-depth analysis of different methods for controlling runoff in urban areas.
3. Comparison of status quo (based on the simulation results) and post-implementation scenarios of LID methods for successfully comparing the effectiveness of these techniques before and after they are implemented.
4. Prioritization of LID methods using Fuzzy TOPSIS considering economic and social conditions, to provide an impressive study that has examined which techniques are most effective in different economic and social features

Upon reviewing the scientific literature on the use of LID methods for reducing hydrological disturbances, it becomes evident that scattered studies have been conducted regarding the planning of LID methods. The primary focus of recent studies has been on the hydrological benefits of LID methods, with other environmental, social, and economic factors influencing the use of these methods being overlooked. If we are determined to use LID methods to improve the hydrological performance of the city, it is essential to identify and prioritize other influential criteria for the use of these methods. Prioritizing each of the various forms of LID methods may not be effective because these methods generally have synergies when combined. Based on the aforementioned considerations, the main objective of this research is to achieve a framework for the multi-criteria prioritization of various forms and combinations of LID methods for controlling urban runoff in Tehran.

2. MATERIALS AND METHODS

2.1. Methodology

The methodology for the present study is illustrated in Figure 1, which outlines the different steps undertaken to assess the effectiveness of LID methods in reducing runoff volume and peak flow rate in a study area. Initially, the stormwater collecting systems of the study area were modeled using the SWMM software, which enabled the estimation of the volume and peak flow rate of the entire basin and sub-basins at the outlet of the study area. Next, a range of LID methods, including 'Rain Barrel', 'Green Roof', 'Infiltration Trench', 'Bio Retention Cell', and combinations of these methods such as 'Green roof + Infiltration trench' and 'Rain barrel + Bio retention cell', was applied to investigate the reduction in volume and peak flow rate of runoff achieved by each method. To determine the most appropriate LID method, four criteria were selected through a brainstorming session: 'runoff volume', 'peak runoff flow', 'economic', and 'social'. These criteria were then used to prioritize the methods and configurations in the study area using the Fuzzy TOPSIS algorithm, with emphasis on economic and hydrological considerations. Finally, the most effective LID methods were introduced in the study area to reduce the negative impacts of stormwater runoff, such as flooding, and to promote sustainable urban development.

2.2. Case study

Tehran is the largest city in Iran and the second-most populous city in the Middle East. It is bounded to the north by the Alborz mountain range and to the south by the deserts of Qom. Flowing through the northern outskirts of the city are the river valleys, witnessing multiple seasonal floods annually due to high precipitation, extensive catchment areas, and the topography of the city's foothills. Annual rainfall in Tehran is generally influenced by the north-south elevation changes within the city, varying from a maximum of 422 mm in northern Tehran to 145 mm in the southeast. The number of rainy days follows a similar trend, fluctuating from around 89 days in northern Tehran to 33 days in the southern part of the city. Moreover, within the Tehran region, there are 205–213 days with clear to slightly cloudy weather. On average, the highest precipitation occurs in the winter and spring seasons, with Tehran experiencing the least rainfall in the summer. This challenge has become a serious threat to Tehran with the increase in population and the development of impermeable surfaces. Tehran has faced

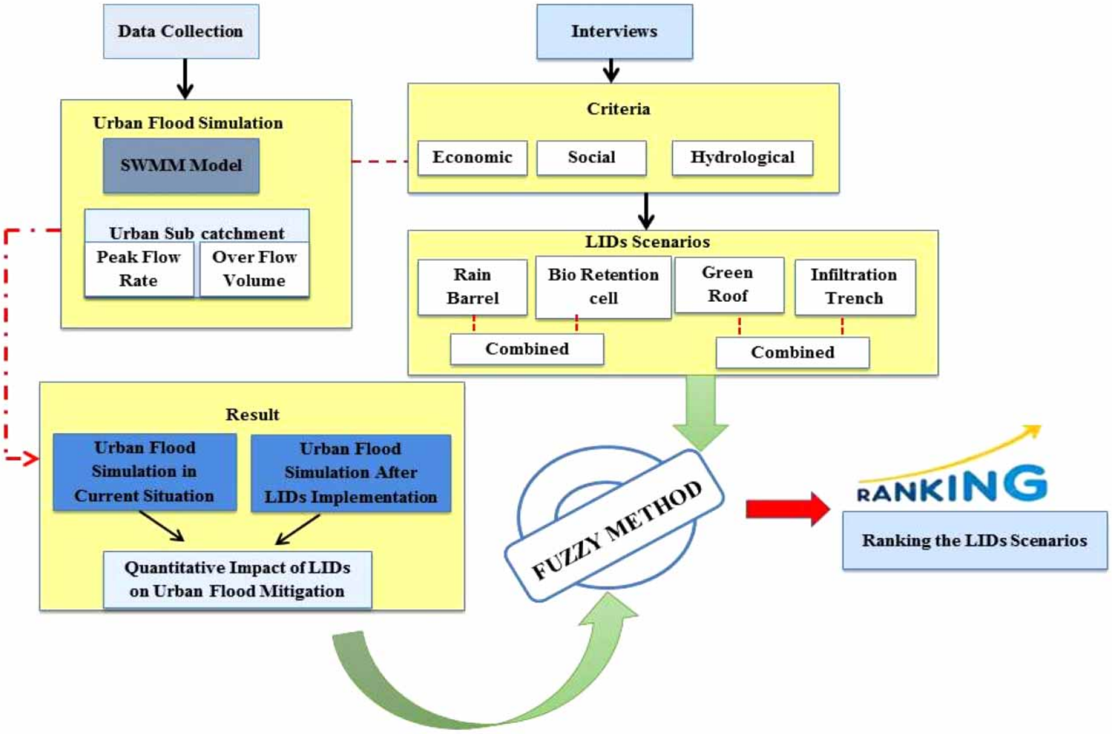

Figure 1 | Flowchart of the study including the different components of the methodology and their interaction.

numerous significant floods in recent years. The recent strategies of urban planners have focused on expanding civil infrastructure, such as building walls, widening rivers, canals, flood barriers, and increasing infiltration wells throughout the city. However, the issue of runoff and floods remains the second most serious threat to Tehran.

The study area being examined is located in the northwestern part of Tehran, specifically in Region 2, District 3. The region is primarily used for residential purposes and covers a vast area of 230 ha. The area comprises residential land, roads, highways, and lawns, as shown in Figure 2. To better understand the surface runoff in the study area, it has been divided into 17 sub-catchments. The surface runoff has been estimated using the SWMM software, which simulates a non-linear reservoir model. The average slope in the north-south direction is 0.5%, indicating that the terrain is relatively flat. The study area is highly developed, with approximately 85% of the area covered by impervious surfaces such as alleys, main streets, and sidewalks, mostly covered with asphalt. Due to this, the surface runoff is high. The study area is a high-intensity residential region and includes private properties, schools, public buildings, malls, and shopping stores. It is an established area with no possibility of land-use alteration. The remaining 15% of the study area consists of a few public parks and the existing swales located along the alleys and streets. In conclusion, the study area is a highly developed residential region that covers a vast area, and due to its impervious surfaces, the surface runoff is high.

2.3. Introducing the SWMM model

The SWMM software was developed by the United States Environmental Protection Agency in collaboration with Metcalfe and Eddy Engineering and the University of Florida from 1969 to 1971 to simulate the quantitative and qualitative associated aspects with runoff pipes.

The required data are very extensive and includes physiographic data of sub-catchments, specifications of system structures, system maintenance information, discharge intensity in the dry period, rainfall information, flood hydrographs, and flow quality in conduit. The surface Water Management Model is a dynamic model of rainfall–runoff simulation and can simulate the quality and quantity of runoff for urban areas for one single event or a continuous one. It can also be combined with other models. Since this model is widely used to design, analyze and estimate the cost of constructing a drainage network system in urban areas, in this study, this hydrological-hydraulic model was selected. Because SWMM is a distributed model it allows a study area to be subdivided into any number of irregularly shaped sub-catchment areas to capture best the effect that spatial variability in topography, drainage pathways, land cover, and soil characteristics have on runoff generation.

The complete form of St. Venant equations is solved in the dynamic wave method and thus produces the most theoretically accurate results. The method accounts for conduit storage, backwater effects, entrance/exit losses, flow reversal, and pressurized flow. The time step should be small to maintain numerical stability. Numerical instability is characterized by flow and water surface elevation oscillations that do not dampen over time. Stable explicit solutions of the St. Venant equations require smaller time steps than those for a dynamic wave to travel down the length of the conduit (Cunge *et al.* 1980). The friction and gravity terms are only considered in the kinematic wave method. Many studies that confirm the accuracy of the dynamic wave

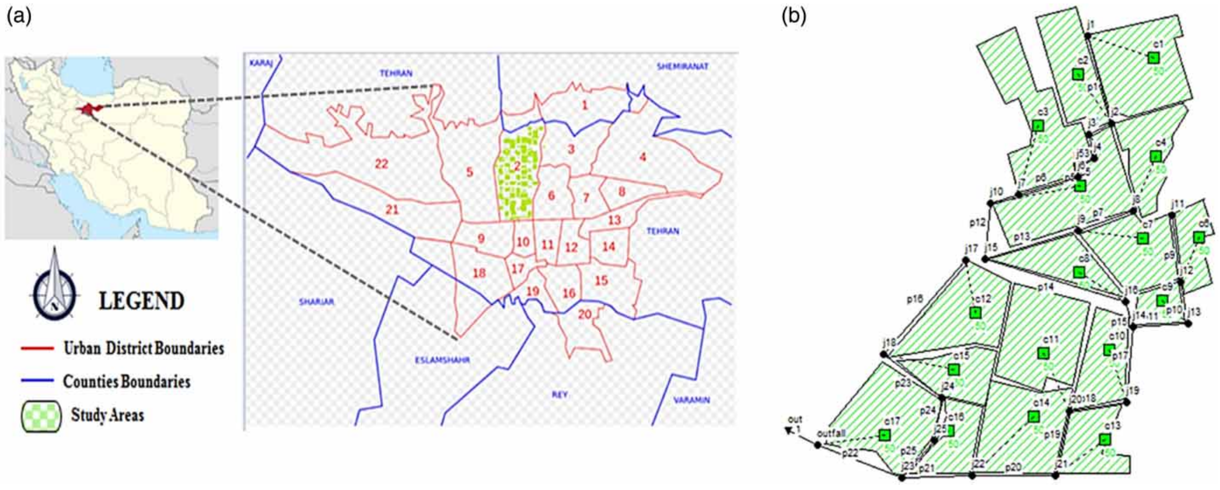

Figure 2 | (a) A schematic view of the study area included. (b) Location of sub-catchment and output point of catchment.

model method have been conducted, such as Helmiö (2005), Zhang (2005), Anderson *et al.* (2006) and Akbari & Barati (2012). This model simulates a rainfall event based on topography, precipitation input data, watershed system, and drainage network to generate the output hydrograph (Sin *et al.* 2014). In this model, each watershed is subdivided into smaller sub-watersheds and simulated as a non-linear reservoir. In this approach, input flows are generated from precipitation or upstream sub-watersheds. The outputs include evaporation, infiltration, and surface runoff. The capacity of this reservoir is equal to the maximum detention storage, which includes the maximum surface storage created by depressions, surface moisture, and interception. When the water depth in the reservoir exceeds the maximum detention storage (d_p), surface runoff is generated, forming the output flow. This flow is determined by the Manning equation. The water depth on the sub-watershed surface (d) over time is obtained by numerically solving the differential equation of the water balance on the sub-watershed. Due to the limited and negligible role of factors such as evaporation and transpiration in flood formation, the effect of evaporation is disregarded in modeling the rainfall–runoff process (Sadeghi *et al.* 2022). The Horton method is used for soil infiltration in this model. The parameters of the Horton infiltration equation are obtained using the soil permeability information for the region and relevant tables from the SWMM software guide.

2.3.1. Developing SWMM simulation model for the test case

The sum of the total concentration time of the individual basins and the concentration time required for water flow through the flooding channel to reach the outlet was less than 6 h due to a concentration-time review within Tehran sub-basins (Yazdandust *et al.* 2013; Movahedinia *et al.* 2019). According to Tehran's stormwater master plan reports, rainfall is most severe toward the middle of the rainy period (October to April) for events taking three hours and more prolonged. Based on the rainfall data available at weather stations, the hydraulic models were simulated for return periods of 2, 5, and 10 years, given the importance of floods in the design of hydraulic structures, especially the surface water collection channels, and given the urban considerations concerning Tehran's District 2. The Horton equations were applied to determine the infiltration rate. The hydrologic soil group in the study area was B, including silt loam/ loam types, and C, including sandy clay loam, based on the soil classification in Tehran's Stormwater Master Plan Reports inspired by USDA's hydrologic soil groups. The SWMM simulations were performed for each scenario under return periods of 10 years. In the present study, the existing surface water collection network in the study area and four LIDs, including RBs, GRs, BRCs, ITs, and combinations, were defined and modeled. The approach of placing LIDs in the present study was creating a new sub-catchment devoted entirely to a single LID practice based on the intrinsic characteristics of the selected LIDs. This placement approach enables the selected LIDs of the rain barrel and green roof to act in series so that the outflow from the green roof becomes the inflow to the rain barrel. The BRCs within the existing green spaces were modeled in the study area.

- Bio Retention: Biological retention units can be utilized in various developed urban areas such as green spaces, parks, open parking lots, or any other space with spatial constraints. These systems are divided into two types: Rain Gardens and GRs. They are basin-like structures with a sandy bottom for runoff drainage, covered with cultivable soil and organic materials where different plants are grown. By temporarily storing runoff, gradually releasing it, and to some extent treating it, these systems contribute to reducing the volume and peak flow of outgoing runoff, as well as improving runoff quality. They are also beneficial for recharging groundwater. In simple terms, planting vegetation on a gravel bed for rainwater and runoff drainage. In this study, the width of each unit is 1.2 m, and their area is 3.6 m^2, in accordance with expert opinions and considering the study area.
- Infiltration Trench: Infiltration trench is a long and narrow trench filled with coarse-grained particles and rock fragments, without any outlet, allowing the temporary storage of runoff in the voids between the coarse-grained particles for infiltration through the bottom and walls into the surrounding soil. In this research, the trench thickness is considered to be 150 mm, and its height is 30 mm.
- Rain Barrel: Collecting rainwater from building roofs using barrels. The collected water can be from clean roof surfaces, ground surfaces, or stone areas. This water is typically stored in a reservoir or directed to recharge groundwater. These small tanks collect and store rainwater that would otherwise runoff or be diverted through drainage systems and channels. In this study, the barrel diameter is 1 m, and its height is 2 m.

The values of the input parameters to the SWMM model for simulating the study area according to the land use defined in the study area and the SWMM software guide are shown in the Table 1.

Table 1 | Values of input parameters to the model according to the software guide

Parameter	Value
Roughness coefficient of pervious areas	0.24
Roughness coefficient of impervious areas	0.15
Depression storage of impervious areas	1.53 mm
Percent of impervious area	5%
Percent of impervious area with no depression storage	90%

2.4. Decision criteria

2.4.1. Volume and peak flow rate of runoff

To determine the impact of LID methods on surface runoff, a simulation was conducted twice using the SWMM model. The first simulation was done without considering LID methods, while the second simulation was conducted using LID methods. In order to run the simulations, input information such as the area, perimeter, percentage of impervious areas, runoff curve number, and average slope of each sub-basin was collected using land-use maps, detailed plans of field visits, and GIS software. The rainfall intensity–duration–return period curves in Figure 3 were used to analyze the runoff and determine the reduced runoff volume and peak flow rate due to applying LID methods.

2.4.2. Economic criteria (cost)

As with any project, one of the most critical aspects is the economic component and the expenses involved in executing it. In this study, we began by determining the coverage area of each LID technique. We then calculated the cost of implementing each urban runoff management scenario across the entire basin based on previous investigations and a list of building prices. The findings shed light on the financial feasibility of different approaches to urban runoff management, providing valuable insights for decision-makers and stakeholders.

2.4.3. Social criteria

Experts were consulted to gauge the level of acceptance of different urban runoff management scenarios. To this end, a series of questionnaires were developed, each containing questions with varying degrees of acceptance levels (high, medium, low, and very low) to evaluate how well each LID method was received.

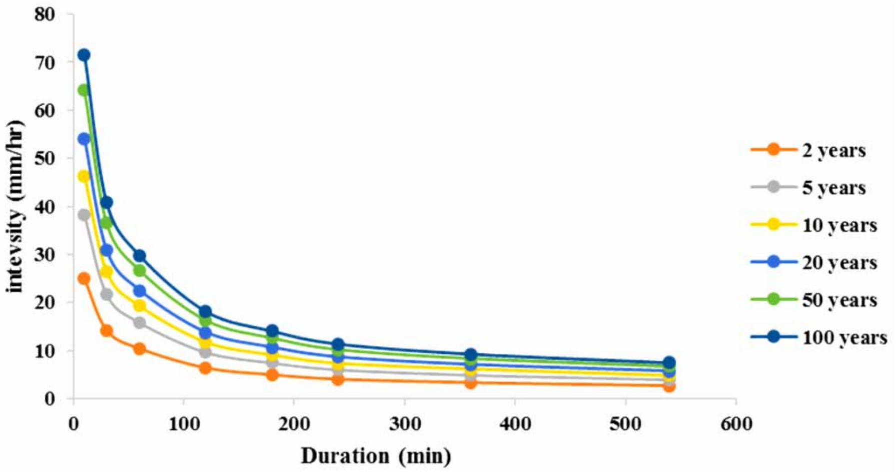

Figure 3 | The rainfall–intensity–duration–return period of the station covers the case study region.

2.4.4. Social and economic information gathering

During the 4-month-long field study, a wide range of social and economic criteria, considerations, limitations, and information were meticulously collected through various means such as interviews, questioning, and brainstorming sessions. The study's primary objective was to develop optimal LID layouts within the sub-catchments of the study area. To achieve this goal, every bit of information that could impact the purpose was included in the questionnaire. The study presented the individual residents with brief explanations of the LIDs and their benefits in reducing flood consequences in the area. Furthermore, the residents, building manager, or representative were interviewed to gather additional information. The local authorities were also consulted through brainstorming sessions with their experts, and access to their library archives was granted to acquire urban planning and housing information. Detailed information about the field study is provided in Table 2.

2.5. TOPSIS

Among seven methods of multi-criteria models, the TOPSIS method has the lowest deficit in ranking alternatives. This widely used method is one of the best MADM models. The sorting technique of preferences due to similarity to ideal solution is one of the most common methods developed by Hwang and Yoon. This technique is based on the notion that every factor should have the minimum distance from the positive (most important) ideal and the maximum distance from the negative (the least important) ideal. It is assumed that the utility of each criterion is steadily increasing or decreasing. In other words, in this

Table 2 | The description of the field study's levels

Field study levels	**Level I**	**Level I: Promoting community education** • Educational axis: – urban stormwater runoff basics and challenges; – stormwater utility; – how to reduce negative stormwater impacts; – green infrastructures and lids; – how to implement the lids in a residential area; – benefits of lids on the regular life of the residents
	Level II	**Level II: Interviews and questionnaires** • Social info: – number of households living in each building; – properties ownership status (tenant vs. owner) – the average level of education; – level of interest in participating in solving the problem of the neighborhood; – resident's opinion about the impacts of the local municipality's efforts in solving – the problems with flooding of passages – previous follow-up rates from the municipality to solve the problems with flooding of passages • Economic info: – average revenues; – amount of annual and total economic damages to their building due to flooding of passages; – costs of flooded areas for their properties; – level of financial participation in the implementation of the lids in their building
	Level III	**Level III: Acquiring information from the municipality** • EPA-SWMM model's requirements: – study area's land use and cadaster maps to extract property's metes-and-bounds of the sub-catchments; – topographic map; and climatology and hydrological data; – study area info such as soil type, slope, and other details • Stormwater collecting system data: – the drainage network maps in AutoCAD format – rainfall data – measured runoff information during the rainfall events – cadaster and land-use maps;

method, the distance of one factor from the positive and negative ideal is measured, which is a classification and prioritization scale. The method is also easy to use, and its calculation is quick enough. For mathematical calculations, all values attributed to the criteria should be quantitative, and if these values are qualitative, they should be converted into quantitative values.

2.5.1. Fuzzy TOPSIS method

Chen (2000) extended the TOPSIS method to a fuzzy environment using triangular fuzzy numbers to replace the numeric linguistic scales for rating and weighting. After that, a number of methods proposed extensions of the Fuzzy TOPSIS method.

The procedure of applying the Fuzzy TOPSIS method is explained as below:

Step 1: Create a fuzzy decision matrix

A fuzzy decision matrix ($\otimes$ D) is created by obtaining the linguistic variables from the experts or decision-makers. The decision-makers use linguistic words to present preference such as 'very low,' 'low,' 'medium,' 'high' and 'very high.' These linguistic variables are converted to fuzzy sets following fuzzy logic. Table 3 highlights the linguistic variables, notations and corresponding fuzzy set. In this way, the weight of the ith option is obtained in relation to the jth index, which is calculated in the form of Equations (1)–(3):

$$\mu_{x_{ij}} = \sum_{K=1}^{N} x_{ijk}, \qquad (N = Number\ of\ samples) \tag{1}$$

$$\sigma_{x_{ij}} = \frac{\sum_{K=1}^{N} (x_{ilk} - \mu_{ij})^2}{N} \tag{2}$$

$$\tilde{x}_{ij} = (\mu_{x_{ij}} - \sigma_{x_{ij}},\ \mu_{x_{ij}}, \mu_{x_{ij}} + \sigma_{x_{ij}}) \tag{3}$$

(Standard deviation + average, the average question related to the ith option compared to the jth index, standard deviation – average).

In this research, a systematic approach of Fuzzy TOPSIS has been presented, which is used in accordance with the accepted principles of mathematics and statistics. This method is very suitable for solving group decision-making problems in a fuzzy environment and has a good match with real decision-making conditions.

Step 2: Identifying evaluation criteria and appropriate linguistic variables

According to the explanations given in the transformation of expressive words into fuzzy numbers, it will be assumed that (Khatami Firouzabadi *et al.* 2013):

$$\tilde{x}_{ij} = (\mu_{x_{ij}} - \sigma_{x_{ij}},\ \mu_{x_{ij}}, \mu_{x_{ij}} + \sigma_{x_{ij}}),\ \tilde{x}_{ij} \in R^+,\ i = 1, 2, \ldots, m;\ \ j = 1, 2, \ldots, n \tag{4}$$

Equation (4) is a triangular fuzzy number and is equivalent to the score assigned to the option Ai by the decision maker D_k based on the criterion C_j. Also suppose (Khatami Firouzabadi *et al.* 2013):

$$\tilde{w}_j = (e_j^k, f_j^k, g_j^k), \quad \tilde{w}_{ij} \in R^+, j = 1, 2, \ldots, n; \quad k = 1, 2, \ldots, t \tag{5}$$

Equation (5) is a triangular fuzzy number that is equivalent to the weight assigned by the decision maker D_k based on the criterion C_j.

Table 3 | Linguistic variable, notation, and corresponding fuzzy set

Linguistic variable	Notation	Fuzzy set
Very low	VL	(1, 1, 3)
Low	L	(1, 3, 5)
Medium	M	(3, 5, 7)
High	H	(5, 7, 9)

Step 3: Creating the normalized fuzzy decision matrix

The matrix of the weights of the ith option in relation to the jth criterion in the fuzzy environment is shown as follows:

$$DM = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \tilde{x}_{1j} & \tilde{x}_{1n} \\ \tilde{x}_{i1} & . & \dots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \tilde{x}_{mj} & \tilde{x}_{mn} \end{bmatrix} \tag{6}$$

$$\tilde{W} = (\tilde{w}_1, \tilde{w}_2, \ \dots, \tilde{w}_n) \tag{7}$$

In order to ensure consistency between scores and average weights, they should be normalized to become comparable scales. The TOPSIS method uses soft Euclidean normalization (vector normalization method), which is the same method used in the fuzzy environment. It should be noted that in some cases, for ease of calculation, the linear normalization method is used for Fuzzy TOPSIS.

$$\tilde{r}_{ij} = \frac{\tilde{x}_{ij}}{\sqrt{\sum_{j=1}^{m} \tilde{x}_{ij}^2}} \qquad R = [\tilde{r}_{ij}] \tag{8}$$

Step 4: creating the fuzzy weighted normalization decision matrix

The normalized matrix can be scaled using the following relationship.

$$\tilde{V} = \tilde{W} \otimes \tilde{R} \tag{9}$$

Step 5: determining 'positive ideal solution' and 'negative ideal solution'

In the matrix $\tilde{V}$ for profit criteria, the maximum value of each column is selected and finally a fuzzy number for $\tilde{V}^+$ is obtained. It is necessary to mention that the minimum value is selected for cost criteria. Also, for profit criteria, the minimum value of each column is selected and finally the fuzzy number for $\tilde{V}^-$ is obtained.

$$\tilde{A}^+ = (\tilde{v}_1^+, \tilde{v}_2^+, \ \dots, \tilde{v}_n^+), \qquad \tilde{v}_j^+ = (\, Max\ \tilde{v}_{ij}^a\ ,\ Max\ \tilde{v}_{ij}^b,\ Max\ \tilde{v}_{ij}^c\ ) \tag{10}$$

$$\tilde{A}^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ \dots, \tilde{v}_n^-), \qquad \tilde{v}_j^- = (\, Max\ \tilde{v}_{ij}^a\ ,\ Max\ \tilde{v}_{ij}^b,\ Max\ \tilde{v}_{ij}^c\ ) \tag{11}$$

Step 6: obtaining the distance of each option from ideal positive and negative options and calculating the proximity coefficient (cci)

The distance of each option from the positive ideal option and the negative ideal option is calculated as follows:

$$\tilde{d}_i^+ = \sum_{i=1}^{n} d(\tilde{v}_{ij},\ \tilde{v}_j^+) \tag{12}$$

$$\tilde{d}_i^- = \sum_{i=1}^{n} d(\tilde{v}_{ij},\ \tilde{v}_j^-) \tag{13}$$

Using formula 14, the proximity coefficient of each option is obtained.

$$cc_i = \frac{d_i^-}{d_i^- + d_i^+} \tag{14}$$

Step 7: ranking the options by area method

The most important methods of comparing fuzzy numbers are: area method, average and standard deviation comparison method, and coefficient of variation. In this research, the area method is used for the final comparison of fuzzy numbers. In the area method, the difference between two fuzzy numbers is written and the area of the triangle that represents the difference between two fuzzy numbers is calculated. The area method has priority because all the space occupied by the triangular fuzzy number is evaluated and compared. In this method, first, the difference between two options is calculated:

$$\widetilde{CC}_{Ai} - \widetilde{CC}_{Aj} = (a, b, c) \tag{15}$$

The triangle obtained from this fuzzy number is drawn and its area is calculated.

$$S = \int_{a}^{c} \mu_{z_{ij}}(x)dx \tag{16}$$

$$S_1 = \int_{0}^{c} \mu_{z_{ij}}(x)dx \qquad e_i = \frac{s_1}{s} \tag{17}$$

$$S_2 = \int_{a}^{0} \mu_{z_{ij}}(x)dx \qquad e_j = \frac{s_2}{s} \tag{18}$$

If e_i is greater than 0.5, then Ai is preferred over A_j, and if e_i is 0.5, there is no preference between A_i and A_j, and if e_i is less than 0.5, A_j is preferred (Khatami Firouzabadi *et al.* 2013).

3. RESULTS AND DISCUSSION

3.1. SWMM model calibration and validation

The calibration of the model was based on data collected by the operation staff from Tehran municipality's civil technical deputy. The data comprised measurements of water level in one of the nodes of the existing surface runoff collection network during four storm events in December 2021. Two of the events were used for calibration, while the other two were used for validation. To evaluate the model's accuracy, the observed and simulated runoff depth was compared using the Nash–Sutcliffe Efficiency (NSE) and Root Mean Square Error (RMSE) indicators. The N-Impervious, N-Pervious, D-Store-Impervious, D-Store-Pervious, W, and CN parameters were selected after analyzing the model's parameters for sensitivity. The study's sensitivity analysis revealed a direct relationship between the CN and W parameters and total runoff, with an increase in these parameters leading to increased runoff. The sub-catchments' width demonstrated higher sensitivity values within these two parameters, with a 25% increase resulting in a 2.15% increase in total runoff. After calibration, the runoff depth was evaluated for two separate December 2021 storm events. The NSE and RMSE indicators resulted in high values during both calibration and validation, indicating the simulation's accuracy.

3.2. Storm water simulation results

A model was created to evaluate the rainfall intensity equivalent to a 10-year return period after gathering all the necessary data. The connections' performance, existing network channels for transferring runoff, and the impact of LID methods were assessed for different scenarios. The results showed that during the 10-year return period, 48% of the network length was in critical condition, and most regions were flooded due to the urban runoff collection system's inadequacy. The channels of the runoff network have also lost their efficiency. To resolve this issue, six surface runoff management scenarios were implemented, which resulted in a reduction of the volume and flow rate of the entire catchment. The combined method of 'Green roof + Infiltration trench' was the most effective in reducing the volume and peak flow rate of the runoff, and it is recommended to implement this method in the studied area to decrease the risk of flooding and improve the urban runoff collection system's performance.

3.3. Economic analysis results (cost)

The implementation cost of various LID methods is shown in Figure 4. It can be observed from Figure 5 that the combined Rain barrel + Bio retention cell scenario is the most expensive, while the Green roof scenario is the most cost-effective. However, the Bio retention cell scenario is only 10% more expensive than the Green roof scenario and provides significantly

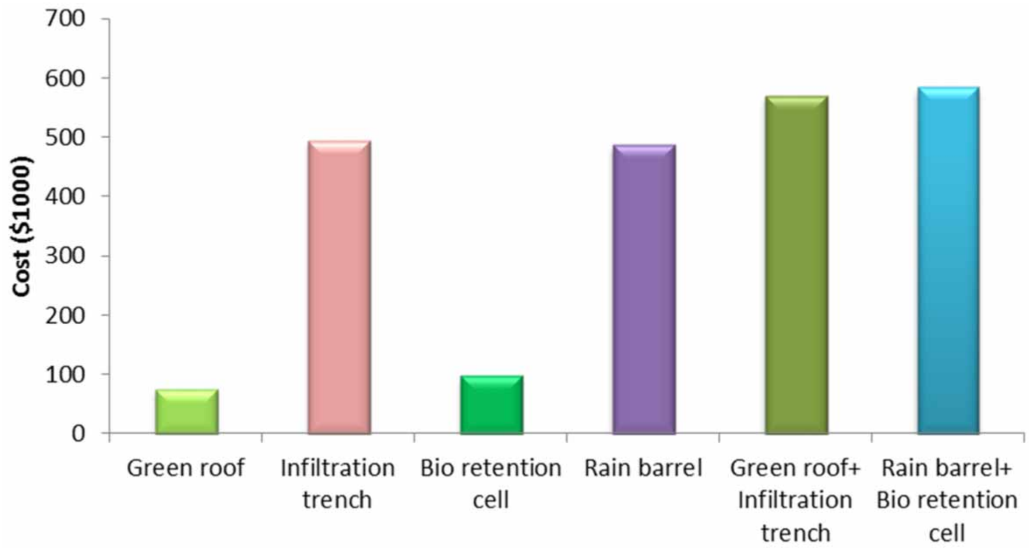

Figure 4 | Column diagram regarding the total cost of each of the scenarios.

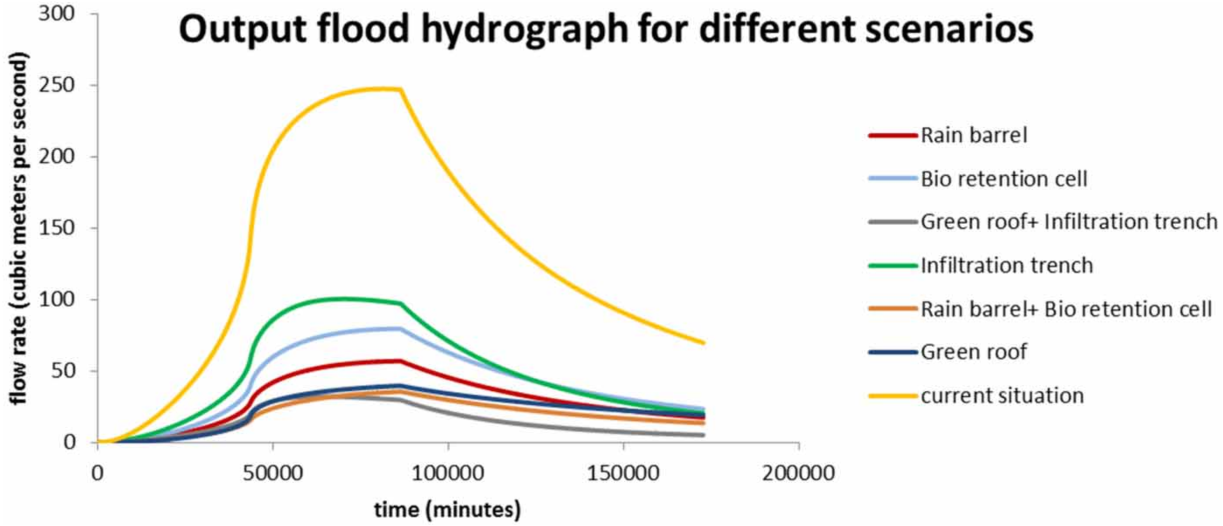

Figure 5 | Outflow flood hydrograph for different scenarios with a return period of 10 years.

better outcomes than other scenarios. Similarly, in situations where the Rain barrel and Green roof + Infiltration trench scenarios have a smaller difference (6%), the sixth scenario is found to be more effective based on the hydraulic modeling results. Nevertheless, the availability of funds, the project's significance and priority, and the regional conditions determine all decisions. Although the implementation cost of LID methods may be higher in certain situations, it is worth investing in them because they effectively reduce the peak flow of floods.

3.4. Social assessment results

To assess the acceptance level of each scenario by local experts in the study area, 20 questionnaires were completed. The questionnaire included questions that examined the permeability of roadways, the transfer of pollution by runoff, the performance of the municipal authorities in the study area regarding stormwater management, the effectiveness of LID methods in reducing runoff volume, and the efficiency of each stormwater management scenario in reducing road permeability and runoff volume. Respondents provided ratings on a scale of very low, low, moderate, high, and very high. To convert the questionnaire results into fuzzy numbers, the average for each option (very high, high, moderate, low, very low) was considered as the middle bound, and the minimum and maximum percentages of acceptance, determined by the experts for each scenario, were considered as the lower and upper bounds, respectively. Table 2 presents information related to social indicators. Subsequently, the results were transferred to the SPSS software, and the average and standard deviation for each method were obtained. Table 4 displays the results. With the determination of the standard deviation and mean, fuzzy TOPSIS methodology, as described in the text, was used to rank the scenarios.

Local experts in the study area completed 20 questionnaires to assess the level of support for various urban runoff management scenarios. The questionnaires covered a range of topics related to urban runoff, such as road flooding, pollution transfer through runoff, effectiveness of LID methods to reduce runoff volume, and the municipality's performance in managing urban runoff. Using a scale of five options, each question was answered and the responses were transformed into fuzzy numbers as per the materials and methods section. The data collected are analyzed and presented in Table 4, which displays the average and standard deviation of each urban runoff management scenario as rated by the experts.

3.5. LID prioritization results

Based on the presented materials, the Fuzzy TOPSIS method was utilized to prioritize LID methods. To achieve this, a fuzzy decision matrix was created, considering two social and economic indicators (cost) as uncertain and represented them as triangular fuzzy numbers. On the other hand, the two indicators of peak flow reduction and runoff volume reduction were regarded as certain, and their values were obtained from the SWMM software. The method was used to rank LID methods based on their effectiveness in reducing storm water runoff. The complete method and its steps are explained in detail in the materials and methods section of the study. The results of these calculations can be found in Table 5. A fuzzy decision matrix is created by experts or decision-makers to obtain linguistic variables. The weight assigned by the decision maker based on the mentioned criteria is represented by triangular fuzzy numbers. The fuzzy weighted normalization decision created matrix is obtained through a set of equations. The maximum and minimum values of each column are selected for profit and cost criteria, respectively, to obtain fuzzy numbers for positive and negative ideal solutions. The distance of each option from the positive and negative ideal options is then calculated. Detailed calculations and results are presented in Tables 5 and 6.

Table 7 displays the outcomes of the TOPSIS technique employed to prioritize various urban runoff management scenarios. By utilizing the given correlations, a positive ideal solution has been determined for each scenario, and the values range between zero and one. The scenarios that have values closer to one are considered better solutions, as they are closer to the ideal solution.

Based on the results presented from the prioritization using the Fuzzy TOPSIS method and considering economic and social criteria, as well as the reduction of peak runoff flow and volume, it was determined that the combined method of Rain barrel + Bio retention cell is the most effective LID approach for the specified area. Subsequently, considering all four criteria, the Bio retention cell method is identified as the best approach after the combined method. The priorities of other methods are presented in Table 7. However, as economic analysis indicates, the Green roof has a lower economic cost and is the best method economically. From a social perspective, the Infiltration trench is considered the best method with the least deviation, according to Table 4. According to the results in Table 8, considering volume and peak runoff reduction, the Green roof + Infiltration trench is the most effective method. Therefore, selecting the best method that

Table 4 | Average and standard deviation of the urban runoff management scenarios from the expert's opinion

Scenario	Average (μ)	Standard deviation (σ)
Green roof	5.6	2.25
Infiltration trench	4.4	2.1
Bio retention cell	4.5	2.57
Rain barrel	6.7	2.61
Green roof + Infiltration trench	8.5	2.57
Rain barrel + Bio retention cell	8.4	2.54

Table 5 | First, second, third, and fourth stage calculations of fuzzy weighted normalization decision matrix

First, second, third, and fourth stage calculations	Criterion scenario	Reduction of peak runoff flow			Reducing the volume of runoff			Economic			Social		
Fuzzy decision matrix	Green roof	0.271	0.271	0.271	1,902	1,902	1,902	37,010	75,482	46,020	3.35	2.25	7.85
	Infiltration trench	0.028	0.028	0.028	273	273	273	455,838	494,310	879,030	2.3	2.1	6.5
	Bio retention cell	0.041	0.041	0.041	321	321	321	59,232	97,704	482,424	1.93	2.57	7.07
	Rain barrel	0.224	0.224	0.224	1,718	1,718	1,718	448,192	486,664	871,384	4.09	2.61	9.31
	Green roof + Infiltration trench	0.3	0.3	0.3	2,737	2,737	2,737	531,320	569,792	954,512	5.93	2.57	11.07
	Rain barrel + Bio retention cell	0.32	0.32	0.32	2,503	2,503	2,503	545,896	584,368	969,088	5.86	2.54	10.94
Fuzzy weighted normalization decision matrix	Green roof	0.442	0.672	0.745	0.205	0.413	0.453	0.399	0.616	0.352	0.064	0.184	0.324
	Infiltration trench	0.439	0.669	0.708	0.204	0.401	0.423	0.374	0.569	0.318	0.064	0.177	0.304
	Bio retention cell	0.385	0.569	0.569	0.176	0.332	0.315	0.318	0.439	0.201	0.055	0.141	0.258
	Rain barrel	0.448	0.746	0.821	0.228	0.477	0.561	0.456	0.747	0.536	0.066	0.200	0.379
	Green roof + Infiltration trench	0.398	0.718	0.796	0.217	0.464	0.502	0.431	0.877	0.703	0.063	0.179	0.353
	Rain barrel + Bio retention cell	0.408	0.727	0.809	0.225	0.471	0.531	0.443	0.924	0.753	0.063	0.184	0.364

Table 6 | Calculation of d_i^+ and d_i^- using fuzzy numbers

Calculation of d_i^+ using fuzzy numbers						Calculation of d_i^- using fuzzy numbers				
Scenario	Determining the positive ideal solution				Sum	Determining the negative ideal solution				Sum
Green roof	0.402	0.652	0.556	0.816	2.426	0.6331	0.3729	0.4701	0.2181	1.6942
Infiltration trench	0.412	0.665	0.589	0.824	2.49	0.6169	0.3566	0.4340	0.2062	1.6137
Bio retention cell	0.500	0.729	0.688	0.853	2.77	0.5149	0.2828	0.3336	0.1728	1.3041
Rain barrel	0.366	0.595	0.438	0.795	2.194	0.6906	0.4449	0.5922	0.2505	1.9781
Green roof + Infiltration trench	0.401	0.619	0.377	0.810	2.207	0.6603	0.4141	0.6950	0.2315	2.0008
Rain barrel + Bio retention cell	0.392	0.606	0.354	0.806	2.158	0.6707	0.4300	0.7345	0.2384	2.0736

Table 7 | Final ranking of options

Scenario	Proximity coefficient and final ranking	
Green roof	0.2062	5
Infiltration trench	0.1728	6
Bio retention cell	0.2384	2
Rain barrel	0.2181	4
Green roof + Infiltration trench	0.2315	3
Rain barrel + Bio retention cell	0.2505	1

Table 8 | Reduction of runoff volume and peak flow due to the use of the scenarios

Scenarios	Green roof	Infiltration trench	Bio retention cell	Rain barrel	Green roof + Infiltration trench	Rain barrel + Bio retention cell
Volume reduction (m^3)	1,902	273	321	1,718	2,737	2,503
Reduction of peak flow (m^3/s)	0.271	0.028	0.041	0.224	0.3	0.32
Percentage reduction of peak runoff flow (%)	50.1	23.1	38.3	45.2	66.1	59.2

considers all criteria and provides the best overall results requires MCDM, which was addressed in this study. By considering all criteria and utilizing the fuzzy TOPSIS method, the best LID method was selected.

LID designs were allocated based on the characteristics of LID and the current situation of the study area. Specifically, implemented LID practices should be suitable for various land uses in the study area. Precise implementation locations for the three LID options were determined, considering the appropriate integration of land uses and the flood-prone areas. The dimensions of installing LID options were calculated by multiplying the installation percentage by the corresponding land-use area. Additionally, the dimensions of installing a combined LID option represent the total value of all utilized LID methods.

The Fuzzy TOPSIS method was used to analyze the data and it was discovered that the combination of Rain barrel and Bio retention cell outperformed all other scenarios in terms of hydrological, economic, and social criteria. Hence, it can be inferred that this combination is the most efficient and effective way to manage water resources while taking into account the economic and social factors.

Based on the results presented, the prioritization using the Fuzzy TOPSIS method, considering economic, social, reduction of peak runoff flow, and reducing the volume of runoff criteria, revealed that the combined method of Rain barrel + Bio retention cell is the best LID implementation for the specified area. Subsequently, considering all four criteria, the Bio retention cell method is the second-best after the combined method, as presented in Table 7. The priorities of other methods are also provided in Table 7. However, economic analysis results indicate that the Green roof method has lower economic costs and is the best option economically. From a social perspective, the Infiltration trench is considered the best method, considering the lower deviation in Table 4. Additionally, based on the results in Table 8 regarding the reduction of volume and peak runoff, the Green roof + Infiltration trench method is the best. Therefore, selecting the best method that considers all criteria and provides the optimal results requires MCDM, and in this research, it was achieved by considering all criteria and utilizing the fuzzy TOPSIS method. Furthermore, referring to Table 9, which compares the current research results with similar studies in Tehran, it can be observed that in most similar studies, despite the consideration of various criteria, a combination of LID methods is introduced as the recommended approach. However, considering this table and similar research, for LID implementation, various criteria such as economic, social, environmental, technical, and runoff reduction are taken into account. The combination of methods or their separate implementation depends on the study area conditions. For instance, if only economic criteria are crucial and other factors are less important, Green roof is the best method according to the results of this research. Similarly, based on the research by Poursahebi *et al.* (2019), if only technical criteria are considered, and other aspects are not significant, the Green roof method is also recommended. Therefore, it can be concluded that selecting an LID method depends on the specific conditions of the study area and government policies. The best method selection should be based on the opinions of experts, relevant managers, and the importance of each criterion in accordance with policies and plans.

4. DISCUSSION

The study introduces a framework for prioritizing LID methods to control runoff in the city of Tehran. To achieve the research objective, the Fuzzy TOPSIS method was used to analyze the data. The study proposes the use of multi-criteria prioritization methods to select various forms of development that control runoff effectively. This method has been previously introduced in other studies. For example, the TOPSIS method was used in a study to prioritize surface runoff management scenarios conducted by Izanloo and Sheikh in different weighting conditions (2019). Another research used the combination of priority TOPSIS method for Fuzzy TOPSIS and appropriate classification of LID forms for a part of Isfahan city (Mahabadi *et al.* 2022).

The hydrological results of the research show that the combined scenario of Green roof + Infiltration trench is the most effective method in Tehran in terms of reducing the volume and peak runoff. The scenarios Rain barrel + Bio retention cell, Green roof, Rain barrel, Bio retention cell, and Infiltration trench follow in ranking as the second to sixth most effective, respectively.

The economic results of the research show that the combined scenario of Rain barrel + Bio retention cell is the most expensive, while the Green roof scenario is the least expensive. However, the Bio retention cell scenario, with only a 10% difference compared to the Green roof scenario, provides a much better result than the other scenarios. Comparing the Rain barrel and Green roof + Infiltration trench scenarios, which have a 6% difference compared to other scenarios, the sixth scenario is recommended because the results of hydraulic modeling show much more effective results.

The study used the prioritization method with fuzzy TOPSIS to choose the best LID method that considers all social, economic, and hydrological criteria. Finally, the results of the research showed that the combined scenario of Rain barrel + Bio retention cell is the most suitable LID method for the city of Tehran, while Infiltration trench is the least suitable. The second to sixth most suitable scenarios are Bio retention cell, Green roof + Infiltration trench, Rain barrel, Green roof, and Infiltration trench, respectively.

The published manuscript on this subject delves into various types of LIDs used for both quantitative and qualitative analysis across several major cities worldwide, spanning different climate conditions. However, to draw a meaningful comparison, the present study has focused on examining the studies conducted in the Tehran metropolis and recently published. The results of the comparison are presented in Table 9. The present study differs from others in its practical orientation, which was followed during the various stages of the research, including:

(1) Study area selection: The region was selected based on the city's priority list for rehabilitation projects. It is a region with a mix of old and new buildings, narrow alleys, and wide streets, creating an inconsistent region.
(2) Field study method: The study's preliminary plan included limited data collection and interviews for 1 month. However, the plan was extended by providing helpful information to the residents based on expert opinions. The study's experience

Table 9 | Comparing the similar studies conducted in Tehran metropolis

Study	LIDs	Simulation model	Objectives	Rainfall return period	LID selection procedure	Final suggestion	LIDs implementation consideration			
							Environmental	Social	Economic	Technical
Ahmadisharaf *et al.* (2016)	Detention Basin	SWMM	Reducing quantity impacts	2 5 10	None	Detention Basin	–	–	–	✓
Ghodsi *et al.* (2016)	Bio-Retention Cell Rain Garden Green Roof Infiltration Trench Permeable Pavement Rain Barrel Vegetative Swale	SWMM	Improve urban runoff quality	2 5 10	1) Game Theory 2) Nash Bargaining Theory 3) Social Choice Procedure	Combination	✓	✓	✓	✓
Poursahebi *et al.* (2019)	Green Roof Permeable Pavement Vegatative Swale Combination	SWMM	Reducing quantity impacts	2 5 10 50 100	Simulation results	Green Roof	–	–	–	✓
Movahedinia *et al.* (2019)	Bio-Retention Cell Rain Barrel Combination	SWMM	Reducing quantity impacts	2 5 10	Simulation results	Combination	–	✓	✓	✓
Raei *et al.* (2019)	Green Infrastructure	MLP-based meta-model	Runoff quality and quantity Control	2 5 10	None	Green Infrastructure	✓	✓	✓	✓
Taghizadeh *et al.* (2021)	Infiltration Trenches Bio-Retention Basins Permeable Pavements	SWMM	Improve urban runoff quality	2 5 10	MOPSO Optimization Algorithm	Combination	✓	–	–	✓
The Present Study	Green roof, Infiltration trench, Bio retention cell Rain barrel, Green roof + Infiltration trench, Rain barrel + Bio retention cell	SWMM	Reducing quantity impacts	10	Fuzzy Topsis	Combination	–	✓	✓	–

in presenting mass education to residents and families shows that providing the necessary explanations to familiarize them with new technologies can easily reduce daily problems associated with floods. Informing them about the importance of maintenance and non-destruction of Bio retention cells installed in streets and public places will not only decrease the failure risk of these cells but also raise the level of social participation in financing the Bio retention and GR installed in their properties.

The study's findings in the form of the regionalization map of the study area enable the city's authorities to:

(a) evaluate the performance of LIDs in mitigating floods (hydraulic perspective)
(b) implement a restricted number of LIDs localized for the study area relying on technical, social, and economic criteria
(c) propose specific scenarios for implementing LIDs for different neighborhoods, based on residents' opinions (social perspectives), infrastructural capabilities and limitations (technical perspectives), and, above all, the approval of its executive guarantee by the people.

In conclusion, the practical orientation of the present study, along with its findings, provides valuable insights for the city's authorities to implement LIDs effectively and efficiently, taking into account various perspectives, including technical, social, and economic.

5. CONCLUSION

A comprehensive research study was conducted to identify the most effective LID methods for managing surface runoff in Tehran. The study evaluated six different LID scenarios, including Green roof, Bio retention cell, Infiltration trench, Rain barrel, Green roof + Infiltration trench, and Rain barrel + Bio retention cell. A prioritization method using Fuzzy TOPSIS was employed to determine the best LID method that considers social, economic, and hydrological criteria.

The results of the study revealed that the combined scenario of Rain barrel + Bio retention cell is the most suitable LID method for managing surface runoff in Tehran. This method helps to enhance the quality of water, reduce the volume of runoff, and mitigate the negative effects of urbanization on the environment. On the other hand, Infiltration trench was identified as the most unsuitable LID method due to its limited ability to remove pollutants and its potential to cause groundwater contamination.

The remaining LID scenarios, in order of priority, were Bio retention cell, Green roof + Infiltration trench, Rain barrel, Green roof, and Infiltration trench. These scenarios can be used to promote sustainable urban development, reduce the risk of flooding, and improve the quality of life for urban residents. While acknowledging the limitations of the study, such as potential subjectivity in expert opinion, the research provides valuable insights for urban planners and designers to address flooding problems and promote the reuse of runoff through the implementation of various LID scenarios. The results can also guide decision-makers to choose relevant scenarios based on their operational-management goals and priorities. By utilizing the research findings, better planning can be done for the management and control of urban surface runoff in Tehran.

To enhance the study, future research can propose a spatial analysis of the prioritized LID scenarios in Tehran by incorporating geographic data and using geographic information system. Additionally, integrating matrix analysis of strengths, weaknesses, opportunities, and threats with qualitative methods can further prioritize the LID scenarios used in this study. This will help to develop more effective strategies for managing surface runoff in Tehran and other urban areas facing similar challenges.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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