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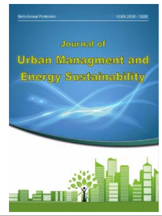

ORIGINAL RESEARCH PAPER

Urban Flood Management Using the Green Roof System (Case study: Tehran City)

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ABSTRACT

With the expansion of construction and impermeable surfaces in large cities, the urban flood phenomenon is considered an important problem. Various cities in Iran have recently been affected by floods and damages, which are high-intensity rainfall and inefficient drainage networks. This study aimed to provide urban flood management solutions concerning the various advantages of green roofs and the environmental, climatic, and geographical characteristics of the Tehran metropolis. For this purpose, the types of green roofs and their components have been analyzed using the content analysis method. The novelty of this research is in prioritizing the use of green roofs according to their advantages, especially the feature of optimizing the urban sewage network, and according to the price range of their different types. The result is that the construction and implementation of green roofs in order to take advantage of the optimizing the urban sewage system and reducing runoff require special policies and methods of encouragement and punishment, which should be used by all governmental and non-governmental organizations and also according to the precipitation patterns in the areas with flood risk should be used with an extensive green roof. However, due to the high cost of intensive green roofs in some cases, this type of roof can be used in new buildings with large and expensive areas. Due to the slope of Tehran and the pattern of canals and runoff, green roofs in the north and east of Tehran city are a priority.

Running Title: Urban Flood Management Using the Green Roof System

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1. Introduction

Iran is a flood-prone country, and due to droughts and water shortages, part of it should be managed using different methods. Most of the floods in the country occur suddenly due to changes in the physical conditions of watersheds and the loss of vegetation. Today, familiarity with the dangers of urban floods and dealing with them are of great importance in urban management systems. The importance of urban flood management can be considered due to its harmful effects on urban environment. In developed urban areas, roof surface areas account for 40–50% of all total impervious surface areas (Mentens et al., 2006) (Stovin et al., 2012). Due to climate change in the country and the consequences of floods, the necessary measures should be taken to predict and deal with floods. Under these circumstances, a green roof is considered an effective technique to reduce runoff and peak flows because it can retain stormwater in the soil and the vegetation medium for an extended period compared to a control roof approach (Stovin et al., 2013) (Shafique et al., 2016). It improves the optimal use of water and, on the other hand, reduces destructive effects such as flood protection, river floods are particularly important. An extensive range of these measures relies on different hydraulic structures and non-structural projects (Siviglia1 et al., 2009). The main purpose of flood control is to reduce or eliminate economic, social and environmental damage (especially human and financial) from floods. Structural and managerial methods can control it. In general, various researches in the field of flood management methods include flood reduction, vulnerability, reduction of damages and preparation for damage tolerance. The green roof is one of the technological solutions that can contribute to the sustainable development of cities (Chiesura, 2004). This technology has numerous advantages from a social, economic and environmental point of view, so, it is an effective factor in improving the climate change (Bianchini and Hewage, 2012). In addition, through green roofs, unnecessary water consumption in buildings can be prevented by storing purified water and used for sanitary purposes, irrigation of green spaces, floor and facade washing, etc. (Stovin, 2010). The novelty of this research is in prioritizing the use of green roofs according to their advantages, especially the feature of optimizing the urban sewage network, and according to the price range of their different types.

2. Materials and methods

Stormwater runoff control is an important function of a green roof and it is well-documented as stormwater best management practice (BMP) by many influential organizations and design standards: (1) stormwater menu of BMPs, USEPA; (2) low impact design (LID) approach to managing stormwater runoff, USEPA; and (3) leadership in energy and environmental design (LEED), US Green Building Council. In the realm of hydrology, a green roof is utilized to retain a volume of precipitation, reduces peak runoff discharge, and delays the peak flow. The reported performance varies among the published experimental studies depending on the configuration of the green roof (VanWoert et al. 2005). This study aimed to provide urban flood management solutions concerning the various advantages of green roofs and the environmental, climatic, and geographical characteristics of the Tehran metropolis. For this purpose, the types of green roofs and their components have been analyzed using the content analysis method. Content analysis is a research method used to identify patterns in recorded communication. To conduct content analysis, you systematically collect data from a set of texts, which can be written, oral, or visual. By comparing environmental patterns and green roof structures, the principles of green roof design are analyzed based on native patterns, emphasizing the concepts of flood management and the priority of using green roofs in different areas of Tehran city which will be examined following the analysis results (Figure 1).

3. Research literature

The structure of the green roof includes the plant-covered space of the roof. Plant-covered space can be underground, on the ground, or above ground. There are two types of green roof systems, including extensive green roofs and intensive green roofs. Intensive green roofs are heavy, costly,

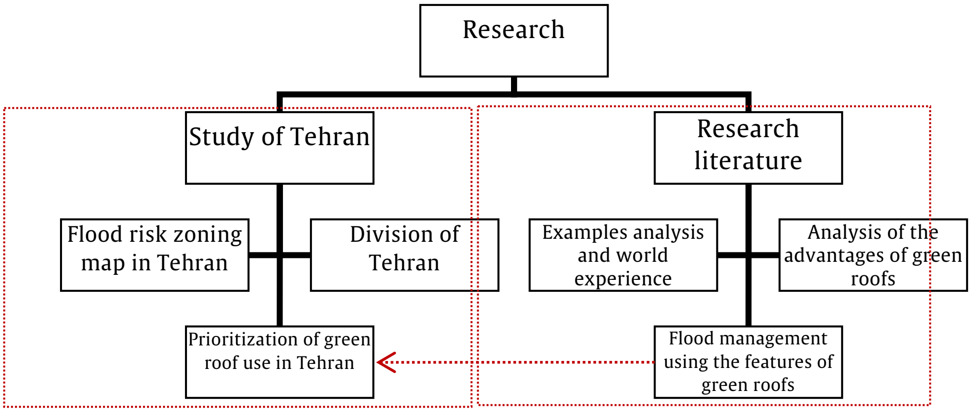


Figure 1: Research framework regarding the prioritization of green roof use in Tehran city

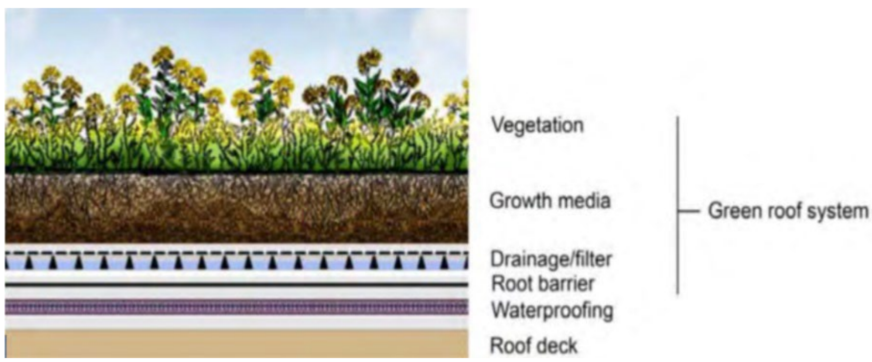


Figure 2: Typical green roof cross section (Andrew, 2015)

have an extensive range of arable crops, and have a lot of maintenance requirements. The depth of planting environment of these roofs varies between 200 to 2000 mm depending on the type of trees and structural requirements (Keshtkar Ghalati, 2009). Due to the increase in soil depth, plant selection becomes more diverse and creates a more complex ecosystem. Extensive green roofs are lightweight and have low maintenance costs. The planting environment in these roofs consists of a mixture of sand, gravel, crushed brick, LECA, fertilizer, organic matter and some soil with a depth of 50 to 150 mm (Keshtkar Ghalati, 2009). The accessible green roof is an open space that people can use as a backyard. These roofs include arable land, planting boxes, walkways, stopping and sitting areas, water supply equipment, playgrounds and awnings. Because these roofs are accessible, safety equipment, the requirements must be observed. These requirements include emergency exit, lighting and security. The details of extensive green roofs, if improperly designed, reduce efficiency by up to 30% and increase the cost of roofing. A green roof system is a vegetative layer grown as an extension of an existing roof. It is built on the new and existing roof structures which need to be prepared to fit this special purpose (Figure 2).

Typically, a green roof design consists of three layers: vegetation, substrate (growth media) and drainage (FLL, 2018). The main components of the green roofs are the same in intensive and extensive roofs (Figure 3 and 4).

An individual green roof system may be a combination of intensive and extensive. Advantages and disadvantages described in Table

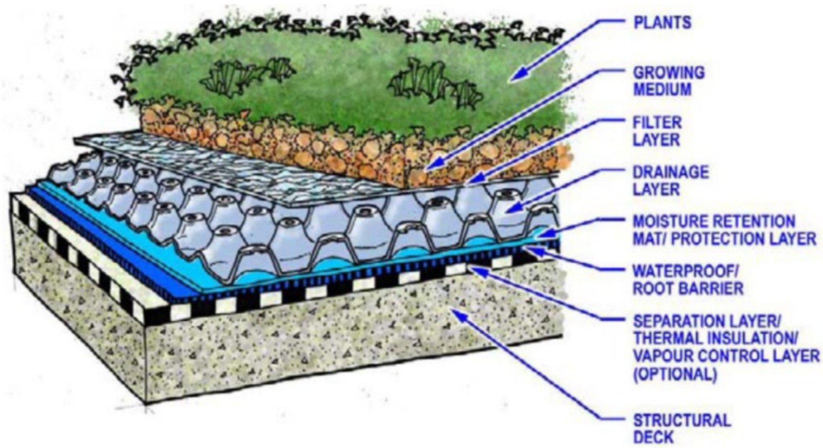


Figure 3: Basic components of a green roof system (Intensive and Extensive) (Townshend, 2007)

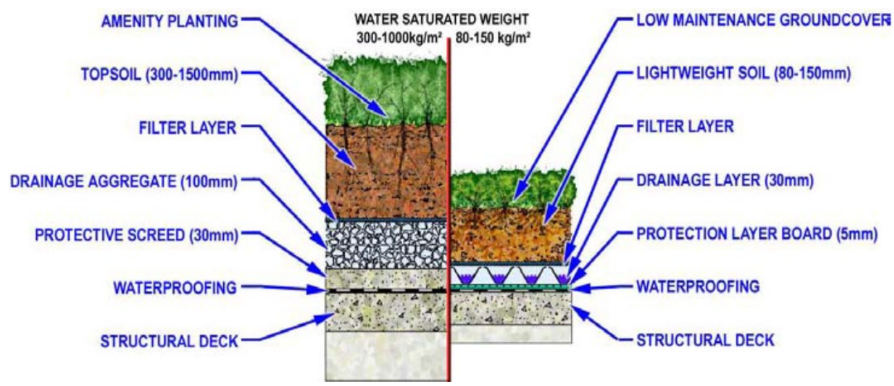


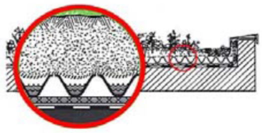
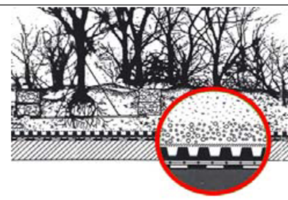
Figure 4: Conventional (Intensive) and lightweight (Extensive) green roof system (Townshend, 2007)

1 provide generic information (Table 1).

Extensive green roof systems with the low surface also specially developed for lightweight structures. Special materials are used in smaller quantities to achieve lower surface weights. Water retention – to ensure the minimal needs of plants – is usually done at the drainage layer, so drainage tiles can retain 10 l water/m^2.

The main advantages of green roofs on a large scale include economic, environmental and physical advantages (Figure 5). Furthermore, green roofs have the ability to extend the life of building roof (Banting et al., 2017), improve the air quality, enhance the aesthetic value of the building architecture and improve the biodiversity (Grant et al., 2003). Green roofs are not a new technique (Köhler et al., 2004), their widespread use, especially for the stormwater management provides benefits in the urban areas all around the globe. Over the last 30 years, green roofs have become more popular, particularly in most of the developed countries such as: Germany, Australia, Switzerland, Austria, USA, Japan, Singapore and South Korea, for example, 14% of the flat roofs in Germany (13.5 km^2) are supported by green roofs in 2003 (Herman, 2003). However, in South Korea, the law of "low carbon green growth building code" (Moon, 2010) strongly endorses green roofs as a Low Impact Development (LID) technology to achieve safer and more sustainable

Table 1: Comparison of extensive and intensive green roof systems (Townshend, 2007)

Typical details		
Brief description	• thin soil (50mm-150mm thick) • little or no irrigation • low maintenance (\$0.8 to \$2.25 /m²/year) • extensive application over large area for optimal environmental benefits	• deep soil (200mm-2000mm thick) • irrigation • normal maintenance (\$6.5 to \$44 /m²/year) • intensive capital and maintenance input for optimal benefits
Advantages	• **lightweight (80 to 150 kg/m²)** • **low maintenance** • **suitable for retrofit projects** • **relatively inexpensive (\$400 to 1000/m²)** • suitable for large areas • suitable for roofs with 0-30° slope • can leave vegetation to develop spontaneously	• **diverse utilization of roof (i.e. for recreation, growing food, as open space) with direct benefit to owner** • greater diversity of plants and habitats • good insulation properties • can simulate a wildlife garden on the ground • can be made very attractive • often visually accessible
Disadvantages	• more **limited choice of plants** • usually **no access for recreation or other uses** • may be visually unattractive to some, especially in dry season	• **relatively higher cost (\$1000 to 5000/m²)** • **not usually suitable for green roof retrofit projects** • greater weight loading (300 to 1000 kg/m²) • need for irrigation and drainage systems hence, greater need for energy, water materials etc.

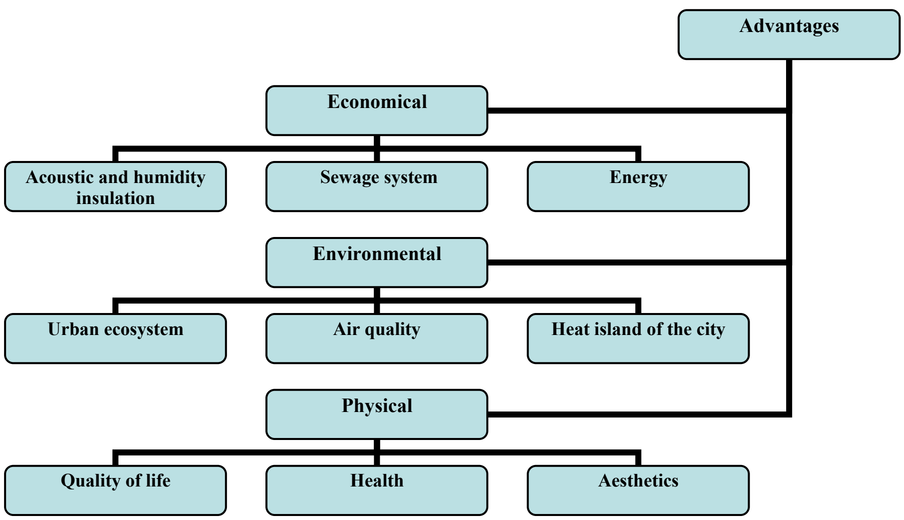


Figure 5: Advantages of using different types of green roofs

cities. Low carbon green growth recognized the guidelines related to the use of green roof in the building architectures (Moon, 2010).

One of green roofs advantages is related to the flood management system. The green roof can be classified depending on the depth of the substrate layer and can be named as extensive roofs and intensive roofs (Hinman, 2013) (Echols and Pennypacker, 2015). Urban spaces include many impermeable surfaces such as sidewalks, roofs, walls and roads, which collect and direct water only into streams, sewers, and canals of the

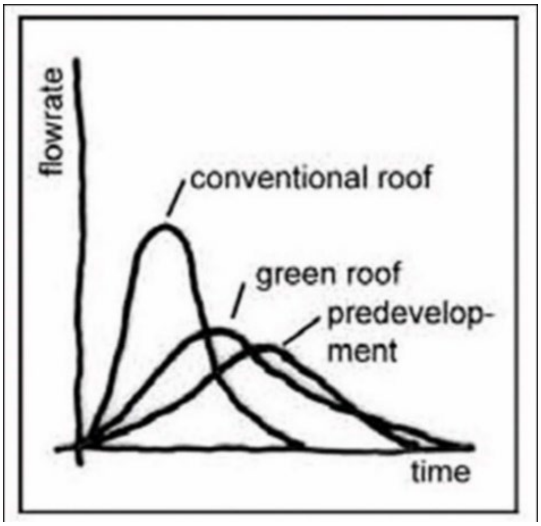


Figure 6: Comparison of the effect of different levels on water flow (Dunnett and Kingsbury 2004)

urban drainage system, and the use of green roofs can have a great effect on the volume of water lost to sewage and streams (Figure 6).

Green roofs reduce the additional loads on the urban sewage system by 70% to 90%. To improve the efficiency of green roofs in flood control, extensive green roofs should cover more than 60% of the available area. In heavy rainfall, semi-extensive roofs perform much better than extensive types. Roof performance depends on the depth of the soil bed (Mora-Melià et al., 2018).

Table 2: Rainwater storage by green roof types (Dunnett and Kingsbury 2004)

Roof type	Rainwater storage and collection
Depth 2 to 4 cm	40 to 50%
Depth 10 to 15 cm	Up to 60%

So far, further research has been done on the effect of each component on the productivity of green roofs in water retention. According to many of these studies, soil depth is directly related to rainwater holding capacity (Carbone et al., 2015). Some studies have shown the positive effect of roof geometry and slope on flood storage (Getter et al., 2007) (Table 2).

In Portland, Oregon, green roofs are recognized as the best practical solution for water and wastewater management, and various policies have been used to develop them (Table 3).

Moreover, in Münster city, the use of green covers for surface water management and increasing green space was pursued through the policy of paying surface water and sewage taxes (Table 4). In Toronto, the use of green roofs in order to use all its advantages is on the agenda (Table 5).

Construction and implementation of green roofs in cities to make use of the advantages of optimizing the urban sewage system and reducing runoff require special policies and methods (Table 6).

Table 3: The executive policy of green roof construction in Portland (Keshtkar Ghalati et al., 2010)

Policy	Description		
New buildings	Area of at least 70% to green roofs		
Existing and old buildings	Green roof replacement		
Reduction of sewage tax	Commercial and industrial	70 %roofing	35 %tax reduction
	Residential	Based on the occupancy surface	Possibility of compaction
Advice and training	Exhibitions, workshops, and experimental and demonstration sites		

Table 4: Analysis of Münster green roof construction for surface water management and increasing green space (Abolghasemi, 2020)

Goal	Description	Policy	Agency
80 %tax reduction for green roofs	Tax bill according to the amount of permeability of the building surface	Payment of surface water and sewage tax	Municipality
Increase green space and reduce negative environmental effects	Direct financial aid	Motivational program	Government

Table 5: Analysis of green roof construction in Toronto in order to use all the advantages of green roofs (Abolghasemi, 2020)

Policy		Goal
Coverage of 50 to 70% green of public buildings		Increase the level of green space
Roofs of municipal buildings: reference and education of citizens		Technical and green design
Educational workshops and introduction of builders: training camp and website		Technical considerations for construction and maintenance
Academic studies	Awards and conferences Modeling	Study and calculate implementation costs and benefits.
	Analysis and calculation	Extensive green roof implementation criteria

Table 6: Global experiences of using the advantages of a green roof (Abolghasemi, 2020)

Example	Agency	Scope	Policy	Goal
Portland	Municipality	New and old buildings Area of at least 70%	Reduce sewage taxes Compaction based on occupancy surface	Sewage system optimization
Münster	Municipality Government	Surface water tax Motivational program	Tax bill Direct financial aid	Surface water management and increasing green space
Toronto	Municipality	New public buildings Roofs of municipal buildings	Incentive program Reference and training	Increasing green space per capita
	University	Calculation of executive costs and modeling on the existing building		
Tokyo	Government and people	Private buildings larger than 1000 m^2 Public buildings with more than 250 m^2	Require 20% of the green roof area or an annual fine of $ 2,000	Tokyo green program

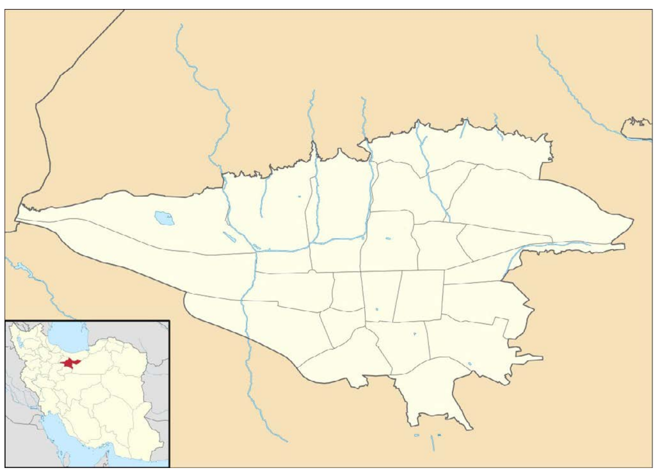


Figure 7: City of Tehran (Salehi et al., 2013)

Tehran, the capital city of Iran and the center of the province of Tehran, located in north-central Iran at the foot of the Elburz Mountain range. Tehran has grown from a small city to a major metropolis: situated in an urban region of 14 million inhabitants (Figure 7).

The area of existing green roofs has not been measured in Iran. For example, green roofs

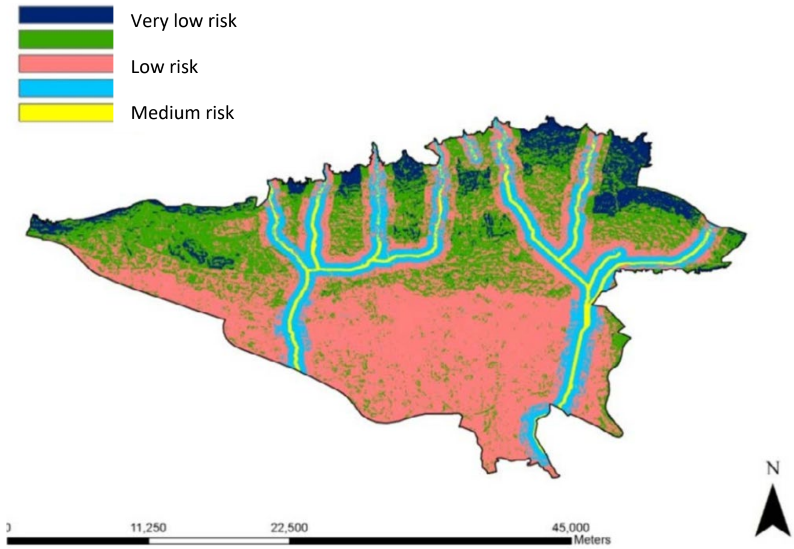
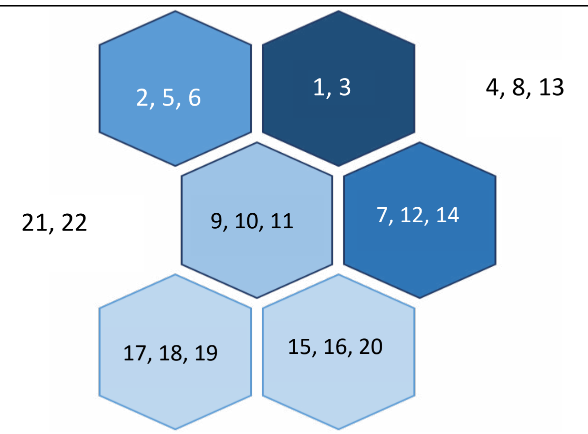


Figure 8: Flood risk zoning map in Tehran (Salehi et al., 2013)

Table 7: Analysis of flood risk in Tehran



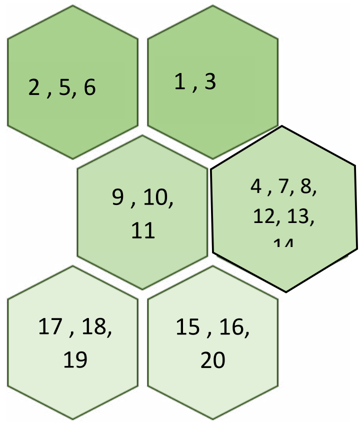
Possibility	District
1	1, 3
2	7, 12, 14
3	2, 5, 6
3	4, 8, 13
4	9, 10, 11
5	15, 16, 20
6	17, 18, 19
7	21, 22

only exist in luxury and expensive buildings or in mega shops and brand projects. Although, recently, Tehran Municipality has made a policy to promote the expansion of green roofs.

From the stormwater management perspective, it is very important to study how green roofs normally function in runoff retentions under different rain events for a long period of time (Bengtsson, 2005). In this section, due to the increase of impermeable levels, northern and southern basins and the arrival of runoff caused by precipitation in the mountains in the north and east have high flooding potential. The collapse of the Tehran drainage system due to the execution of some projects is increasing the intensity of urban floods. As the urban network is created regardless of the natural drainage direction and flood damage which is local, it has imposed a great deal on the city (Ghahroudi Tali, 2009). Figure 7 shows the flood risk zoning map in Tehran city (Figure 8).

Green roof is a sustainable stormwater

Table 8. Priority analysis of the use of extensive green roof types in Iran



Type	District
Extensive and intensive	1, 3, 2, 5, 6
Extensive with high surface	4, 7, 8, 9, 10, 11, 12, 13, 14
Extensive with moderate surface	15, 16, 17, 18, 19, 20
Extensive with low surface	21, 22

management practice, which can store rainwater for a longer period of time than the conventional roof. To estimate this, the water level of green roof was measured during small rain events. Figure 7 shows the amount of water that was retained on the green roof. From the analysis of the green roof results, it can be seen that the green roof water level varies from 0.01 to 0.027 m during the different time periods. The results indicated that in the case of big rain events, the green roof has the ability to hold more water in soil media; therefore, the water level during big rain events will be higher as compared to during the small rain event (Shafique et al., 2018) (Table 7).

Based on the zoning map, flood risk in Tehran is extracted, and its results are obtained based on land slope and water movement as well as existing flood channels. Due to the slope of Tehran and the pattern of canals and runoff, green roofs in the north and east of Tehran are a priority.

4. Results and discussion

The effect of green roofs, in constant rainfall conditions, increases with the reduction of the height of the land. This result is consistent with previous studies, which have shown that they are more effective for smaller storm events (Chapman and Horner, 2010; Mentens et al., 2006; Qin et al., 2013; Palla and Gnecco, 2015). Runoff volume reduction depends on the vegetation, growth media, initial water content, and slope of the roof, meteorological conditions, and precipitation characteristics (Hathaway et al. 2008; Speak et al. 2013). In addition to reducing total runoff volume and peak flow rate, green roofs can also delay the occurrence of the peak flow also potentially helping alleviate the adverse effects of stormwater runoff. A green roof can act similarly to a detention basin which delays the conveyance of water, hence reducing the cumulative downstream peak flow rate and associated erosion. Several studies have investigated peak flow delays affected by green roofs. Carter & Rasmussen (2006) found that the green roof delayed the peak runoff for 57% of the events. The water retention capacity of a green roof with respect to a precipitation event is related to the physical properties of the green roof growth media, the initial water content, and meteorological conditions such as temperature, humidity, solar radiation, and wind speed. According to Table 7, based on the zoning map, the flood risk in Tehran city was extracted and the results were obtained based on the slope of the land and water movement as well as the existing flood channels. According to the ability of green roofs to store rainwater and optimize urban wastewater, each type of green roof was assigned in each urban area. Regarding the green roof implementation policy, according to the precipitation patterns and areas with a risk of flood risk, an extensive green roof should be used. However, due to the high cost of intensive green roofs in some cases, this type of roof can be used in new buildings and expensive areas (Table 8).

According to figure 9, the areas at risk of flooding are of the semi-intensive type and a combination of extensive and intensive types, which, of course, are intensive due to the problems caused by the structural load caused by the green roof. Plant transpiration is affected by climatic factors such as temperature and solar radiation, and therefore, seasonal conditions may affect green roof hydrologic processes. Deeper media provided for greater plant growth with sufficient water but also required greater irrigation because of the higher ET rates resulting from greater biomass.

5. Conclusion

The construction and implementation of green roofs to use the advantages of optimizing the urban sewage system and reducing runoff require special policies and methods of encouragement and punishment that all governmental and non-governmental organizations should use. Besides, according to the precipitation patterns in areas with flood risk, an extensive green roof should be used. However, due to the high cost of intensive green roofs, in some cases, the green roofs can be used in new buildings with a large area, and in expensive areas, this type of roof can be used next to an extensive green roof. In order to use green roofs optimally, the nature of each of their types should be examined. In order to use the advantages of green roofs in flood management, it can be expected to have good efficiency in proportion to the thickness of the soil bed. For this purpose, it is possible to use extensive types of roofs in areas with low flood risk areas, semi-extensive areas with moderate flood risk, and intensive types in areas with high flood risk. Therefore, to determine the type of green roof used, we must first analyze the districts' priorities based on the land's features and the flood channels' location.

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