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CASE STUDY

Performance evaluation of green roofs in urban runoff reduction

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ABSTRACT: Urbanism directly affects the hydrological cycle. One of the ways to manage runoffs in urban areas that is considered nowadays is green roof creation. Green roof is mainly created in humid and semi-humid areas, and efficiency of green roofs in arid and semi-arid areas has attracted less attention. In the current study, to evaluate the effect of green roof in arid and semi-arid to reduce runoff, an experimental green roof without vegetation was designed in Behbahan city of Khuzestan province in Iran. The city has an arid and semi-arid climate. Experimental Green roof was studied during 7 months. During the study, the data regarding the height of rainfall, soil moisture in different soil layers of the experimental green roof as well as the amount of output runoff were measured. The results showed that the amount of moisture in the surface layer of soil is severely affected by rainfall. The average surface soil moisture has been about 20.5 % and in the deep and middle layers has been 24.8 and 24.1, respectively. In addition, regarding runoff reduction and delays in creating runoff, the results showed that in the observed rain events, in average, 92.2 percent of volume of rainfall has been kept in soil, and has not been converted into runoff. Due to arid and semi-arid climate of the target area and high-intensity of rainfall, green roof can reduce a considerable percentage of runoff.

KEYWORDS: *Arid and semiarid climate; Green roof; Runoff; soil moisture; Urbanism*

INTRODUCTION

Urbanism leads to replacement of permeable surfaces and vegetation with impervious surfaces and buildings, as a result, intensity of production runoff and volume will be increased (Lee *et al*., 2013). One of the most important problems in urban flood management is reduction concentration time and increasing flood volume and peak flood (Rodriguez *et al.,* 2003; Huang *et al.,* 2008). Studies have shown that runoff volume in urban areas is severely affected by features of impervious surfaces (Ogden *et al.,* 2011). Several studies have focused on the effect of urbanization on the hydrological changes of basins and all of these studies have confirmed the changes in hydrologic properties of basins due to expansion of urban areas (Band & Brun 2000; Hamel *et al.,* 2013). Study by Braud *et al.,* (2013) showed that the increase of impervious surfaces significantly increases the amount of runoff. Therefore, besides development of impervious areas due to urbanism expansion, managers and experts are trying to increase permeability of urban areas. A study conducted by Haifeng *et al.* (2012) showed that by using some activities such as permeable sidewalks, green roof and rain's water collection tanks, the effects of urbanism in an area can be reduced, and urban runoff in an area can be managed. The Harper *et al.* (2015); Lamera *et al*. (2014); Lee *et al.* (2013) found that

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building's green roofs and enhancing green spaces can help to manage urban runoff by reducing the negative effects of runoff. Lee *et al.* (2013) believe that green spaces play a positive role in reducing urban runoff and by creating green roofs and increasing green spaces, urban runoff management can be enhanced through runoff reduction (Harper *et al.,* 2015; Lamera *et al.,* 2014; Lee *et al.,* 2013). Reviewing environmental challenges and considerations in the management of urban runoffs is one of the most important issues in urban management projects.

In traditional methods, the main purpose of managing urban runoff was collecting and disposing runoff from urban areas as fast as possible through drainage methods in order to prevent flooding in the major cities during big rainfalls. But now, the subject to delay runoff in urban areas is greatly taken into consideration. Green roofs also called living or eco roof have been taken into consideration as a part of modern architecture to manage environmental problems and flooding in urban areas. Green roofs have been used in humid and semi-humid areas; and they have a little use in arid and semi-arid areas. The use of green roofs in different parts of the world with different objectives such as reducing runoff, pollution decentralized management, reducing sound pollution has been very common (Getter and Rowe 2007; Teemusk and Mander 2007). Green roofs reduce urban runoff at the source (Carter *et el.,* 2007; Mentens *et al.,* 2006; Gendreau *et al.,* 2007), while they lead to retention penetration and storage of a part of rainwater by plants and the subsequent reduction in evapotranspiration. As a result, such phenomenon can decrease the volume of annual runoff up to more than 50% (Berndtsson 2010; Voyde *et al.,* 2010; Gregoire and Clausen 2011). In this regard, this study reviews the effects of green roofs in runoff management in Behbahan city that has arid and semi-arid climate. This study has been carried out in Behbahan in southern part of Iran in 2015-2016.

MATERIALS AND METHODS

The region

Behbahan City is located in East of Khuzestan province southern part of Iran with the geographical location 50Ë% 14´ longitude and 30Ë% 36´ latitude. Fig. 1 shows the location of the target location. The average rainfall of Behbahan is 329 millimeters 50.3 percent of it is in winter, 7.5 percent of it is in spring and 42 and 0.2 percent of are in fall and summer respectively. Average temperatures in the city is 27.6 degrees of Celsius. According to the Domarten climate classification, it has an arid and semi- arid climate.

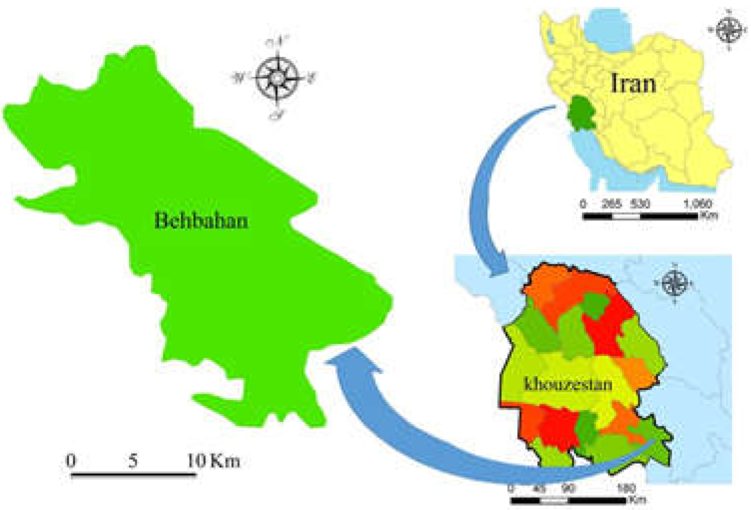

Fig. 1: Geographic location of the study area

Methods

To study the effects of green roof in reducing of runoff, experimental green roofs were made. The method was that first a metal box with dimensions of 1 × 1 m of galvanized iron was designed and built. At the bottom of the box, a hole with a diameter of 10 cm was placed as a drainage. Then, the metal box was placed on a stool keeping the box at a height of half a meter from the ground. In the next step, the agricultural soil available in the area (clay loam soil texture with 5.0 percent of organic matter) was used to fill the box. The made site was placed in a convenient location to receive direct sunlight from sunrise to sunset. A container was placed below the box to collect water of drainage. After the establishment of green roof pilot project in the right location, due to the problems in simulating rain by rain-makers, natural rainfalls were used.

To measure rain, a rain gage was placed beside the box and higher than the box, so that the walls of the box have less impact on collected rainfall. From December 2015 till May 2016, all precipitation events were examined, and in each event, the height of precipitation, runoff and soil moisture levels and changes of soil moisture were recorded. It was done as the following that immediately after each rainfall, three soil samples from three levels of zero, 10 and 20 cm were taken. In addition, the soil moisture was measured using weight method. At the end, moisture content obtained from various depths was compared. Due to the volume of runoff collected in each rainfall event, the runoff height is calculated, and by using the relationship between height of collected runoff and rainfall height, the retention coefficient for green roof is calculated.

RESULTS AND DISCUSSION

To evaluate the effectiveness of green roofs to reduce urban runoff in Behbahan with arid and semi-arid climate, after design and establishment a replica of green roof in the convenient location, height of rainfall, runoff and soil moisture levels, and changes of soil moisture, natural rainfalls were recorded and analyzed from December 2015 till May 2016. In the following, the results will be presented separately.

Rainfall

Cumulative height of rainfall in each 24 hour was measured by a rain gage reservoir at the site. According to information gathered during the study period, 35 cases of rainfall were recorded. In Fig 2, show rainfall height of a number of recorded events.

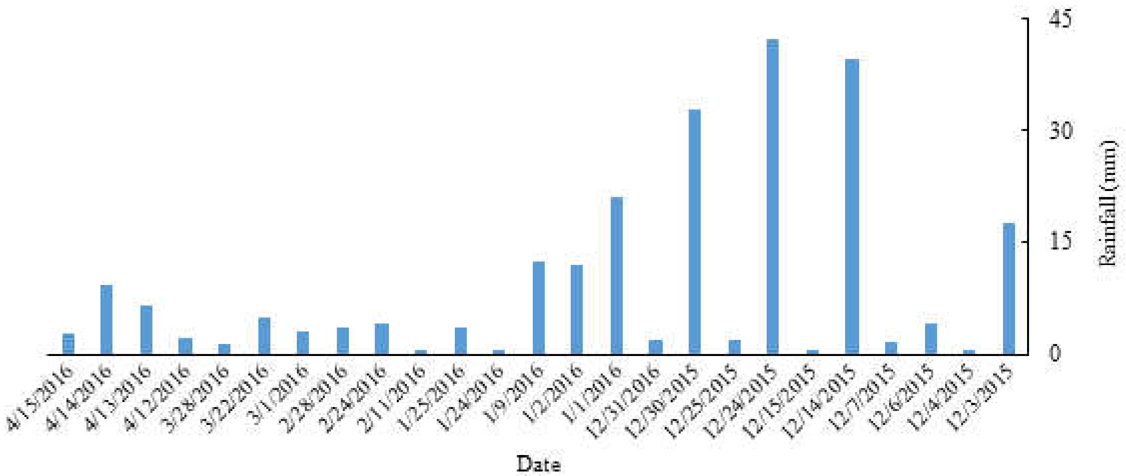

Fig. 2: The measured rainfall height in some of the recorded events

According to classification done by VanWoert *et al.,* (2005), the 24-hour rainfalls can be classified into three main groups according to the amount of rainfall. So, the rainfalls less than 2 millimeter are classified as light precipitation, rainfalls with 2-6 millimeter height as average precipitation, and the ones having more than 6 millimeter of height as heavy precipitation.

During the period when the study was conducted, 35 precipitations were recorded and the total height of recorded rainfall was 230 mm. In Table 1 the type and number of recorded rainfall are listed.

Soil moisture

Since the construction of the test site, all day and every day, three times the amount of soil moisture at depth zero, 10 and 20 cm were measured in experimental green roof. Therefore, the graph of soil moisture's changes during the target period was obtained. Fig 3 shows a graph of average soil moisture's changes.

Comparison of soil moisture in different depth

The amounts of green roof's soil moisture in different depths were compared, and the results are provided in Table 2 and Fig. 4.

Moisture in the middle and deep layer of soil was mostly higher than that of surface layer, so that the average moisture of surface layer of soil has been about 20.5 percent, while it has been 24.8 and 24.1 percent in deep and middle layers, respectively. The difference in soil moisture content can be attributed to evaporation and soil hydraulic conductivity. In addition to the mentioned factors, due to presence of a fabric filter layer having the ability to retain moisture and the effect of filter layer in trapping fine particles in deep layers,

Table 1: Number and amount of the recorded rainfalls

Type of rainfall	Number of the recorded rainfalls
Heavy	11
Average	12
Light	12

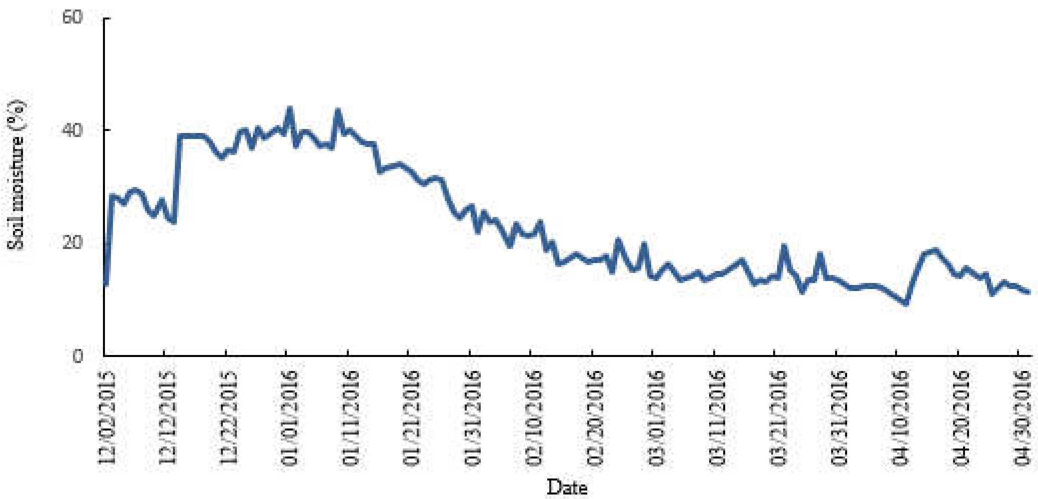

Fig. 3: Average changes of green roof soil moisture measurements during the study period

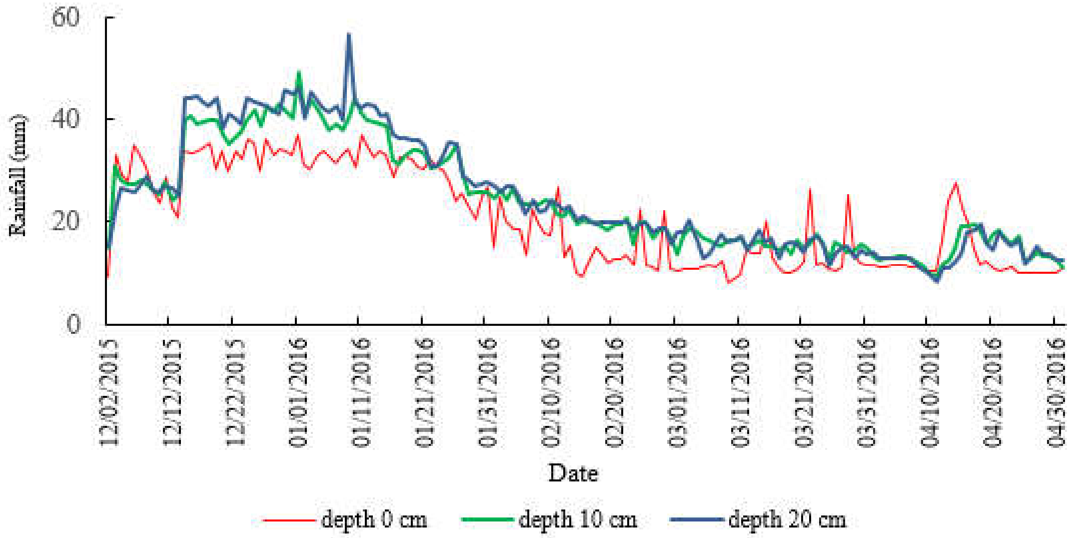

Fig. 4: A comparison of the amount of moisture in different soil depths of Green Roof

Table 2: The average soil moisture at different depths of green roof during the study period

Depths (centimeters)	Soil moisture (%)
0	20.47
10	24.1
20	24.9

increase of the moisture level in the middle and deep layers can be interpreted. On the other hand, a slight difference among soil moisture in various layers can be attributed to arid and rainless days in the target area, so that during the total 35 days period of study, there has been rain, and other days have been rainless. During the rainless days, deep soil loses its moisture because of evaporation, and its moisture content will be greatly reduced. However, in rainy days and some days after the rain ends, difference of moisture content of deep and surface layers of soil is very much.

Runoff

During the implementation of the program, containers collecting runoff were visited three times per day. In addition, height and volume of the runoff collected from green roof were measured. In Fig. 5, the amount of collected runoff in some rainfall events in the experimental green roof has been shown.

The retention amount of green roof

With the height of rainfall and depth of runoff in all the events, the retention of green roofs was investigated and finally, the average percentage of retention of green roof was determined. The results obtained from calculating the rate of retention in a number of events have been presented in Fig. 6.

Depending on the rainfall type, the average retention rate of green roof for a variety of precipitations was determined that the results are given in Table 3.

According to the evaluation of rainfalls in the studied period and the area, it can be concluded that most of the precipitations are in the category of light and average precipitation. In such precipitations, a great volume of rainfall is kept in green roof, and in most of light and average rainfalls, the rate of retention is very high. In the events which are categorized as heavy precipitations, the effect of green roof will decrease, and retention rate will also decrease. Totally, in both light and heavy precipitations, green roof has a positive effect in reduction of runoff compared to common roofs. The obtained results are aligned with the findings of Bursztа-Adamiak (2012), Gromaire *et al.* (2013) and Palla *et al.* (2010).

In Fig. 7 changes of the amount of moisture and precipitation during the study period are presented. As it is clear in the figure, during the early days of sampling, some high precipitation volume has occurred and soil moisture in different layers has been greatly increased. But in the final period of the sampling, the amount of rainfall has decreased, resulting in decreased soil moisture.

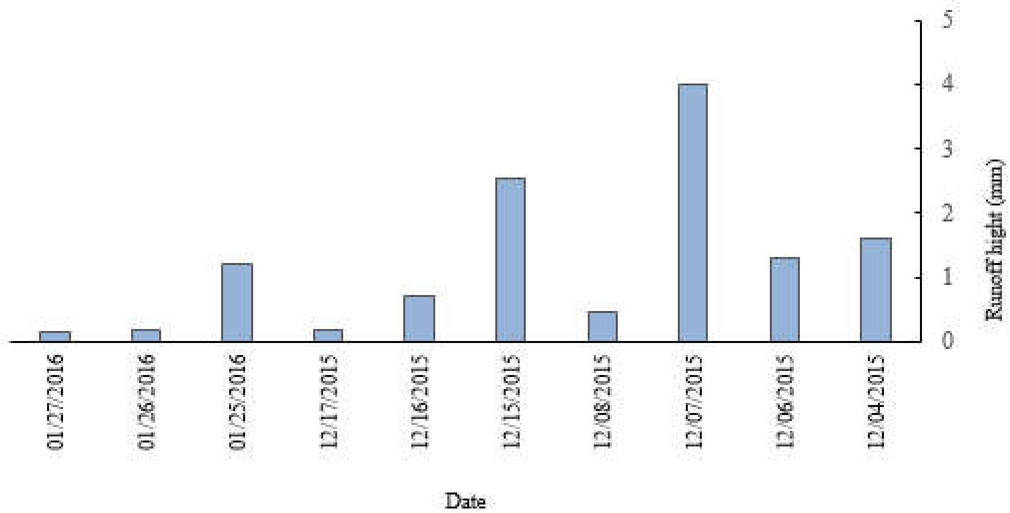

Fig. 5: Height of the collected runoff in some rainfall events

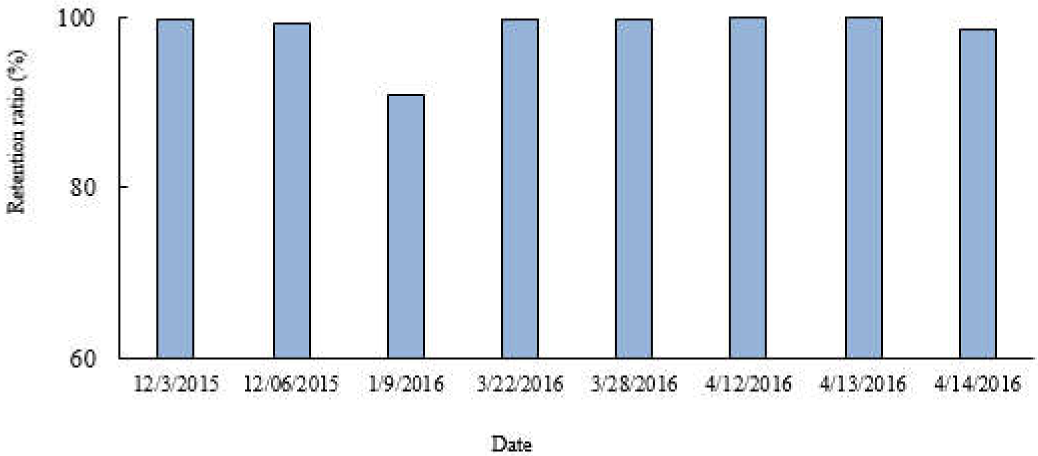

Fig. 6: rain retention rate in some rainfall events in the studied sample green roof

Table 3: The average amount of retention amount in a variety of precipitations

Type of rainfall	Retention rate (%)
Heavy	80
Average	95.8
Light	99.8

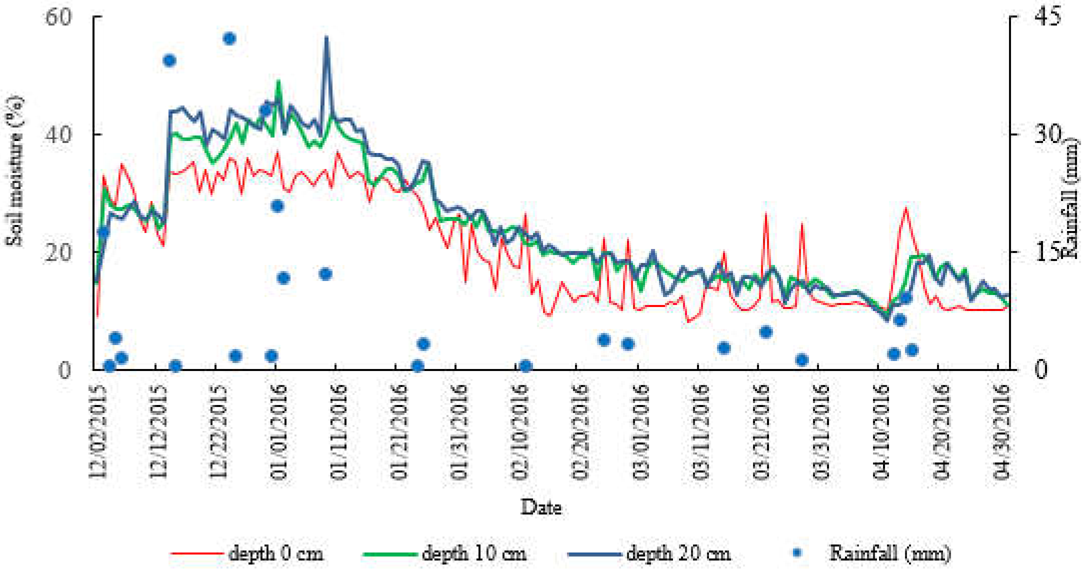

Fig. 7: Moisture changes in various depths and rainfall

The results showed that the moisture in the surface layer of soil is heavily influenced by rainfall. By each rain, the moisture of surface layer of green roof will increase, and after the rain, it will decrease rapidly. The rapid changes of surface soil moisture content can be attributed to evaporation from surface and soil hydraulic conductivity. It must be noted that, as it has been shown in Fig. 7, during the period that the rainfalls have occurred in short intervals, the amount of moisture in middle and deep layers is more than that of surface layer of soil. In addition, in periods when rainfall is low or there is a long dry period (the periods at the end of project time), the amount of moisture in the surface layer increases immediately after each rainfall, then, after the end of rainfall, moisture of surface layer decreases rapidly.

CONCLUSION

Green roof with vegetation or without vegetation is a managerial strategy in urban areas that can have many advantages. In arid and semiarid area having rains with high intensity, flood due to increase of impervious surfaces in urban areas is a main problem for city officials. Application of green roofs in arid and semiarid area is according to the capability of such roofs to retention and delay flood or, in other words, to reduce peak discharge of flood in urban areas. According to the results of the present study, the green roof without vegetation in all the studied rainfall events has maintained 92.2 percent of the rainfall volume in itself. As it is clear, a great volume of rainfall can be maintained in green roofs, and not be changed into runoff. Creation of green roofs in such areas can somehow reduce urban floods.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

ABBREVIATIONS

%	Percent
Km	Kilometer
mm	Millimeter
°	degree
′	minute

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