Effectiveness of Non-monitored Green Roofs for Stormwater Management

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Abstract. A green roof is an alternative roofing system of any building or house that provides a better environment for urban areas. It has the potential to mitigate urban water problems. This study aims to investigate the rainfall runoff performance of two non-monitored green roofs with two different slopes. The experiment uses two types of non-monitored green roofs, namely flat roofs and sloped roofs that were exposed to climatic conditions in Parit Raja. The physical characteristics of the roofs were observed and rainfall runoff data was collected. The results showed that when 4 L of water was manually poured onto the roofs, an average of 60.4% of water was retained on sloped roofs whereas 48.4% was retained on flat roofs. Based on the 5-minute interval data, the retention ranges between 55.6% and 71.2% for both roofs. In terms of daily rainfall for a week, the average percentage was 69.2% for sloped roofs and 70.6% for flat roofs. All three approaches show that the green roofs produced less water runoff compared to normal roofs with both slopes retained water efficiently. Therefore, rainfall runoff performance for two types of green roof slopes was investigated and the available storage for the green roofs was recorded. In conclusion, with little maintenance, non-monitored green roofs can be efficiently used as a water mitigation system for urban areas.

1. Introduction

The hydrological cycle is the process of water changes from the oceans, rivers, lakes and any water bodies, in the form of precipitation, transpiration, percolation, infiltration, run-offs and its return to the source areas [1]. The most readily available source of water with the highest volume is groundwater, followed by lakes, reservoirs, rivers and wetlands [1-2].

Urban areas are mostly covered with concrete and solid surfaces that are impermeable and impervious surfaces have been increasing. Urban development has also reduced the natural spaces that normally retain water before it turns into runoff and significantly changes the natural hydrological cycle. Rainwater will turn into runoff faster in urban areas compared to natural areas. Decreasing permeable areas had reduced infiltration volume and increased runoff production [3]. Increasing runoff means increasing the probability of peak flow and volume of flood in urban areas, where higher volume of rainfall becomes runoff compared to the volume of rainfall infiltrating the soil layer.

The urban drainage system has the potential to be improved by sustainable development known as Sustainable Urban Drainage System (SuDS) where the aim of this system is to design, manage and provide storage for water quantity (flooding), water quality (pollution), biodiversity (wildlife and plants) and the amenity of urban areas [4]. One of SuDS structure is green roof. Green roofs have been an
increasingly popular structure used globally for urban stormwater management in order to promote SuDS [5-8]. Green roofs have the potential to reduce peak flows and runoff volume which help to reduce flooding events [5-8]. Vegetation planting on wasted roof areas has the potential to manage stormwater at source by reducing a small amount of the volume per roof area and delaying the velocity flow of stormwater runoff before reaching downstream.

Green roofs act as a storage structure for retaining water in the green roof layer. A green roof is also known as a vegetative roof that consists of plants and soil layers on the roof surface which is normally constructed for its aesthetic values. Green roofs have increasingly been chosen over conventional roofs due to its benefits towards the environment [9]. However, [10] it has been reported that the dynamic state of living roof systems that experience growth and changes due to weather, plant species competition and insect disease may reach its maturity due to the aging process and maintenance regime. The preliminary work by [11] also found that older extensive green roofs are correlated with substrate properties (pH, organic matters, depth and nutrients) and vegetation (cover abundance and species diversity) where lower soil pH, less biomass, less substrate depth and greater soil organic content were observed compared to the younger roofs [11]. Fortunately, [12] also reported that the hydrological performance of their green roofs has not declined after 5 years of operation. In fact, they found that the aged substrates have properties that enhanced hydrological performance.

Although this paper has not extensively explored the properties of aged substrates and their compositions, the preliminary performance of rainfall runoff and the physical characteristics of unmonitored green roofs were examined.

2. Materials and Methods

2.1 Data collection

Four green roof test beds with a dimension of 60 cm (L) × 60 cm (W) × 15 cm (H) were constructed in 2015 in Universiti Tun Hussein Onn, Malaysia, Parit Raja, Batu Pahat Johor. The substrate media consists of perlite, vermiculite and peat soil at a weight ratio of 3:5:2 and a depth of 80 mm. Based on its attractive flowers, easy and rapid grow, drought tolerance and its ability to survive under bright sunlight, the low-cost, succulent flowering plant *Portulaca Grandiflora* was used for the vegetation layer.

The test beds were used to simulate the typical roof housing/building with the top roof area for green plantation and the gutter for runoff water collection, as well as its downspout system for rainfall runoff measurements. The four green roof test beds were constructed based on two types of slope gradients; two sloped roofs at a 30° gradient (Figure 1a) and two flat roofs at a 10° gradient (Figure 1b). Different roof slopes indicate the typical types of roof slopes in Malaysian housing developments (the steep roofs), where flat roofing resembles the top roof of high buildings. In this experiment, one of the roofs functioned as a control roof for each gradient (empty with no substrate and vegetation layer) to simulate rainfall data collection. Meanwhile, the other roof contained the substrate and vegetation layer for runoff data collection. Comparisons were made between the control roof (rainfall) and the green roof (runoff) for each slope gradient.
3. Results and Discussion

As mentioned above, for the purpose of examining and verifying the test beds for further monitoring activities, maintenance activities were done for four experimental roofs which are i) onsite inspection on the roof’s physical characteristics; and ii) examination and verification of the rainfall runoff data performance.

3.1 Physical characteristics of the test beds

i. Vegetation layer: Figure 2a – 2b shows the growth and health progress of the vegetation layer. Figure 3a shows healthy Portulaca G. when they were first planted on the roofs. All the vegetation was in good condition during the first year in 2015-2016, with good nutrition from fertilisers and watering. Since December 2016, no monitoring was conducted on these roofs, and the condition of the vegetation after one year without any monitoring and fertilisation is shown in Figure 2b(i). The substrate media was almost full of weeds, and a few of the Portulaca G. were still trying to survive together with the weeds. It also seemed that they had grown longer. Later, the weeds were removed and the vegetation layers were watered, fertilised and replanted (the same long Portulaca G. were used and replanted on the cleaned soil areas). It seemed that the vegetation can grow healthily and flower again as seen in Figure 2b(ii).
Figure 2a. Vegetation layer condition during test bed development – after one week of plantation (September 2015)

Figure 2b. (i) Vegetation layer condition after 1 year (November 2016) (ii) Vegetation layer condition after some maintenance (March 2017)

ii. Roof structure: The main purpose for the roof structure examination is to check on the leaking points. The roofs were poured with water from a pipe until it was saturated and the wet areas (that should not be wetted) due to leaks were observed. All the leaking points spotted were then repaired by filling the leaking gaps with silicone fillers.

3.2 Verification results – Manual collection using 4 litres of water

After a few weeks of maintenance, the first examination and verification of the data were done manually. The first preliminary experiment was conducted on 20/3/2018 (Figure 3). The average percentage of retention for the sloped green roofs had a water retention of 60.5% while the flat green roof had a water retention of 48.1%. Table 1 shows the summary of the experiment results on 20/3/2018 and 25/3/2018. The data shows the time to start runoff, time to start peak flow, peak flow reduction (between rainfall and runoff) and rainfall retention. The highest rainfall retention of flat roofs occurred during the experiment on 20/3/2018, was the first experiment (after few days of dry days) at 9.30 am with water retention percentages of 77.3% and 73.3% for flat roofs and sloped roofs, respectively.

Figure 3. Examples of cumulative rainfall runoff with different dry days (during short intervals) on 20/3/18 at (a) 9.30 am; and (b) 10.30 am
The second preliminary experiment on 25/3/2018 (Table 1) resulted in average water retention percentages of 60.4% for sloped green roofs and 48.7% for flat green roofs. After 5 days of dry days, the highest rainfall retention of flat roofs during the experiment occurred at 9.00 am with water retention percentages 74.8% and 72.9% for flat roofs and sloped roofs, respectively. Both experiments show that slope roofs retained more most of rainfalls than the flat roofs, but peak flow reduction were varies between roofs. It seems that both roofs can retained not more than 80% of the rainfall (of 4 L volume), and the variety values found in peak flow reduction, may be due to the technical issues on the experiment itself. Slope roofs also delays runoff more than 120 s, while flat roof delays runoff at minimum of 60 s. The roofs also delay the time for runoff to start peak flow compared to peak flow of rainfall more than 30 s.

**Table 1. Summary of runoff results from the preliminary examination test on 20/3/2018 and 25/3/2018**

| Date & Time     | Time to start runoff (s) | Time to start peak flow (s) | Peak flow reduction (%) | Rainfall retention (%) |
|-----------------|--------------------------|-----------------------------|-------------------------|------------------------|
|                 | Flat | Slope | Flat | Slope | Flat | Slope | Flat | Slope |
| 20/3/18 9.30 am | 210  | 180   | 210  | 30    | 65.7 | 66.7  | 73.9 | 72.2 |
| 20/3/18 10.30 am| 60   | 120   | 150  | 150   | 57.8 | 22.7  | 42.4 | 54.9 |
| 20/3/18 12.30 pm| 60   | 150   | 120  | 120   | 41.4 | 51.9  | 39.5 | 54.5 |
| 20/3/18 4.30 pm | 120  | 150   | 120  | 120   | 50.0 | 26.9  | 36.5 | 60.4 |
| 25/3/18 9.00 am | 210  | 180   | 90   | 90    | 66.1 | 65.6  | 74.8 | 72.9 |
| 25/3/18 10.00 am| 60   | 120   | 60   | 90    | 33.3 | 49.2  | 41.0 | 54.0 |
| 25/3/18 12.00 pm| 60   | 180   | 30   | 120   | 35.9 | 47.1  | 40.1 | 57.3 |
| 25/3/18 4.00 pm | 120  | 180   | 60   | 210   | 38.3 | 50.9  | 38.8 | 57.4 |

3.3 Verification results-Manual monitoring at 5-minute intervals and daily intervals.

For the monitoring process with a 5-minute interval, only two rainfall events were collected on 22/4/2018 and 1/5/2018 (Figure 4). All the roofs were monitored simultaneously whenever rainfalls occurred, with empty roofs representing rainfall data and vegetated roofs representing the runoff data. Table 2 presents the summary of rainfall runoff performance for these rainfall events. It seems that for local rainfalls, it takes at least 5 minutes for both roofs to start runoff and the green roofs delays the peak flow at minimum of 5 minutes. Peak flow and rainfall retention values for the flat roofs seems less than the sloped roofs for both events with differences not more than 10%.

**Table 2. Summary of results for rainfall event on 22/4/2018 and 1/5/2018**

| Date & Time | Time to start runoff (min) | Time to start peak flow (min) | Peak flow reduction (%) | Rainfall retention (%) |
|------------|---------------------------|-------------------------------|-------------------------|------------------------|
|            | Flat | Slope | Flat | Slope | Flat | Slope | Flat | Slope |
| 22/4/18    | 5    | 10    | 10   | 5     | 37.7 | 45.6  | 55.6 | 59.6 |
| 1/5/18     | 10   | 5     | 20   | 15    | 76.4 | 78.3  | 65.0 | 71.2 |
For daily rainfall events, the data was collected between 2/5/2018 and 8/5/2018. The observations were conducted daily at 8.00 am and 5.00 pm for all roofs and the values of these runoffs were totalled as the rainfall runoff of the day. During seven days of observation, there was rainfall on 4 days and 3 days without rainfall. Out of 4 rainy days, only one day had more than 1 rainfall. Three consecutive rainfalls occurred on 6/5/2018 at 2.20 - 3.00 pm, 6.50 - 7.20 pm and 9.00 - 9.30 pm.

Figure 5 shows the daily performance of the roofs for a week. The total rainfall on 2/5/2018 was 0.0544 mm and the water retention percentages for sloped roofs and flat roofs were 83.3% and 84.4%, respectively. On 3/5/2018 and 4/5/2018, lesser rainfall was recorded, namely 0.0234 mm and 0.0321 mm, respectively. The water retention percentages were still between the range of 80% – 83% for both roofs, namely 80.0% and 81.8% for sloped roofs and 82.5% and 82.7% for flat roofs on 3/5/2018 and 4/5/2018, respectively.

Due to the occurrence of three consecutive rainfalls, the highest total rainfall event on 6/5/2018 was observed at 0.1087 mm. A reduction in water retention was observed at 31.7% for the sloped roof and 32.8% for the flat roof. It seems that the water retention for both green roof slopes was quite similar but there was a slightly high retention observed in the flat roofs. The difference was only 1% for every rainfall event. Both roofs can also efficiently retain water during moderate and light rainfall as both roofs retained more than 50%. For higher total rainfall, less water retention was observed as only 31% - 33% of water was retained by both roofs. However, more data is needed in order to measure the efficiency of the roofs in retaining water.
All roofs were tested simultaneously so that they experience the same rainfall runoff condition. Vegetated roofs produce less runoff compared to conventional roofs. This proves that the green roofs are able to provide storage capacity and have a good ability to retain rainfall in the soil layers even though the dry time between two rainfall events was less than 6 hours. The green roof also acts as sustainable drainage that releases the remaining rainfall water gradually to downstream in term of time and volume. Thus, it will give time for rainfall to disperse from the upstream and prevent flash flooding at downstream. Overall, both slopes exhibit the ability and the efficiency of green roofs in retaining rainfall.

4. Summary

Through the experiments, the efficiency of rainfall runoff performance of green roofs was measured by indicating the percentage of water retained. Based on the results, an average water retention of 60.4% was obtained for sloped roofs whereas an average water retention of 48.4% was obtained for flat roofs when 4 L of water was used. During the rainfall with 5-minute intervals, there was a similar ranges of retention between 55.6% and 71.2% for both roofs. An average retention of 69.2% was obtained for sloped roofs and an average retention of 70.6% was obtained for flat roofs from daily rainfall for a week. All three approaches show that the green roofs produced less water runoff compared to normal roofs with both slopes retained water efficiently. However, further observation on the substrate and vegetation properties may be needed. The results also prove the potential of green roofs to be used in urban stormwater management for long term operation, especially for flash flood problems.

5. References

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