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Green Roof for Stormwater Management in a Highly Urbanized Area: The Case of Seoul, Korea

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Received: 26 December 2017; Accepted: 21 February 2018; Published: 26 February 2018

Abstract: Urbanization changes natural pervious surfaces to hard, impervious surfaces such as roads, buildings and roofs. These modifications significantly affect the natural hydrologic cycle by increasing stormwater runoff rates and volume. Under these circumstances, green roofs offer multiple benefits including on-site stormwater management that mimics the natural hydrologic conditions in an urban area. It can retain a large amount of rainwater for a longer time and delay the peak discharge. However, there is very limited research that has been carried out on the retrofitted green roof for stormwater management for South Korean conditions. This study has investigated the performance of retrofitted green roofs for stormwater management in a highly urbanized area of Seoul, the capital city of Korea. In this study, various storm events were monitored and the research results were analyzed to check the performance of the green roof with controlling the runoff in urban areas. Results also allowed us to conclude that the retention mainly depends on the intensity and duration of the rain events. From the analysis, average runoff retention on the green roof was 10% to 60% in different rain events. The application of an extensive green roof provides promising results for stormwater management in the highly urbanized area of Seoul.

Keywords: green roof; stormwater management; flash flooding; storm events; rainfall runoff

1. Introduction

Green Roof as a Mitigation Strategy for Urban Water Related Problems

In the natural environment, ground surfaces allow water infiltration [1] which balances groundwater supply and water quality. Surface runoff has decreased to a relatively low level because most precipitation events are not large enough to fully saturate the ground soil. However, urban impervious areas such as roads, buildings and roofs produce significant stormwater runoff under the big storm events that may cause flash flooding and other water-related problems. In the developed urban areas, roof surface areas account for 40–50% of all total impervious surface areas [1,2]. Therefore, it is very important to consider roof areas while designing the drainage system for an urban area. Under these circumstances, the green roof is considered an effective technique to reduce runoff and peak flows because it has the ability to retain stormwater in the soil and the vegetation medium for a long period of time as compared to a control roof approach [3–6]. Green roof may detain the rainwater for the longer period of time, thus can reduce the risks for flash flooding problems in urban areas [6].

A green roof is also generally referred to as vegetated roof/living roof and eco-roof [7–13]. It can retain the runoff for a longer period of time than a common roof [2,6]. It can delay peak discharge time [2,6,14] and can also extenuate peak discharge volume [2,6,14,15]. Consequently, past research has suggested that green roof may be a useful approach to mitigate the combined sewer overflow (CSO) and flash flooding problems in urban areas [6,16,17].

Typically, a green roof consists of three layers: vegetation, substrate and drainage. The green roof can be classified depending on the depth of the substrate layer and can be named as extensive roofs and intensive roofs. Extensive roofs generally have a substrate depth of less than 150 mm and the intensive roofs have thicker substrate. Green roofs provide an opportunity to retain the stormwater for a longer period of time in urban areas (Figure 1). At first, the rainwater is stored in soil media and then to the vegetation layer of the green roof, which normally helps to reduce the peak flow and volume as compared to the conventional roofs as manifested in Figure 1. Green roof vegetation also allows evapotranspiration (EV) [16], which can also help to reduce the runoff volumes as compared to the conventional roofs where evapotranspiration (EV) is almost zero. Figure 1 shows the runoff peak and volume delay by using green roof in an urban area. As indicated below, the green roof is an effective approach to decrease runoff and to increase the time of concentration as compared to a conventional roof in urban areas. In addition, it can also help to reduce the total runoff volume reduction in the urban drainage system.

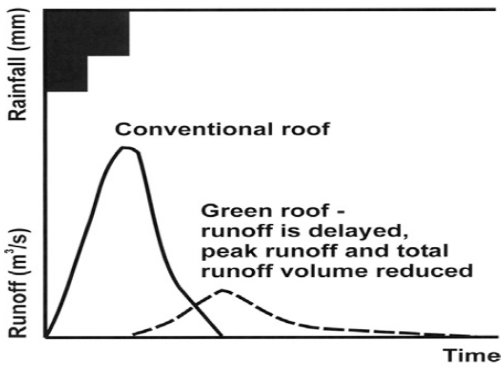

Figure 1. Rainfall runoff response of the green roof and conventional roof [2].

On the other hand, green roofs also have the ability to extend the life of building roof [18], improve the air quality, enhance the aesthetic value of the building architecture and improve the biodiversity [19]. Green roofs are not a new technique (Köhler, 2004 [20]), 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 [21]). However, in South Korea, the law of "low carbon green growth building code" [22] strongly endorses green roofs as a Low Impact Development (LID) technology to achieve safer and more sustainable cities. Low carbon green growth recognized the guidelines related to the use of green roof in the building architectures [22]. However, the use of green roof was limited because of higher construction costs, lack of proper design and suitable guidelines in Korea. Recently, the Korean government has been encouraging the use of green roof by giving incentives (by providing construction costs) to the public to develop cities safe, sustainable and resilient to the climate change.

The main potential of green roof is noted in the rainfall runoff management, which may reduce the outflow volume (volume reduction), losses of water from the vegetation and the evapotranspiration process from vegetation at different time periods. Previous studies reported the hydrologic performance of extensive green roofs in terms of runoff reduction volume and peak runoff delay when compared to conventional roofs [23–28]. The average runoff retention value monitored from the past studies comes to light on an average 67%, although it generally ranges between 50% and 80% (Table 1). The percentage of runoff retention is usually defined as the percentage of the total rainfall control by a green roof following a rain event [29]. The prominent difference in retention results may be observed from different extensive green roofs depends on the multiple factors such as climate conditions, roof designs, green roof slope, duration of study, depth and type of substrate of green roof, vegetation types and the life of the green roof [2,24,27,29]. The stormwater management performance of the green roof is different under the different compositions of green roof and climate conditions (rainfall events intensity, duration etc.) [2,3]. Furthermore, the antecedent dry weather period (ADWP) is also considered a prominent factor which affects the hydrologic performance of the green roof [15].

Table 1. The reported average runoff retention value (%) from different green roofs studies.

References	Runoff Retention Value Observed (%)	Location
Stovin et al. (2012) [2]	50.2	Sheffield, UK
Stovin et al. (2013) [3]	59.0	Sheffield, UK
Seters et al. (2009) [23]	63.0	Toronto, Canada
Fioretti et al. (2010) [24]	68.0	Northwest and Central Italy
Palla et al. (2011) [25]	68.0	Genoa, Italy
Carter and Rasmussen (2006) [26]	78.0	Georgia, USA
Morgan et al. (2013) [27]	50.0	Michigan, USA
Getter et al. (2007) [28]	80.8	Michigan, USA
Carpenter and Kaluvakolanu (2011) [29]	68.3	Michigan, USA
Fassman-Beck et al. (2013) [30]	56.0	Auckland, New Zealand
Bengtsson (2005) [31]	62.0	Lund University, Sweden
Mentens et al. (2006) [1]	76.0	KU Leuven, Belgium
Köehler (2005) [32]	77.0	Univ. of Neubrandenburg, Germany
Centgraf (2005) [33]	64.0	Technical University of Berlin, Germany
Tillinger et al. (2006) [34]	80.0	Columbia University, New York, NY, USA
Prowell (2006) [35]	78.0	University of Georgia, Athens, GA, USA
Shafique et al. (2016) [5]	68.0	Seoul, Korea

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) [31] applied the water balance approach to check the hydrologic performance of a green roof at the Lund University, Sweden. The results proved that the green roof can capture a large amount of rainwater and runoff outflow from green roof could be reduced to almost 64%. Other studies also showed almost the similar results in runoff retention performance from the other green roof. According to the Stovin et al. [2,3] who planted the small green roof in Sheffield (UK). The results have shown the runoff retention approximately to 50–59%. Similarly, Kohler et al. [6] studied the green roof (5 and 12 cm depth) in Germany; and his results indicated that resulting from a large amount of evaporation from the green roof, rainfall runoff can reduce up to 60–80%.

Runoff retention results of the green roofs also depend on the age of the green roof [14,28]. Previous studies showed that the older green roofs can retain more rainfall runoff as compared to the new green roof [28]. An example of this can be found from Getter et al. (2007) [28] experiments, whose results indicated that over a 5-year period, the organic matter content of the green roof's soil substrate was doubled. Therefore, the pore spaces were doubled and it increased the water holding capacity of the green roof. According to the study of Seters et al. [23] the green roof in Toronto, Canada, indicated that the green roof can reduce the runoff outflow to almost 63% as compared to the common roof. Similar results were obtained from the two sites from Italy [24,25], where the green roof reduced the runoff volume almost 68%. Therefore, the application of green roofs will definitely reduce the runoff volume and peak flow delay, thus also helps to mitigate the flash flooding problem in urban areas.

The characteristics of soil substrates are also the most prominent factor in the runoff volume retention. The effect of plant/vegetation is a much less important factor in retention as compared to substrate of green roof [15,35]. However, for a green roof vegetation plays a more important role to enhance the evapo-transpiration rate, which can help to cool the building by lowering the outer temperature [8,18,29]. Carter and Rasmussen (2006) [26] applied the green roof at the University of Georgia, USA to evaluate its performance for runoff reduction. Runoff retention was monitored from 31 storm events. The results indicated that the green roof has the ability to hold rainfall for longer period and can retain to almost 78% of runoff as compared to the common roof. A similar procedure was followed for other studies in the USA, i.e., [27–29,34] and the runoff retention results from the green roofs reduced runoff almost 50–80% respectively.

Volume detention (temporary water storage in the substrate and slow release of water) calculates the attenuation and delay of rainfall runoff peak flow at the inflow to the sewage system. The selection of green roof soil media depth is a very important factor to reduce the peak outflows. By using green roofs peak outflows was reduced to 20–75% in the above Table 2. Fassman-Beck et al. [30], monitored the hydrologic performance of four extensive living roofs in Auckland, New Zealand. In those four green roofs, 50–150 mm depth of the substrate was used over synthetic drainage layers. The research results indicated that the soil substrate depth has a great impact on the runoff retention performance. During the analysis, it was also found that green roofs could reduce 56% of runoff as compared to the conventional roofs [30]. Shafique et al. [5] retrofitted the green blue roof in the highly populated area of Seoul, Korea for runoff reduction. The results indicated that the green blue roof can reduce runoff up to 68% as compared to the common roof. From the above-mentioned studies, it is noted that the green roofs have the ability to reduce the peak flow volumes in the urban areas. Green roofs are the sustainable stormwater management practices as it can transform urban impervious roof areas to the pervious area (by using green roof) which may help to reduce water related problems in urban areas.

Up to date, the most of the green roof hydrologic studies in Korea are carried in the laboratory by using artificial storm events [36,37]. In additions, only a very few studied were carried out in real storm events [5]. Therefore, there is a high need to carry out more research on the real time scenarios to check the hydrologic performance of green roof in different rainfall events. Similarly, retrofitting green roof is a relatively new concept in South Korea, there is a lack of written work on how to retrofit green roof's performance and how to tackle stormwater management in highly urbanized cities. The main purpose of this study was to evaluate the rainfall retention of a retrofitted extensive green roof in Seoul city, Korea. Different storm events were monitored on the green roof and performance was evaluated for runoff retention in a highly urbanized area. This study will also provide useful data which determine the stormwater management performance of retrofit extensive green roof in Seoul, Korea and encourage the public and private sectors to adopt the green roof as the sustainable stormwater approach to reduce the flash flooding problems and to reduce the load risks on the combined sewage systems in urban areas.

2. Study Objective and Approach

The main aim of this study is to check the performance of green roof for rainfall runoff attenuation in a highly urbanized area of Seoul, Korea. This study also measured the green roof performance to capture rainfall runoff during different storm events to reduce flooding problems. The key objectives of this study are as follows.

- To install the green roof to evaluate its potential for stormwater management in highly urbanized area.
- To quantify the rainfall runoff retention properties of the retrofitted green roof in Seoul, Korea.

3. Material and Methods

3.1. Site Description

Seoul is the major city and the capital of the Republic of Korea with a population of almost 10.93 million [38]. Generally, the main cause of flash flooding in the Seoul city is the big storm events for the longer period of time [39]. This study determines the stormwater mitigation performance of the retrofitted green roof that consists of different combined assemblies of dimensions (0.5 × 0.5 × 0.2 m each). A green roof was installed on a building rooftop of police administration building Jongno-gu, Seoul, Korea. The maximum rainfall at the site was noted around 1300 mm per year with highest and lowest monthly average temperature variations (15 °C and 31 °C) [40].

Table 2. Climate conditions and site characteristics of the green roof.

No.	Characteristics	Seoul, Korea
1	Underlying roof type	Conventional concrete
2	Latitude, longitude (°)	37°34′ N 126°56′ E
3	Roof area (m^2)	663
4	Yearly rainfall (mm)	1100~1360
5	Monthly average temperature	15 °C to 31 °C
6	Climate region	Humid continental (warm summers, cool winters)
7	Plant used in green roof	Sedum with mix vegetation
8	Soil media depth	30 mm
	Soil composition	Natural soil and organic matter
	Insulation layer depth	40 mm

The green roof was retrofitted on an open arrangement of 3-storey buildings. This building was situated in the urbanized areas of Seoul that consist of high to middle rise buildings. A total open surface area of the building was around 881 m^2. Figure 2 show the extensive green roof location in a highly populated area of Seoul, Korea. The green roof consists of vegetation and soil substrate layers which were placed in the 'square box' as shown below.

Figure 2. Show the overview of the green roof.

3.2. Experimental Setup Detail

Extensive green roof has a total surface area of around 663 m^2 was established on the flat rooftop of the police administration building Jongno-gu, Seoul, Korea (approximately 25 m above ground level). The extensive green roof modular consists of square assemblies (dimensions 0.5 × 0.5 × 0.2 m each). All these assemblies are connected with each other to cover the total area of around 663 m^2. Sedum with mix vegetation is used as the vegetation layer in this green roof. This green roof has more than 85% vegetation that are grown on 30 mm soil media depth (GR-Soil). Green roof substrate consists of natural soil (clay, sand, silt and gravel) with organic matter and has a density of about 1.2 g/m^3 and porosity around 40%. In green roof design, 20 mm drainage mat with a 40 mm insulation layer was used for the easy drain of the extra water from the green roof in big storm events. The green roof is connected to a big drainage pipe to drain overflow water from the green roof to the ground as shown in Figure 3. This green roof does not require any irrigation system. The first rainfall runoff water retention and moisture content was measured at the small modular as shown in Figure 3b and then the rainwater flow from the entire green roof was measured at ground surface as shown in Figure 3c point 2. Different real storm events were monitored and the results were analyzed to check the performance of the green roof.

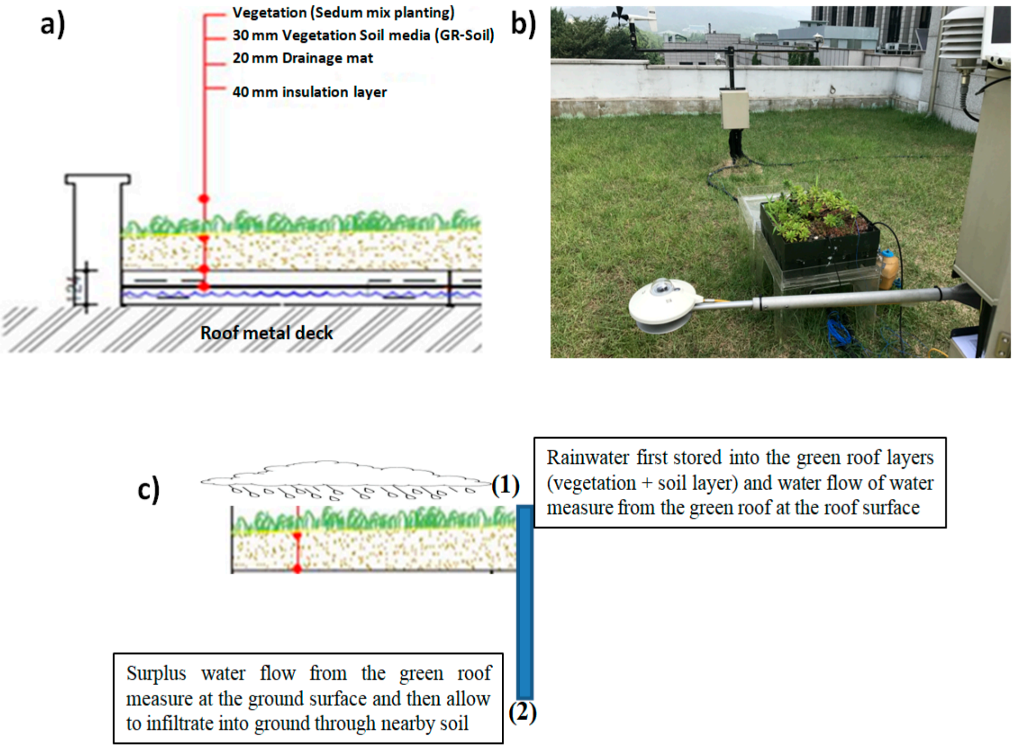

Figure 3. Shows the detail of the green roof, (**a**) explain the layers depth of the extensive green roof; (**b**) real site image; (**c**) explains how water in capture and distribute through the green roof, where point 1 and 2 are rainwater flow monitoring points; (1) is on the green roof and; (2) measuring the overflow of the green roof at the ground surface.

3.3. Overview of Data Record

The extensive green roof was installed in June 2015. The green roof rainwater runoff was monitored for around 6 months of continuous rainfall data (June–November 2017). Continuous measurements rainfall runoff retentions were taken to a comprehensive evaluation of green roof stormwater mitigation performance during real storm events in the Seoul metropolitan area. The most of the data was recorded using different storm events when the rainfall is big enough to easily estimate the effect of the green roof to detain a large amount of rainwater for a longer period of time. Figure 4 explains the overview of the runoff management procedure at the site. Rainfall runoff first collected in the green roof (vegetation + soil layer), then surplus water is flowing through the connected pipe and goes to the ground surface for infiltration into the ground. The location of the ground water level already checked and it allows water to infiltrate to ground surface near the building area. Then the excess amount of water is entered into the sewage system.

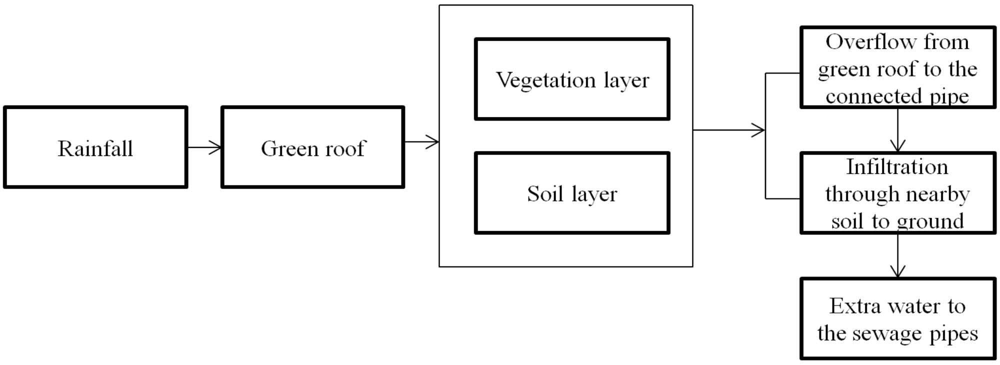

Figure 4. Schematic procedure for the rainfall runoff management at the site.

3.4. Data Collection and Analysis

Rainfall was measured through the Korea Meteorological Administration (KMA) data [40] during the study whole period. The uncertainty in rainfall data which was collected from KMA was found to be less than 10% during the analysis. Over the period monitored from June to November 2017, different storm events (minimum intensity 60 mm/h—maximum intensity 120 mm/h) were recorded at the Seoul, Korea green roof site. This site is equipped with a weather station (for water flow, soil moisture, humidity and temperature measurement) with different hydrologic devices for continuous monitoring outflows from the green roof. Ultrasonic open channel flow meters, venire soil moisture sensors and OTT Orpheus mini water level loggers (Model DT80) were installed on the internal surfaces of the green roof. Green roof discharges were measured at the green roof surface and at the ground surface. Water flow and soil moisture contents also measured from the green roof with the help of the above-mentioned devices. Rainfall data were measured from the KMA data site by selecting the nearest rain gauge [40]. Total retained rainfall runoff on the green roof during different storm events is analyzed in this study.

Retention is expressed as the percentage of rainfall stored in green roof and is calculated by the following formula [41]:

$$\text{Retention } (\%) = \frac{\text{Rainfall (mm)} - \text{Runoff (mm)}}{\text{Rainfall (mm)}} \times 100 \quad (1)$$

4. Results

4.1. Rainfall Runoff Attenuation

The rainfall runoff outflow of the green roof was observed over a period of 3 days (24 June 2017 to 27 June 2017), during which different rain events occurred. Rainfall retention of green roof was observed on the green roof as shown in Figure 5. There rain events were used to demonstrate the green roof's ability to reduce peak runoff, delay peak runoff and distribute runoff over a longer period of time. During the rain events, the rainwater retains and store in green roof layers and excessive rainwater flow from the green roof to the ground surface. The 24 of June was a day when there was no rainfall, therefore there was no runoff outflow observed from the green roof. Various storm events of intensity about 30 mm/h were observed on the 25th of June. Therefore, the runoff outflows of the green roof began to start (Figure 5).

The 26 June 2017 rainfall events were observed with rainfall intensity of about 50–100 mm/h. During this long-term rainfall event, the rainfall runoff outflow response of the green roof began to increase rapidly and the green roof outflow was increased from 0.2 to 1 L/s (Figure 5). The main reason for the runoff outflow increase is that the green roof substrate was fully saturated and does not have the capability to retain more rainwater. This can be clearly seen on the right side where the results are shown more precisely. During this analysis, it was found that the outflow from the green roof is less than 10% to 60% as compared to actual rainfall runoff. This will help to capture more rainfall runoff in green roofs and hence reduce the surface rainfall runoff in urbanized areas. As a result of this, flash flooding problems were reduced.

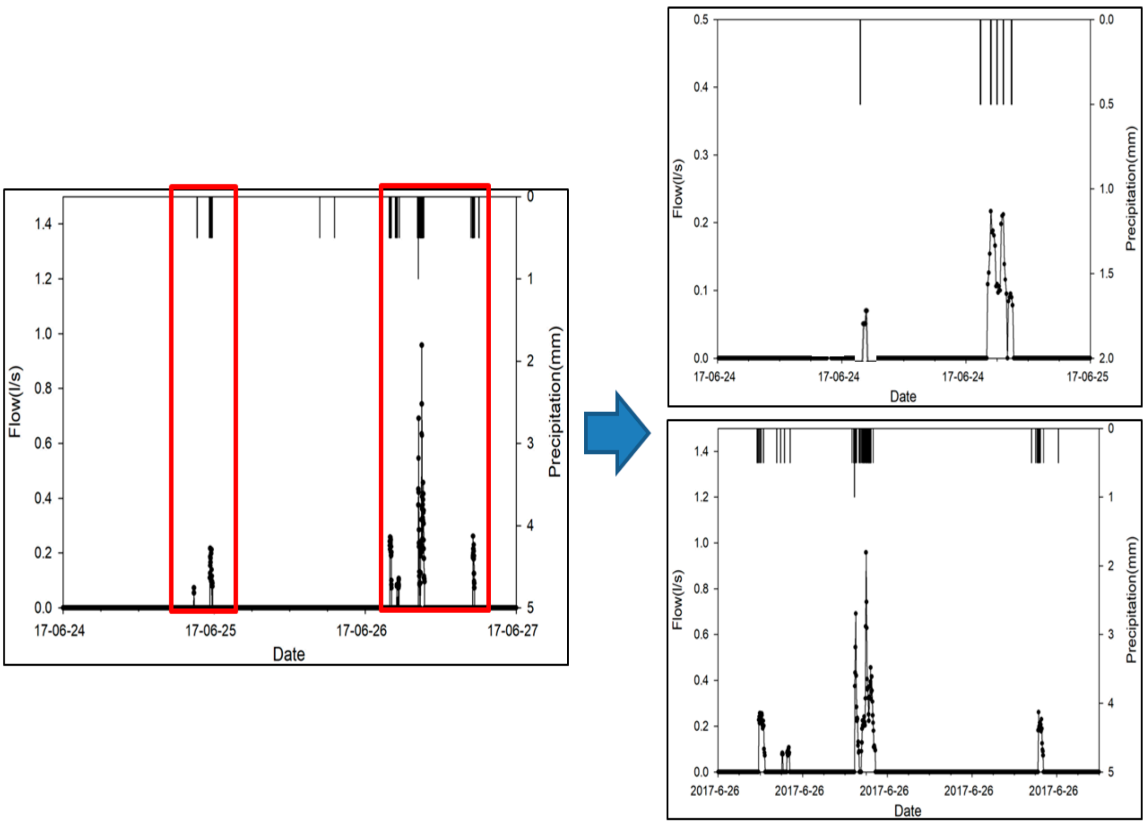

Figure 5. Shows the rainfall runoff outflow from green roof during the various storm events of 24–27 of June, 2017.

4.2. *Overflow Outflows Measurement at the Ground Level*

Rainfall runoff during the different rain events were detained in the entire green roof. However, excessive water overflows were collected through the connected pipe and was diverted to the ground surface. The overflow at the ground surface was measured to check the excess amount of rainfall runoff during the rain events (intensity 60 mm/h–120 mm/h). This is because, when the soil of the green roof becomes fully saturated then it allows the excessive water to flow to the ground surface. The results indicated that the excessive outflows from the green roof were found at 2 L/s during the storm events (intensity 120 mm/h) as shown in Figure 6d. Similar results followed as shown in Figure 6e where the maximum outflow value was 0.5 L/s. The excess outflow normally depends on the intensity and the duration of the rainfall. Therefore, if the green roof soil becomes saturated enough, then most of the rainwater will overflow from the green roof. At the ground surface, the excessive water from the green roof is diverted to the nearby soil to infiltrate into the ground.

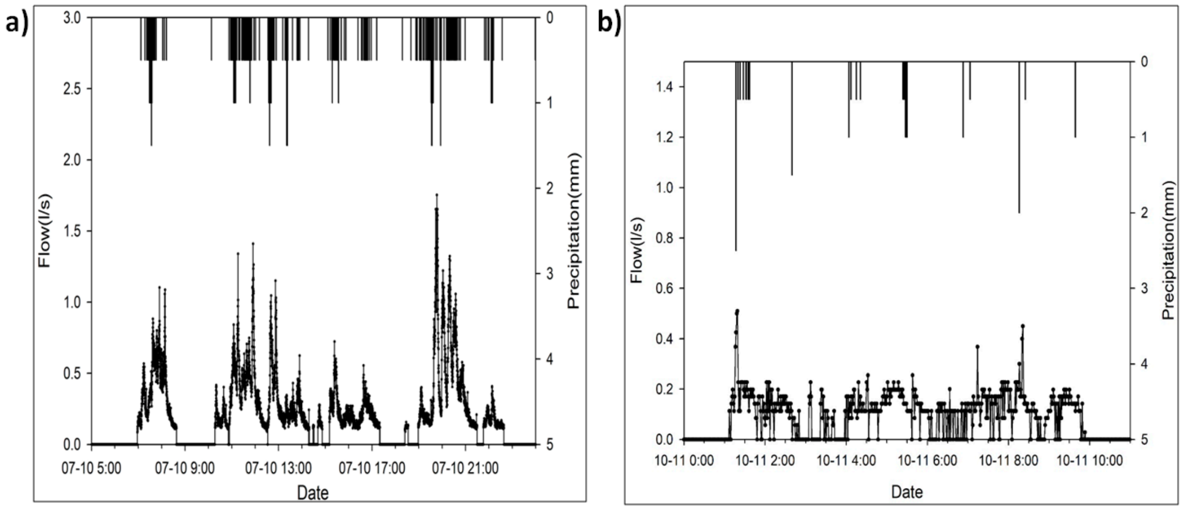

Figure 6. Shows the overflow outflows of the green roof that were measured at the ground surface, (**a**) storm event of 10 July 2017; and (**b**) storm event of 11 October 2017.

4.3. Water Level Measurement in Green Roof

Green roof is a sustainable stormwater 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 events.

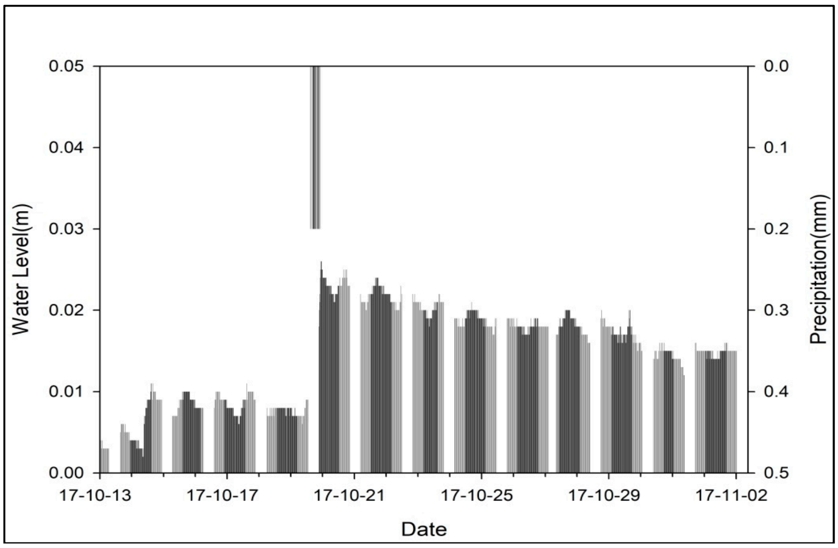

Figure 7. Surface rainwater retention of extensive green roof (13 October–2 November 2017).

4.4. Soil Moisture Measurement during Different Rain Events

Figure 8 shows the changes in the soil water content (%) of the green roof, as influenced by different storm events. The plant increases the evapotranspiration and causes the change in soil moisture content of the green roof. Soil moisture was measured with the help of a venire soil moisture sensor from the green roof during a storm event (intensity of storm event about 50 mm/h to 120 mm/h) of August 19 to September 12, 2017. From the analysis, it was concluded that the in case of large storm event soil with an intensity of about 120 mm/h the moisture value 30%, which is greater when compared with a small rain event where the soil moisture was found to be only 15% (Figures 8 and 9). Figure 9 below shows that the soil water content varies in different storm events. Results also showed that the substrate green roof retained more rainwater during big rain events, which resulted in more water content. This study also indicated that green roof is very helpful in detaining a large amount of water in soil media and hence contributing to reducing the chances of flash flooding in urban areas. Figures 8 and 9 show the percentage of water in green roof soil during the different storm events.

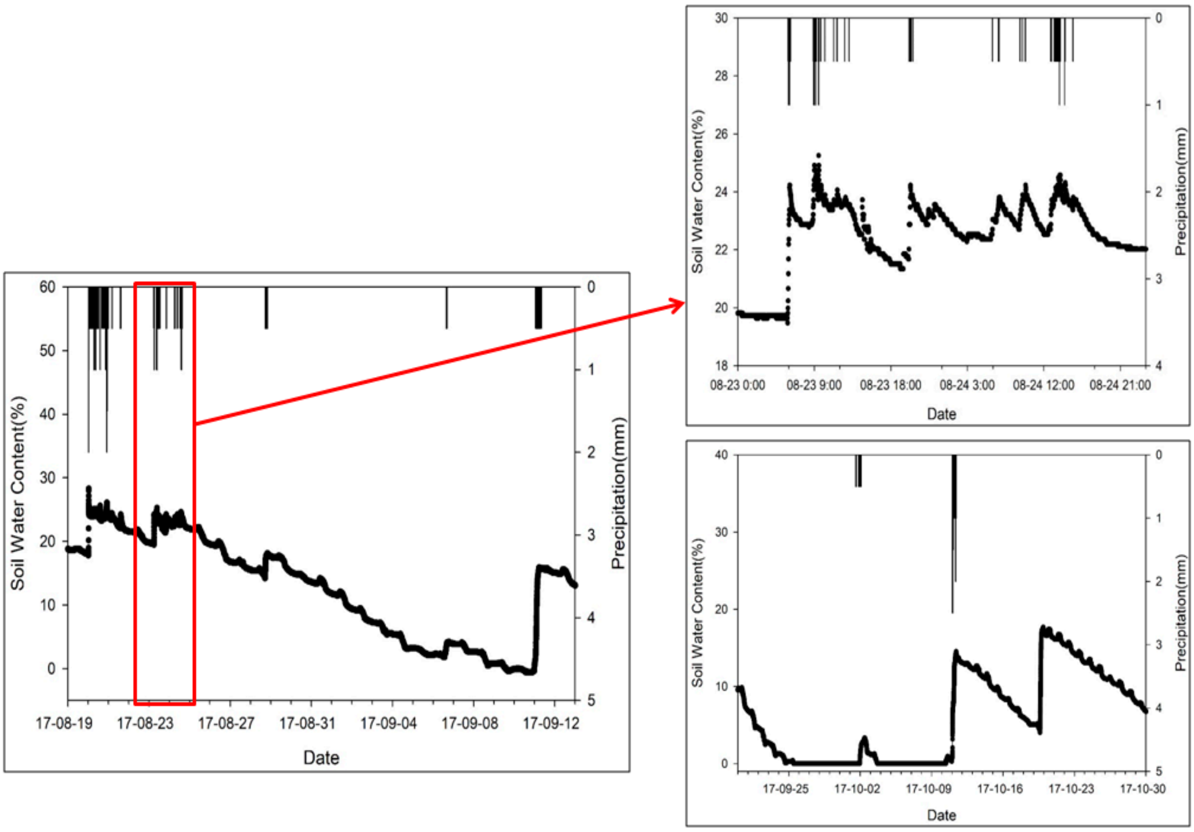

Figure 8. Green roof soil moisture content measurement in a time period of 19 August–12 September 2017.

The obtained results confirm that the retrofitting green roof was very effective, which coincided with the series of the previous research results, indicating that the green roofs can reduce the risks of flash flooding in urban areas. For example, Seters et al.'s study of the green roof in Toronto, Canada, indicated that the green roof can reduce the runoff outflow to almost 63% as compared to the common roof [23].

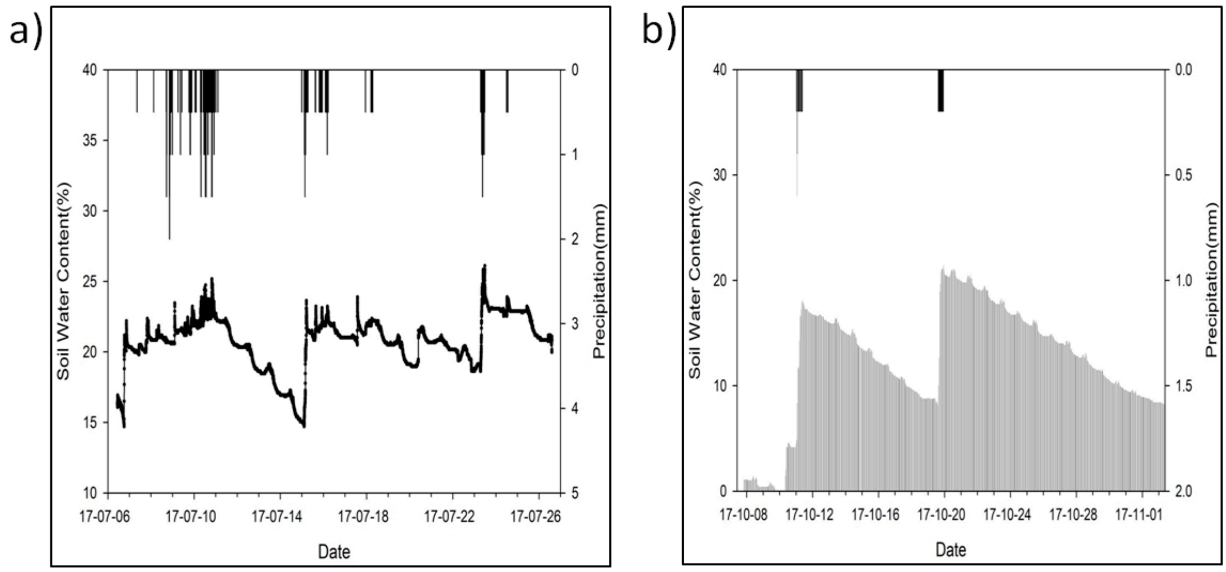

Figure 9. Shows the moisture contents of green roof during different storm events, (**a**) 16 to 26 July; 2017 and (**b**) 8 October to 1 November 2017.

5. Discussion

The main objective of this study was to demonstrate that the retrofitting green roof is a very useful technique for stormwater management in a highly urbanized area of Seoul, Korea. It can capture rainfall runoff for a longer duration and it can minimize the outflow to the sewer system during different storm events. Moreover, the results also demonstrated that the green roof reduced the peak runoff, delayed peak runoff and distributed runoff over a longer period of time.

This study mirrors previous research results [36] and indicates that the retrofit green roof is expected to provide significant improvements in rainfall runoff retention performance over the conventional roof runoff management systems. The retrofit green roof system is expected to retain over 50 % of rainfall runoff on an average of stormwater management. From the analysis of the research results, green roof may retain around 10–60% of the total rainfall runoff. Analysis of different storm events showed the difference in outflow values form the green roofs. Rainfall runoff retention results obtained from green roof were found higher than the Stovin et al. [2], Morgan et al. [27], Fassman-Beck et al. [30]. Therefore, this green roof design is very helpful for stormwater management in Korea. The strategy used in this study is very helpful for reducing flash flooding and for retrieving the natural hydrologic cycle, as the first rainwater is stored in the green roof (vegetation + soil layers), extra water overflow is passed to the nearby ground soil to infiltrate into the ground and then the excess water goes into the sewage system. The soil media layer of the green roof is very important because it can help to capture the rainfall runoff as well as the growth of vegetation. This research emphasizes the importance of retrofitting green roof in South Korea because green roof can provide multiple benefits such as runoff reduction and can also improve the aesthetic value of an area.

This study is focused on the green roof performance for runoff attenuation during different storm events. However, one of the main limitations of the study was that the monitoring of green roof was undertaken only for a certain period of time. There is a need for long term monitoring results to check green roof performance over a larger area. This study was analyzed mostly in the summer period, which is very limited, therefore there is a high need to analyze green roof performance during other seasons as well. This will provide a more accurate picture of its performance with stormwater retention over the longer period. This study only analyzed the stormwater performance of a green roof at the small roof scale. Further work is needed to examine the performance of the green roof at the landscape scale. This could be only achieved if more green roof is implemented to reduce the runoff in an area.

For example, Mentens et al. (2006) [1] noted that if 10% of the entire green roof was applied to the rooftops of buildings in Brussels, it could reduce the runoff of the region to 2.7%. This study also gives an idea of how green roof's extra rainwater outflow can be utilized in a nearby area. In the future, there is also a need to discover more useful combinations of green roofs, which can be applied to achieve multiple benefits.

6. Conclusions

Green roof implementation proved to be a sustainable approach to mitigating the impact of urbanization in developed areas. This study provides a solid background on green roof performance with controlling stormwater in urban areas. Therefore, interest in green roof technology is increasing all around the globe. From the analysis of different rain events, this study has demonstrated the ability of retrofitted green roofs to retain rainwater for a longer period of time. Results indicated that green roof has the ability to hold 10 to 60% of the total rainfall runoff in different rain events. However, after a period of time the outflows from the green roof in big rain events is a larger value as compared to small rain events.

Green roof is an effective strategy for runoff reduction in urban areas. The rainwater is first stored on the green roof and then infiltrates to the ground surface. In this way, it is helpful for delaying the time of concentration and peak flow delay during storm events. As a result of this, it reduces the chances of flash flooding problems in the highly urbanized area. From the research results, the retrofitted green roof has proved to be an effective stormwater management strategy in the context of South Korean climatic conditions. However, further investigations should concentrate on the materials used to construct the green roof, especially the substrate layer and on the maintenance/management problems of extensive green roofs (e.g., fertilizing and irrigations of plants) in South Korea.

Acknowledgments: This research is supported by a grant (15technology innovationC04) from the Advanced Water Management Research Program funded by the Ministry of Land, Infrastructure and Transport of Korean government.

Author Contributions: The paper was guided by Reeho Kim. Muhammad Shafique and Kyung-Ho Kwon monitored the green roof results at the site. The whole manuscript was composed and written by Muhammad Shafique.

Conflicts of Interest: The authors declare no conflict of interest.

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