Comparing the Retention of the Extensive Green Roofs with the Conventional Roof

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Abstract. The inevitable development of cities has necessitated of a searching for new alternative solutions that enable the retention of as much rainwater as possible and increase the biologically active surface in urbanized areas. Green roofs may be the solution to the mentioned problems. The work assessed how meteorological factors influence the retention on two types of green roof substrates. Another practical aspect of the study is determining the difference in retention of mineral-organic and mineral substrate based extensive green roofs. The monitoring of environmental factors and amount of runoff was carried out on two models of green roofs covered by extensive vegetation (moss-sedum-herbs) with substrates of an organic-mineral and mineral composition for 18 months in an urbanized area under moderate climate conditions. Higher values of runoff by approx. 5% were registered in the model with the mineral substrate, which indicates lower retention abilities. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83. Rainwater entering the system of green roofs is the most important input factor in the conceptual model of the retention of a green roof system. The obtained results can provide us with information important to make decisions connected with designing green roofs as far as hydrological advantages are concerned.

Keywords: Extensive green roof · Stormwater retention · Sustainable urban stormwater management

1 Introduction

The progressing development of cities has made it necessary to seek out new alternative solutions which will facilitate the retention of rainwater as well as increase biologically active surfaces in urbanized areas [1, 2]. In many countries, the application of sustainable drainage systems (SUDS) is recommended for the management of rainwater runoff as opposed to traditional pipe drainage systems [3, 4]. Green roofs have the potential to meet these aims and, thanks to this, can work in collaboration with natural environmental processes, contributing to a sustainable urban environment [5–7]. Including green roofs in sustainable drainage systems in urbanized areas, it is

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important to understand, at the design stage, how such roofs function, both in the case of extreme rainfall events (required in the case of flood protection), as well as under during normal rainfalls. Data provided in literature shows that the water retention abilities of extensive green roofs fall within the range of 40–80%, and intensive 80–90% of rainfall depth [8–12]. Retention of 100% for rainfalls of under 2 mm was noted by [13] in Sheffelds (Great Britain) for 9 models of green roofs characterized by different compositions of substrates. On the other hand, for rainfalls of over 10 mm the average retention ranged from 26.8% and 61.8% (depending on the configuration of the roofs). While interregional comparisons can be helpful, one ought to account for factors specific to a given location due to the information necessary for taking decisions regarding the designing of green roofs in terms of rainwater management in urbanized areas [14, 15]. In connection with this, in order to assess the efficiency of green roof systems in Poland, where every year the problem of flooding occurs, more studies in various regions of the country ought to be conducted. The present studies were conducted under conditions of a continental humid climate, where the influence of a large urban agglomeration on the climate is clearly marked. The main novelty of the research was to assess the retention of rainwater by extensive green roofs on the background of conventional roof. Studies on the influence of climate factors on retention on green roofs were also carried out. An extensive type of vegetation was selected because extensive green roofs are the kind of most often applied and require minimum maintenance. This type of green roof, which has the widest scope of application, is affordable and can be constructed on the majority of roofs (even with a slope of up to 45º [16, 17], has significant potential for application in Poland as, among others, a tool aiding the stormwater retention in urbanized areas. Another practical aspect of the studies is determining the difference in retention applying a mineral-organic and mineral substrate. A substrate with a mineral composition was originally prepared to limit P runoff from green roof [17, 18]. The substrate developed from widely available and cheap materials not only decreases P runoff, but allows for proper Sedum development and can be successfully applied in extensive green roofs.

2 Materials and Methods

In the article, results obtained from the vegetation period (IV–IX) in the years 2015–2017 at the area of the Water Centre of SGGW in the southern part of Warsaw were subject to analysis. Models of extensive green roofs were constructed in two cuvettes, one was developed as a reference unit. Each cuvette was drained using an 8 cm diameter drain pipe. All cuvettes have an internal dimension of 2 m/1 m/0.2 m (length/width/depth) and are inclined at an angle of 2%, their internal volume is 0.4 m^3 (Fig. 1). Two types of substrates were used in the green roofs constructions that were implemented in accordance with the [19] guidelines. The characteristics of the green roofs (GR 1–2) and reference (RR) model are shown in Table 1.

Table 1. Characteristics of test models.

Designation	GR 1	GR 2	RR
Extensive vegetation	Pre-cultivated vegetation mat XF317 moss-sedum-herbs; thickness of 2.5 cm (Sedum album, Sedum acre, Sedum kamtschaticum, Sedum spurium, Sedum reflexum, Sedum sexangulare, Dianthus deltoides, Dianthus carthusianorum, and Thymus vulgaris) (Xero Flor 2016)		None
Vegetation layer-an extensive substrate with a thickness of 15 cm	"SPG E-E" - mixture of washed sand, gravel, limestone, crushed red brick, broken fine lime, peat and compost	"SPG E-M - type 1" mixture of washed sand, gravel, limestone, crushed red brick	
Filter layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 125 g/m^2		
Drainage layer	Terrafond Garden drainage mat 20L, height 2 cm		
Protective layer	Polyfelt TS 20 polypropylene geotextile with a GRK 2 strength class, weight 110 g/m^2		
Water insulation	Heat-sealable bitumen sheeting root resistant in accordance with PN-EN ISO 13948		
Underlay	OSB boards with thickness 16 mm with slots not exceeding 5 mm		

Rainfall measurements were carried out using a Hellmann rain gauge, placed next to the measuring stations. Outflows in the months April-September 2015 and April-October 2016 were measured by volumetric method after each rainfall. Since the beginning of November 2016, Odyssey appliances were installed and the outflows were recorded at 10 min intervals. Measurement vessels were calibrated at the Water Centre of Warsaw University of Life Sciences.

Fig. 1. Experimental object

On the basis of the obtained results of the runoff from the green roofs and the reference roof models, the flow coefficients and the amount of retained water were calculated. Measurements of the amounts of precipitation, air temperature carried out in a continuous manner at a weather station situated near the measurement stations. 24-h mean values of the weather parameters prior to the inception of each event were calculated. Based on a conventional approach relying on determining atmospheric precipitation suggested and assumed in other studies of the "green roof" type, rainfall events separated by six or more hours are classified as independent events [20, 21]. There were, however, situations when runoff from a previous event was still ongoing and another event occurred. In such situations, the two adjacent "events" were combined into one. Based on the measurements, a relative daily retention for each container was calculated using Eq. 1 [20]:

$$R = \frac{P - H}{P} \cdot 100\% \quad (1)$$

where:

R - retention [%],
P - precipitation [mm],
H - runoff [mm].

STATGRAPHICS Centurion XIV computer software was used for comparisons and statistical analyses.

3 Results and Discussion

3.1 Weather Profile of the Study Period

During the study period, 232 days of rainfall were noted, with total rainfall of 1106.30 mm (average 4.79 mm; min. 0.1 mm; max. 67.10 mm; median 2.10 mm). Rainfalls with P < 5 mm comprised 73.3% of all noted rainfalls, rainfalls with a 5–10 mm comprised 15.8%, those of 10–20 mm – 7.9%, rainfalls with 20–30 mm – 0.9%, while those of 30 mm – 2.1% (Fig. 2a).

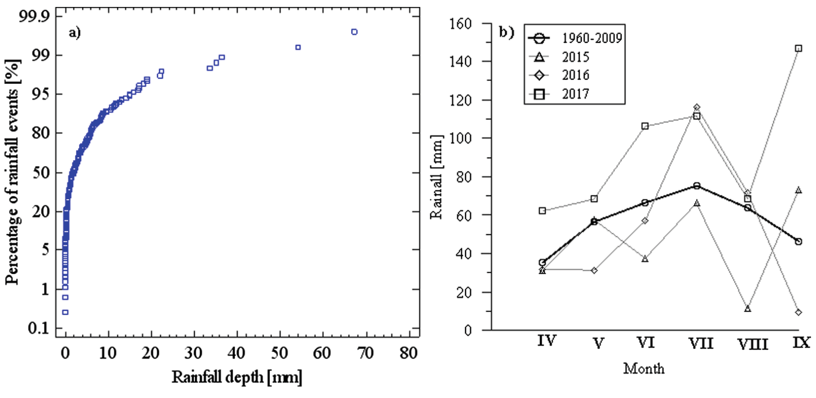

Fig. 2. Distribution of rainfall depths during the observation period (a), rainfall depth in 2015–2017 on the background of multi-year period (b).

In 2015, in the months of June – September, rainfalls differed significantly from the average observed in the multi-year period 1960–2009 (Fig. 2b). The month with the highest total rainfall was September (wet month) – the rainfall total equalled 73.1 mm. The month with the lowest total rainfall was August (extremely dry), when the total rainfall equalled 11.3 mm. In 2016, rainfalls differed significantly from the average from the 1960–2009 period in July and September [22]. The month with the highest rainfall was July 2016, with the monthly total equal to 115.1 mm (average rainfall from the multi-year period of 75.3 mm), while the highest daily rainfall occurred on July 12, 2016 and amounted to 67.10 mm. Similarly to 2015, the month with the lowest rainfall was September, when the total rainfall was 9.3 mm. In 2017, rainfalls were higher in all the analyzed months than the average from the multi-year period. The month which differed significantly from the average from the multi-year period was September 2017 – when the total rainfall amounted to 146.8 mm (average from the multi-year period of 46.4 mm). The maximum recorded rainfall was observed on 17 September 2017 and amounted to 54.10 mm.

3.2 Relationship Between Meteorological Parameters and Retention

In the year 2015, during the period IV-IX, the total rainfall amounted to 277.2 mm (19% less than average from the multi-year period), retention was 90% 84% for GR1 and for GR2 respectively. For the same period in 2016, total rainfall amounted to 317.9 mm (7% less of the average form the multi-year period), retention was 68% for GR1, and 64% for GR2. In 2017, in the period IV–IX, the total rainfall significantly exceeded rainfalls from the multi-year period and amounted to 663.3 mm (64% more than average from the multi-year period), retention amounted to 56% and 50% for GR1 and GR2 respectively. Over the course 3 years of in the vegetation period (IV–IX) on the model with the mineral-organic substrate (GR1), 5% higher retention than in the model with the mineral substrate (GR2) was observed. The Mann-Whitney W-test which was carried out additionally did not reveal any statistically significant differences between the GR 1 and GR2, $p > 0.05$. The linear relationship between rainfall depth and the retention, for both the GR1 as well as GR2 model, showed a negative correlation for $r(232) = -0.45$, $p < 0.05$, and $r(232) = -0.46$ (Table 2). The obtained negative values of correlation showed that, along with an increase in depth, the retention ability of green roofs decreases. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83.

The research covering the three vegetation periods conducted on green roofs models and reference model proved, that green roofs are efficient SUDS measure in the scope of runoff volume reduction. Rainfall-runoff relation for both green roof models showed, that observed retention amounted 67% and 62% and was higher compared to reference model (17%). Obtained values were similar to reported by other Authors base on research run in different regions all over the world, where average retention was in the range of 40–90% [12, 21, 23–28]. [23] obtained 64% of runoff reduction for the sedum-moss roofs with a thickness of 3 cm influenced by natural and simulated precipitation. [21] base on 19 rainfall-runoff events for green roof located in Chongqing in China, concluded that average retention amounted 77.2%. Similar results were reported by [27] for the intensive green roof in Manchester, GB. The noted retention was 65,7% for 69 rainfall-runoff events.

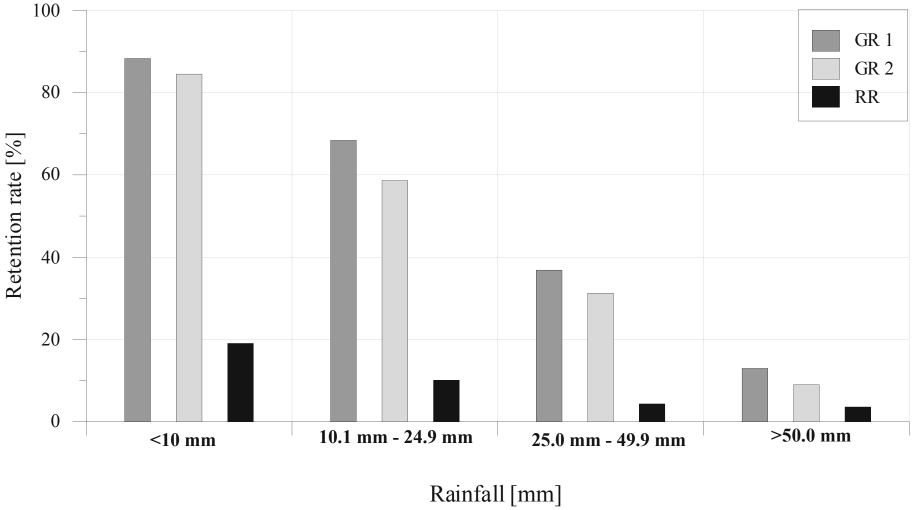

Fig. 3. The relationships between runoff retention in green roofs and outflow with conventional roof.

As shown on Fig. 3, green roofs retained nearly 88–84% of rainwater from small rainfall events (<10.0 mm), 58–68% in from of medium rainfall events (10–24.9 mm), 31–36% from large rainfall events (25.0–49.9 mm), and nearly 9–13% from storm events (>50 mm). [29] carrying out studies on an extensive roof, observed that water retention decreased from 90% for a rainfall depth of 13 mm to 39% with rainfall of 54 mm. Studies on the retention abilities of green roofs carried out by [30] in three Canadian cities showed that, for rainfall events of under 3 mm, retention ranged from 94.5% to 89.6%, and for rainfalls of over 15 mm from 58.5% to 36.4%, depending on the city. Table 2 shows the matrix of correlation for average values calculated for four metrological parameters preceding a rainfall (occurred 24 h prior to the rainfall). Connections between radiation (SR) and air temperature (T) as well as humidity (H) were found, as well as between air temperature (T) and wind speed (W). Additionally, a significant correlation between individual average input meteorological factors – air temperature, radiation and air humidity, and retention was obtained.

Some Authors suggest, that regional climatic conditions are significant factors influencing green roof retention [20, 31, 32]. At the local scale microclimatic conditions may differ between the roofs due to specific site condition. The results shoved, that volume of precipitation, humidity, radiation and air temperature have a significant effect on green roof retention. The obtained data show that the value of retention decreases with increasing rainfall and air humidity, while the increase in radiation and air temperature increases the green roofs retention ability. Performed statistical analysis confirmed that rainfall depth is strongly correlated with retention. Similar results are also reported by [5, 33–35]. [35] additionally stated, that radiation and wind speed are important factors influencing retention. In our study it was not confirmed in case of wind speed. Summing up, the results suggest that the interaction between meteorological factors and the percentage retention are probably complex and indirect. It is expected that some or all of these weather factors will work together with others resulting the influence of the retention of green roofs [35].

Table 2. Pearson correlation coefficient r and probability p (in brackets) of mean antecedent (24 h) meteorological parameters used in the multiple regression analyses. T - air temperature [°C], SR solar radiation [W m^{-2}], W - mean wind speed [m s^{-1}], H - mean relative humidity [%], P - rainfall depth [mm].

	SR	T	W	H	P
GR1	0.33 **(0.0000)**	0.22 **(0.0047)**	0.04 (0.5853)	−0.37 **(0.0000)**	−0.45 **(0.0000)**
GR2	0.24 **(0.0025)**	0.24 **(0.0024)**	0.08 (0.3110)	−0.29 **(0.0002)**	−0.46 **(0.0000)**

p-values below 0.05 indicate statistically significant non-zero correlations at the 95.0% confidence level.

4 Conclusions

In the article, the role of key environmental factors on rainwater retention on green roofs under the conditions of a continental wet climate was assessed. Subject to assessment was the difference in the amount of green roofs retention with a substrate characterized by a mineral-organic as well as mineral composition. Results from the statistical test suggest that rainfall depth, temperature and solar radiation are important factors which have the greatest influence on explaining percentage retention. These results support earlier studies that the total rainfall depth may have a strong influence on retention. Rainwater entering the system of green roofs is an input factor in the conceptual model of the retention of a green roof system. The retention ability of green roofs is, by nature, finite, thus the amount of retention depends largely on the number of rainfalls. Both models of extensive green roofs type were found to have a similar construction, though the model with the addition of low moor peat and compost revealed higher moisture content, both in the substrate as well as vegetation mat as compared to the model with the substrate of mineral composition (as confirmed by retention curves), signifying increased retention abilities. The analysis of two green roofs and references roof showed that the runoff coefficients ranged from 0.33 to 0.38 for GR 1 and GR 2, for RR runoff coefficients was 0.83. Over three years of observations during the vegetation period, the model with the mineral-organic substrate retained 5% more rainwater as compared to the model with mineral substrate. In addition to retention abilities, the mineral substrate reduces runoff of P and allows proper growth of Sedum and is a more practical solution than using the mineral-organic substrate.

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