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Research Paper

The capacity of greening roof to reduce stormwater runoff and pollution

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HIGHLIGHTS

- The green roof could effective reduce stormwater runoff.
- A key factor affecting runoff retention was the depth of rainfall.
- The green roof acted as a sink of NH_4^+-N and could neutralize the pH of rainfall.
- The water quality of runoff was seriously affected by the soil substrate of the green roof.
- The green roof was effective in abating the loading of most pollutants.

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ABSTRACT

To examine the stormwater retention capacity and runoff water quality of a green roof in Chongqing, China, 19 rainfall event samples of runoff and dry and wet deposition were measured. The results showed that the green roof effectively retained stormwater runoff, with retention ranging from 35.5% to 100%, with an average retention of 77.2%. The annual runoff retention of the green roof showed that the retention volume and rate reached 758.7 mm and 68.0%, respectively. When we compared the stromwater quality among the green roof, asphalt (control) roof, dry and wet deposition and rainfall samples, found that the green roof reduced the concentration of TSS, and could neutralize the pH of rainfall; however, it increased the concentrations of TN, NH_4^+-N, NO_3^--N, TOC, COD, BOD5, F^-, Cl^-, SO_4^{2-}, K^+, Ca^{2+}, Si^{4+}, DPb, DAl, DMn, and DFe. When we compared the pollutant loads from the green roof and rainfall samples, found that the green roof was a sink for NH_4^+-N, but was sources of NO_3^--N, K^+, Si^{4+}, Ca^{2+}, TOC and DAl. Overall, the green roof was effective in reducing stormwater runoff, neutralizing acid deposition and abating the loading of most pollutants; however, the water quality of runoff was seriously affected by the soil substrate. Therefore, we suggest that green roofs need to be constructed of suitable materials in order to avoid deterioration of runoff water quality.

1. Introduction

A "Green" roofs are roofs whose construction typically consists of a root barrier, drainage material layer, filter fabric, growing media and vegetation (Berndtsson, 2010; Carter & Rasmussen, 2006). In recent years, green roofs have become a trend in urban architecture and are widely used in such countries as Germany, Sweden, USA, Japan and Singapore. Green roofs benefits (Berardi, GhaffarianHoseini, & GhaffarianHoseini, 2014) include their ability to retain and detain roof stormwater runoff (Berndtsson, Bengtsson, & Jinno, 2008; Lee, Moon, Kim, Kim, & Han, 2013; Vijayaraghavan, Joshi, & Balasubramanian, 2012), reduce urban heat islands (Fang, 2008; Wong, Chen, Ong, & Sia, 2003), improve air quality (Currie & Bass, 2008), and provide wildlife habitats (Dunnett, Nagase, & Hallam, 2008; Gedge & Kadas, 2005), in addition to their esthetic value.

One important aspect often overlooked in previous studies is the quality of the runoff water from green roofs (Chen, 2013; Vijayaraghavan et al., 2012). Green roofs may reduce the pollution

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of stormwater runoff by filtering and absorbing pollutants, as the roofs are covered with soil and vegetation. Berndtsson, Emilsson, and Bengtsson (2006) in Malmo and Lund, Sweden, found that different types of green roofs act as sinks for nitrate nitrogen (NO_3^--N) and also reduce levels of ammonium nitrogen (NH_4^+-N) and total nitrogen (TN). However, green roofs can potentially contribute to pollutants released from soil, plants and fertilizers. Vijayaraghavan and Raja (2015) revealed that green roofs acted as sinks for various metal ions and generated better runoff during metal-spiked artificial rain events. Moran, Hunt, and Jennings (2004) found that compost in the substrate layer could cause high concentrations of nitrogen and phosphorus in the runoff from green roofs in North Carolina, USA.

All previous published studies show the ability of green roofs to retain and detain storm water. Summarizing the studies in German from 1987 to 2003, Mentens, Raes, and Hermy (2006) concluded that intensive green roofs reduce annual runoff by 65–85% of annual precipitation (100%), while for extensive roofs, the corresponding values were 27–81%. Gregoire and Clausen (2011) summarized part of the existing literature through a Meta-analysis, and found that extensive green roofs constructed to reduce stormwater runoff are able to intercept, retain, and evapotranspire 34–69% of precipitation, with an average retention rate of 56%.

The retention capacity of green roofs is affected by many factors. VanWoert et al. (2005) and Getter, Rowe, and Andresen (2007) reported that the retention values of green roofs decrease as roof slopes increase. Stovin et al. (2007) and Lee, Lee, and Han (2015) found that increasing the number of antecedent dry days can help to improve water retention capacity and delay occurrence time. Villarreal and Bengtsson (2005) recorded an inverse relationship between rainfall intensity and the water retention capacity of the studied green roofs.

The main objective of the current study was to thoroughly examine the effects of green roofs on the quality and quantity of rainfall runoff, using both the local soil and a commercial substrate as roof components. The specific objectives were to: (1) investigate the runoff retention capacity of green roofs; (2) determine the relationships between runoff retention capacity and storm characteristics; and (3) assess whether green roofs behave as sinks or sources of chemical substances in the runoff in terms of the pollutants load of the runoff.

2. Materials and methods

2.1. Study site

Roof rainwater runoff was monitored at a newly developed site surrounded by a school, road and building land in Yubei district, Chongqing, China. The area has a subtropical monsoon climate, with a mean annual temperature of 17.5–18.7 °C, and in year 2006 to 2011 annual rainfall ranged from 1100 to 1300 mm. Most of the precipitation occurs during the period between April and July, the highest temperature occurring during the July and September (Fig. 1).

2.2. The structure of the green roof

The studied "green" (vegetated) roof (1.0 m wide × 1.0 m long) and reference (asphalt) roof (1.5 m wide × 1.5 m long) were constructed in August 2010, and laid in parallel on the roof of a school. The two roof types were installed in accordance with local construction material standards and two duplicate pilot-scale roofs were arranged in an alternating sequence. The pilot-scale roofs were positioned 1 m above the school building roof, and had a 40 cm fence with potable-quality polyvinyl chloride (PVC) lining to prevent rainwater splashing out from the roof.

The green roof assembly consisted of four layers, the uppermost being a vegetation layer comprising of a thick (15 cm) growing substrate and plants. The second layer was a filter layer in the form of a non-woven geotextile, which prevented small particles from being washed from the substrate layer into the drainage layer or out of the system. The third layer was a drainage layer in the form of a large drainage board (length × width × height: 33.3 × 33.3 × 2.0 cm). The last layer was an additional waterproof layer, comprising a modified asphalt felt paved onto the original concrete roof.

The substrate composition was based on roof greening material available in China (BLS, 2005) and information from Gregoire and Clausen (2011). In addition, considering the growth environment of plant and bearing capacity of the roof, a mixture of lightweight materials was used as the substrate (the volume ratio of each matrix: peat soil: vermiculite: perlite: sawdust was 4:3:2:1). Buddhanail (*Sedum lineare* Thunb) was selected for the present study because of its ability to survive in conditions of low nutrients, drought and extreme temperature, and was planted in the

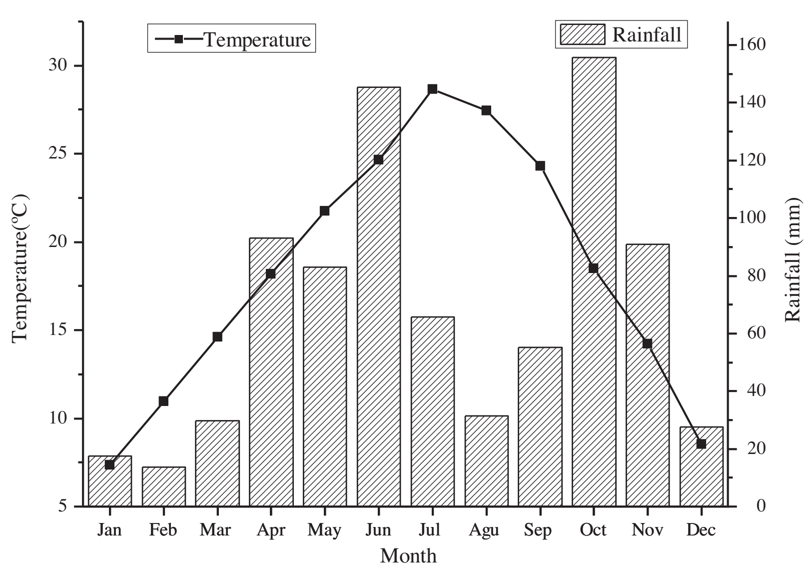

Fig. 1. Temporal variations of rainfall and air temperature for 2011.