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Can green roof act as a sink for contaminants? A methodological study to evaluate runoff quality from green roofs

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ABSTRACT

The present study examines whether green roofs act as a sink or source of contaminants based on various physico-chemical parameters (pH, conductivity and total dissolved solids) and metals (Na, K, Ca, Mg, Al, Fe, Cr, Cu, Ni, Zn, Cd and Pb). The performance of green roof substrate prepared using perlite, vermiculite, sand, crushed brick, and coco-peat, was compared with local garden soil based on improvement of runoff quality. *Portulaca grandiflora* was used as green roof vegetation. Four different green roof configurations, with vegetated and non-vegetated systems, were examined for several artificial rain events (un-spiked and metal-spiked). In general, the vegetated green roof assemblies generated better-quality runoff with less conductivity and total metal ion concentration compared to un-vegetated assemblies. Of the different green roof configurations examined, *P. grandiflora* planted on green roof substrate acted as sink for various metals and showed the potential to generate better runoff.

1. Introduction

In an attempt to combat rapid urbanization, it is necessary to develop innovative technologies to recover green space and improve environmental quality. Installing green roofs is one option that can minimize the negative impact of urban development, while providing numerous economic and social benefits in addition to more obvious environmental advantages (Rowe et al., 2012). These benefits include: storm-water management, decreased energy consumption of buildings, improved water and air quality, decreased noise pollution, extended roof life, reduced heat-island effect and increased green space in urban environments (Getter et al., 2009; Berndtsson, 2010; Niu et al., 2010). As a result of these positive effects, green roofs are becoming popular in many countries. However, the potential of green roofs to achieve these benefits often comes under debate (Mentens et al., 2006; Ascione et al., 2013).

Until now, the focus of green roof developers has been limited to achieving basic aesthetical benefits of green roofs (Berndtsson, 2010). Many other benefits of green roofs are just as achievable, but thus far the green roofs generally are not optimized to meet those. For instance, improvement of water quality is one of main benefits of green roof, which is unfortunately not properly understood. There have been reports indicating that green roofs act as sources of pollutants (Vijayaraghavan et al., 2012; Razzaghmanesh et al., 2014; Speak et al., 2014). However, not much effort has been taken to improve the quality of runoffs generated by green roofs. Green roofs basically comprise several components including vegetation, growth substrate, filter fabric, drainage element, root barrier and insulation. Of these, vegetation and growth substrate play a vital role in influencing the quality of runoff. Green roof plants are usually selected based on their drought tolerance, ground covering ability, and aesthetics. Phytoremediation ability was never a criterion for selection green roof plants by green roof policy makers. On the other hand, green roof substrates are required to be light weight, cheap, and possess high water-retention capacity and air-filled porosity. Substrate components were not screened based on their adsorption capacity or leaching tendency. If green roofs are to be considered environmentally benign and to meet long-term client expectations, then the selection of proper green roof components is extremely important.

Due to the drought-prone and exposed nature of green roofs, *Sedum* species are the most widely used vegetation group (Blanusa et al., 2013). Most of the research studies on green roofs employed *Sedum* and have given less preference to other plant species (MacIvor and Lundholm, 2011; Blanusa et al., 2013). However, *Sedum* species are non-native in many parts of the world, and hence

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green roofs with non-native *Sedum* may not be able to withstand the stresses from the local environment. For this reason, there is a need to identify green roof plant species viable for the local environment. *Portulaca grandiflora* is one such plant species which possesses favourable characteristics for green roofs such as ability to withstand drought conditions, good ground coverage, less maintenance, rapid multiplication, and have short and soft roots (DDC, 2007). It is commonly known as moss rose and can be grown easily in poor to average, dry to moderately moist and well-drained soils in full sun. This annual is a succulent that typically grows six to eight inches tall and spreads to 12 inches or more. Even though *P. grandiflora* is well established in several countries, it was never examined as green roof vegetation.

Most green roof substrates are developed according to the German FLL (Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.) guidelines or the ASTM (American Standard Testing methods). In general, engineered green roof substrates are composed of appropriate mineral aggregates (volcanic rock, expanded clay, shale, slate, pumice, zeolite, or crushed brick) and organic materials (peat, coir, mulch or municipal yard waste). The proportions and components will vary based on the weight, water-holding capacity, air-filled porosity and selected plant species. However, the pollutant-retention capacity of green roof substrate has never been considered, and thus the quality of runoffs generated from green roofs is often questionable (Berndtsson, 2010).

Thus, the objective of the present study is to evaluate the runoff characteristics of local garden soil- and optimized growth substrate-based green roofs during artificial rain events. To achieve this task, several pilot-scale green roof assemblies were constructed and operated on a real roof in an urban setting.

2. Materials and methods

2.1. Green roof assemblies and study site

Green roof experiments were conducted on the roof of Mechanical Sciences Block, IIT Madras, India from March to June 2013. The pilot-scale green roof systems were custom-designed (50 cm × 50 cm × 25 cm glass assemblies) (Fig. 1), with the same principle as full-scale vegetated roofs. All four assemblies were placed on a 4^0 slope to simulate common roof design. Through the opening at the bottom of the assembly, green roof runoff was collected. In general, each assembly was composed of three components with the uppermost being a substrate layer consisting of a 10 cm thick growing substrate. The second layer was a filter layer in the form of a geotextile, which prevents 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 commercial drainage element (flexible drain cell, Bioremegree Technology Solutions, India). The commercial drainage element is designed to store up to 2 L of water/m^2 to supply plants during dry periods, allowing the excess water to be drained off.

2.2. Green roof substrate and vegetation

Two green roof substrates were used, which include local garden soil (sub-1) and an optimized green roof substrate (sub-2). The local garden soil, procured from a commercial nursery, mainly comprises of red soil, clay, sand and cow manure. The exact composition of each component in sub-1 is proprietary. In contrary, green roof growth substrate contains (on volume basis) 20% vermiculite, 30% perlite, 10% sand, 20% crushed brick and 20% coco-peat. The materials used to prepare sub-2 were obtained locally and used in their original form. The physical and chemical characteristics of sub-1 and sub-2 are discussed in Section 3.1. The bulk density was calculated as the ratio of the dry mass (dried at 105 °C) to the volume of the undisturbed sample. The water-holding capacity (WHC) and air-filled porosity (AFP) were determined according to the Australian Standard Methods for potting mixes (Standards Australia, 2003).

In the present study, *P. grandiflora* was selected as test green roof vegetation. One-month-old cuttings of *P. grandiflora* grown in commercial garden soil were purchased from a local nursery. As the cuttings had been grown in commercial mix, they were washed in water prior to planting to reduce the effects of the commercial media on the green roof substrate. The vegetation was then planted in the substrate at a density of 64 plugs/m^2. During the course of adaptation, artificial watering (200 mL) was performed every two days. A small tent-like structure was constructed during the course of the experiment to protect the boxes from rainfall interference. After one month of plant establishment in boxes, field experiments were conducted.

2.3. Experimental

Four green roof pilot-scale assemblies were employed in the present study to evaluate the influence of green roofs on runoff quality. The first assembly (GRA-1) comprised sub-1 without vegetation; the second (GRA-2) comprised sub-2 without vegetation; the third (GRA-3) comprised sub-1 planted with *P. grandiflora*; and the fourth (GRA-4) contained sub-2 with *P. grandiflora*.

To examine the potential roof influence on runoff water quality changes during different events, rain simulations with local utility (tap) water were performed on four assemblies. Considering the volume of water required for experiments was more than 100 L, the simulation experiments were conducted with local tap water. Rain events (5–70 mm) were simulated manually with a sprinkler equally on four assemblies. In total, 10 events were considered with one event amounting to 5 mm (Vijayaraghavan et al., 2012). After sprinkling 5 mm of tap water on each assembly, the runoff at the exit was collected in pre-cleaned plastic cans until there was no sign of runoff for at least 5 min. All assemblies were then left undisturbed for 1 h before next event. Water samples were collected at the exit of the assemblies for each rain event for the analysis of light metals, heavy metals, and other physico-chemical parameters.

In the next set of experiments, the adsorption capacity of green roof assemblies was examined. For this purpose, simulated rain events (5–70 mm) were conducted using metal-spiked tap water. Spiked tap water was prepared by the artificial addition of metal ions by mixing their respective nitrate salts in tap water. To decide the concentration to be spiked, metal ions were classified into four groups: non-toxic (Na, K, Ca and Mg), mildly toxic (Al and Fe), toxic (Ni, Zn, Cu and Cr) and highly toxic (Pb and Cd) metals. In the spiked tap water, the concentrations were in

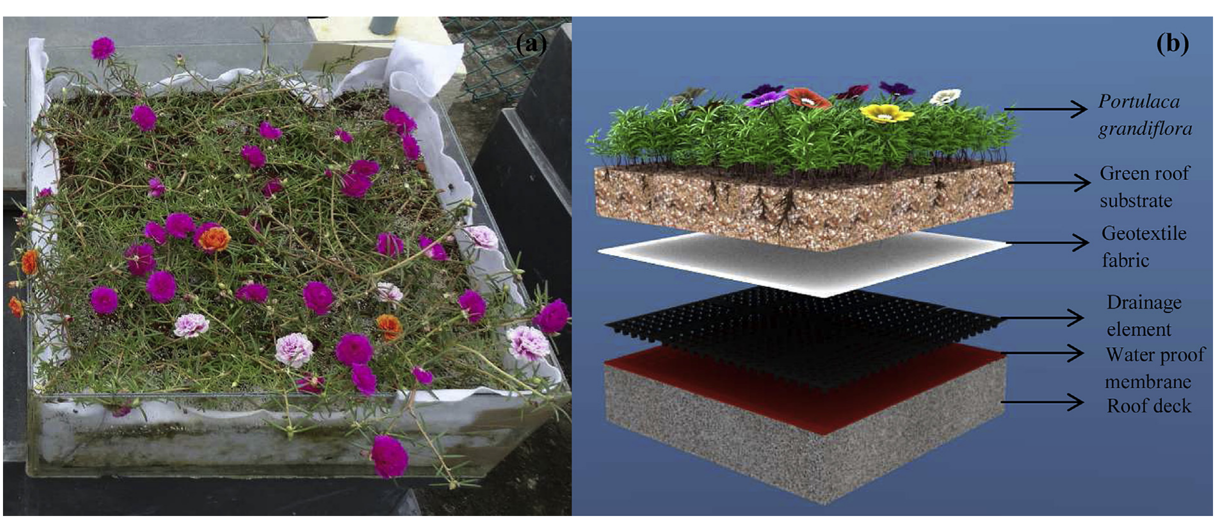

Fig. 1. Experimental green roof assembly in the rooftop of Mechanical Sciences Block, IIT Madras, India (a) and schematic of green roof assembly used in the present study (b).