THE IMPACT OF GREEN ROOFS (GR) RUNOFF IN STORM WATER QUALITY AND QUANTITY

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Abstract

Nature-based solutions are being worldwide implemented in highly impermeabilized city centres, due to the environmental benefits they generate and their contribution to urban sustainability and resilience, especially regarding stormwater management issues. The impact of Nature-based Solutions in the surrounding environment where they are set up, considering all the environmental aspects they have an effect on, with a special focus on stormwater management, is a fundamental aspect that must be addressed before promoting their large-scale implementation. In this scope, this study intended to address the influence of Green Roofs (GR) on rainwater quality and quantity, based on scientific experimental studies published worldwide. The compiled results show that GR dimensions, GR composition of the different layers and plant species used, amongst other characteristics, have a major influence on the quality and quantity of the rainwater downstream. In some reported cases, the quality of the drained rainwater resulted worst and for some conditions, the effect on rainwater retention was minimal, contrary to what was expected. The factors that resulted in these inconveniences are well defined and must be minimized in future GR construction and maintenance. GR are key elements to make resilient cities and thus, a clear understanding of their operation is fundamental to avoid water degradation and minimize potential impacts of malfunctioning of these structures. Furthermore, it is essential to choose the best combination of GR materials regarding water retention, to set GR systems adapted to local climate conditions and the present climate change scenario, with high performance in water management, to help urban areas dealing with extreme precipitation events, avoiding thus the consequent floods and economic damages that arise.

1. INTRODUCTION

The water issues in the present human lifestyle, coupled with an increase in urban population, are one of the challenges of the 21st century, although people are using water more efficiently due to environmental awareness. Nevertheless, due to the climate change scenario, water stress continues to escalate and is then exacerbated due to seasonal variations in water availability. As such, in order to respond to all supply needs, new systems for stormwater management, water harvesting and storage, and also water reuse, must be implemented in highly densely populated urban areas. Nature-based solutions (NbS) are one type of such technological solution that could help to reduce vulnerability to water stress in urban areas. Furthermore, NbS will also help to surpass the soil sealing problems of urbanization which potentiate flood situations in intense precipitation events, that are predicted to occur with more frequency and more intensity, placing thus more pressure on urban population and living conditions, and traditional stormwater management infrastructure [1]. NbS are systems inspired by Nature, that aims to restore vegetation into the urban environment contributing thus to an increase in natural water infiltration into the soil, restoring the hydrological cycle to pre-development years, while contributing to the sustainability and resilience of urban communities, also called as NbS at a neighbourhood or site scale [2]. In general, urban NbS are designed to control stormwater locally in an attempt to reduce the imperviousness of urbanized areas, and if coupled with traditional gray infrastructures they can alleviate urban flooding caused by precipitations of low/moderate intensity more effectively [3]. Furthermore, the use of NbS infrastructure can reduce the cost of stormwater management for new development because material costs and land disturbance are lower than traditional drainage [2]. The European Commission (EC) [4] states that implementing NbS on a larger scale would increase climate resilience while contributing to the Sustainable Development Goals 11 and 13 of the UN 2030 agenda goals. Also, NbS implementation follows the EU Water Framework Directive [5] that requires to manage of precipitation waters as close to the source as possible. In this context, it is intended with the paper to present the impacts of Green Roofs implementation in stormwater runoff management: quality and quantity.

2. GREEN ROOFS

Green roofs (GR), also known as vegetated roofs, are a type of NbS established on building rooftops, encompassing a multilayer structure to support vegetation development [6]. According to some characteristics (growing substrate depth, maintenance and type of vegetation), GR are usually divided into extensive, semi-intensive and intensive. While intensive GR have deep soil layers and can support large plants and bushes, extensive GR have thinner soil layers and smaller plants and are the most commonly GR chosen because they can be implemented in existing buildings (retrofit) given their minimal structural load, and generally maintenance-free and cost-effectiveness [7]. A multilayer structure is typically used, comprising the following components, from bottom to top: a high-quality waterproof membrane, a root barrier to protect the membrane, a drainage layer, a growing substrate and, finally, the plants.

GR provide multiple benefits from the economic, environmental, and social point of view: (1) multiple ecosystem services and biodiversity improvement, (2) Urban heat island (UHI) decrease; (3) air pollution reduction (CO_2 sequestration) and climate change mitigation; (4) buildings energy needs decrease; (5) cities aesthetic value improvement; (6) stormwater management and runoff reduction [6, 8]. Considering the present climate change scenario, the last described benefit related to stormwater management and runoff reduction is one of the most relevant roles to be considered in urban areas. Large-scale implementation of GR can thus improve the mean rainwater retention rate in cities and thus contribute to the reduction of rainwater runoff and flood occurrence. The great advantage of GR is that they do not require additional land given their implementation at the building's rooftop [9] accounting for approximately 40–50% of the impermeable urban surface area [8]. The reported study by Brandão et al [10] described that if 75% of the flat roof area of the Lisbon municipality was covered by vegetation, then approximately 166 500–224 000 m^3 of water could be retained, helping the drainage systems to deal with intense precipitation events and thus preventing floods.

2.1. GREEN ROOFS STORMWATER MANAGEMENT – QUANTITY

GR implementation in urban areas helps to manage stormwater runoff since part of rainwater is detained and retained in the GR multilayer system (both substrate and drainage layers). Then the retained water is evaporated into the atmosphere by the plant's evapotranspiration mechanism. As such, GR changes stormwater runoff, when compared with that from a traditional hard roof, through runoff volume reduction and delaying the peak runoff. Factors that influence GR water retention capacity can be, typically, grouped into two main categories: (1) extrinsic aspects (e.g. rainfall precipitation intensity; length of the antecedent dry weather period-ADWP); (2) intrinsic aspects (e.g. substrate depth, substrate hydraulic characteristics, type of vegetation) – Figure 1.

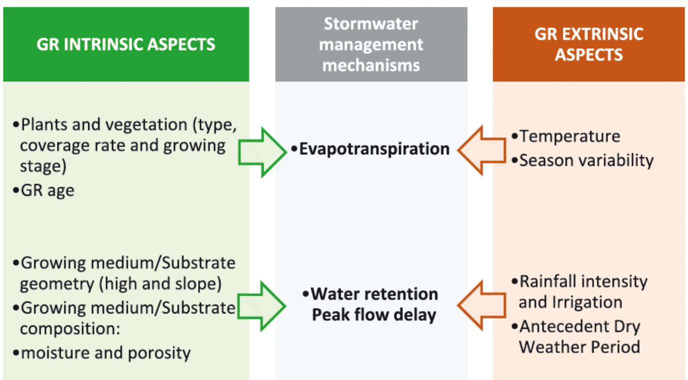

Figure 1. Factors affecting hydraulic performance of Green Roofs (GR) [6]

While water flows through the substrate, it is partially consumed by plants or retained in the substrate porous, so the total runoff volume at the end of rainfall events is also lower for GR than for traditional roofs. The retention capacity of a GR is bigger in small-intensity rain events, considering that the substrate is not saturated. After reaching the peak capacity or if the antecedent dry weather days (ADWD) are not enough to restore the retaining capacity of the substrate, the benefits of the GR concerning stormwater control are minimized.

Regarding intrinsic factors, vegetation and substrate layer are the two key factors affecting rainwater retention and runoff decrease from GR systems. Vegetation plays an important role in the retention and detention capacity of a GR. Despite the 100% vegetation cover of the mat's treatment studied by Kuoppamaki [11], these roofs retained less rainfall annually (40–60%) than less densely vegetated plantings (50–70%). According to Liu et al. [12], trees and shrubs, when compared to grasses, have a higher capacity to retain stormwater. Also, the nine-month GR pilot study performed by Harper et al. [13] showed an approx. 40% reduction in runoff from the unplanted growing medium and an approx. 60% reduction in runoff from the planted growing medium. Another factor that influences GR rainwater retention capacity is the substrate layer. Due to the dynamic of water flowing through the GR, the depth of the substrate and its initial moisture have a major influence on precipitation retention. Lee et al. [14] showed that a GR with a soil depth of 200 mm (intensive GR) reduced runoff by 42.8–60.8% compared to a 13.8–34.4% reduction of a GR with a soil depth of 150 mm. Viola et al. [15] also explored the retention performance of GR as a function of their depth and in different climate conditions, using both an intensive and an extensive GR. The amount of retained water increased in higher substrate depth, because more water was allowed to be stored in the active layer and, consequently, evaporate from the system.

Extrinsic factors are related to climate variables, mainly the characteristics of rainfall events. The size (or depth) of the rainfall is a major factor also reported by some authors, that presented lower retention for high rainfall events [11] and a high retention efficiency for small magnitude rainfall events [13, 14], due to the limited retention capacity of GR. Carpenter et al. [16] reported that under low rainfall inputs, the GR was partially saturated and retained high amounts of rainwater (between 98% and 100% of the incoming precipitation). Inversely, high-intensity rain events and a decrease in the antecedent dry period promoted saturation of the roof, which decreased its retention capability to only 88% [16].

GR system design is extremely important and should account the local climate conditions (extrinsic factor) which in turn will influence the vegetation species choice and development, the local availability of materials for growing substrate and drainage layer (intrinsic factor), giving preference for materials with high water retention capacity [17].

2.2. GREEN ROOFS STORMWATER MANAGEMENT – QUALITY

GR may also influence stormwater runoff quality due to the interaction between water and the different structural components. Both plants and substrate are expected to have a direct influence on the runoff quality, which can be either positive or negative, as they can filter or, eventually, be a source of contaminants. The quality of the drained water flowing from GR is extremely important as cities are becoming greener. As such, if the impacts on stormwater quality are not well known, there is a risk of providing contaminated water to the receiving watercourses.

Liu et al. [18] studied the influence of substrate and vegetation on the water quality of GR outflows by designing a scale-based runoff plot of extensive GR with different substrate and vegetation types. The results showed that the TSS (total suspended solids), TN (total nitrogen), and TP (total phosphorous) average concentrations of the GR runoff were all significantly higher than that of the conventional roof runoff. Furthermore, the TN and TP concentrations of 5 cm substrate depth were significantly lower than that in the 15 cm substrate depth, which could be related not to the depth of substrate but the higher content of organic matter in the substrate itself. Razzaghmanesh et al. [19] also studied the growing medium influence on the water quality of the outflow from intensive and extensive full-scale GR located on the roof top of a 22-storey building in South Australia. The values of the parameters such as pH, turbidity, nitrate, phosphate and potassium in intensive GR outflows were higher than in the outflows from the extensive GR. Generally, the performance of the extensive GR was better than the intensive systems in terms of pollutant removal, which may be related to the reduced volume of substrate that can leach pollutants. The literature studies might suggest, at first sight, that GR are bad solutions regarding stormwater quality runoff. However, despite presenting higher concentrations of some nutrients, the total loads drained by the GR are lower than that drained by the non-vegetated roof, due to the higher volumetric efficiency of the GR [20]. New GR tend to be a source of pollutants, due to the initial nutrient load that comes from the decomposition of organic matter that was incorporated into the original substrate mix. On the opposite perspective, established vegetation and substrates can improve the runoff water quality by absorbing and filtering pollutants [21]. In summary, the runoff quality of GR is influenced by inherent and external factors of the GR, figure 2.

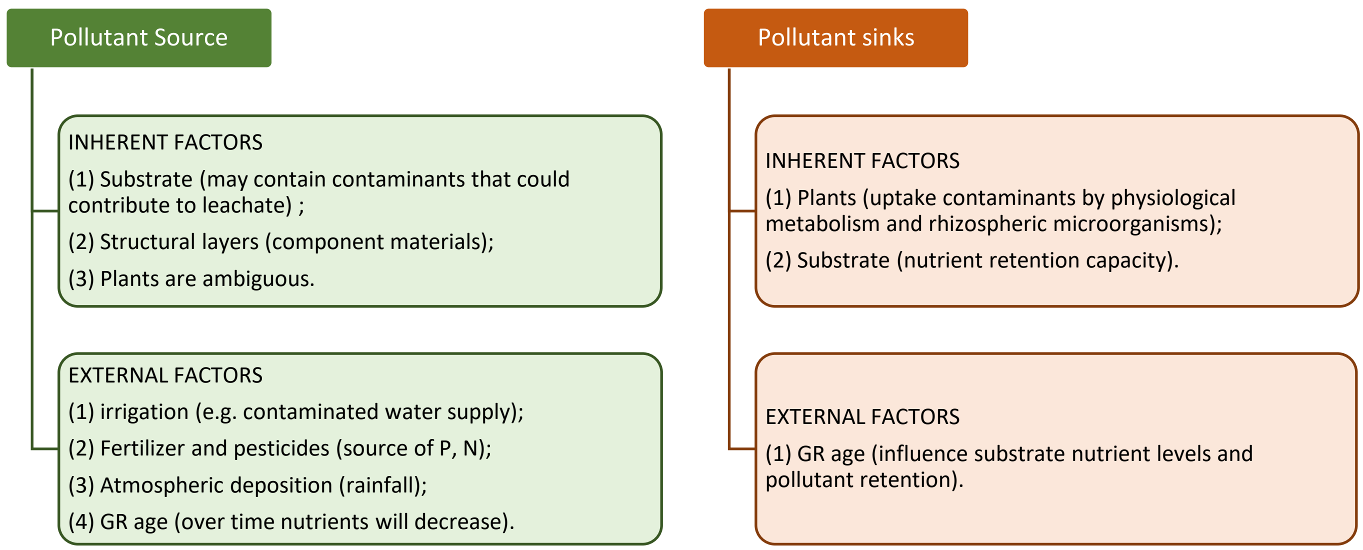

Figure 2. Inherent and external factors affecting runoff quality by GR (adapted from [6]).

In terms of the potential for outflow recycling water from GR, national and international standards indicate that such water can be reused for urban landscape irrigation and non-potable purposes such as toilet flushing [7].

3. CONCLUSION

Stormwater control is critical to the continuous development and sustainability of urban areas, once the soil sealing caused by the increase of urbanization, together with the occurrence of more frequent extreme events due to climate change, will worsen the consequences of urban flood and the degeneration of water resources. GR are a type of NbS which provides several benefits that can help to minimize these problems. The majority of roof tops are unused areas that might be transformed into green spaces contributing to the increase of the rainwater retention rate and the delay of peak flow, which can reduce flood occurrence and negative environmental consequences to cities and its population. GR achieve retention rates above 50%, reaching 100% in many cases, specifically when small-intensity rainfall events occur. Many factors were studied to understand the retention performance of GR, but it seems that the more relevant ones are the depth of substrates (intensive GR have higher retention rates than extensive ones) and the rainfall characteristics. Long-term assessments must be made to consider variable weather conditions between years and seasons. Furthermore, it is necessary to quantify benefits with easily measurable outcomes, which can provide urban leaders the information about GR positive impacts from economic and resilience perspectives, for both the short and long-term, and simultaneously, being a support to increase wider policy adaptations.

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