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Optimisation of lightweight green wall media for greywater treatment and reuse

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ABSTRACT

Green walls are increasingly being considered as a suitable greywater treatment technology. Nevertheless, until now there have been no clear recommendations for the use of effective lightweight media in greywater treating green walls. Previous studies of potentially suitable growing media have suggested that a combination of perlite and coco coir might be the most effective for these novel systems. However, there is no clear understanding of what proportion of perlite and coir should be used and how different mixes would affect greywater treatment. This work tested the hydraulic and pollutant removal performance of six different perlite and coco coir media mixes in an unvegetated column experiment. The results suggested that there is a point between 2:1 and 3:1 ratios of perlite to coir where the infiltration rate significantly increases, as the result of perlite dominance. As the infiltration rate increases, the mix gets less prone to clogging, but this negatively affects pollutant removal performance, with insufficient time for biological processes. We therefore optimised the mix for effective long-term treatment of total suspended solids, total nitrogen, chemical oxygen demand and *Escherichia coli*. Unfortunately, total phosphorus removal from greywater was limited for all tested mixes. This study also showed that attention should be given to greywater inflow dynamics and expected daily water treatment capacity; e.g. systems with a lower hydraulic loading were able to use greater proportion of coir in the mix achieving greater water treatment performance, while systems with higher hydraulic loadings require *faster* flowing mixes with lower coir proportion.

1. Introduction

Green (vegetated) infrastructure that passively treats varying sources of polluted water are currently considered to be one of the most environmentally friendly and low maintenance solutions for water recycling [9]. Wetlands and rain gardens (also known as biofilters or bioretention systems) have been engineered to successfully treat stormwater [10,26] and greywater [1,22,24]. However, these systems usually require significant space for placement, which presents a sizeable barrier in densely built urban areas. Additionally, primary criterion for selection of wetland and rain garden plant species is their functionality, and sometimes do not complement the overall aesthetics of the surrounding urban landscape.

With the rapid growth and densification of our cities, there is an emerging need for on-site green water treatment and reuse technologies which can be built vertically, reducing areal footprint. One such technology are green walls. Green, vegetated walls consist of planter boxes filled with a growing substrate (henceforth referred to as media) and ornamental plants which are suspended on a vertical surface, most frequently walls of the buildings and supported by the additional structure. These systems increase thermal insulation and energy savings [15,45,52], amenity, through air quality improvements and aesthetics [32,42], reduce noise pollution [16,50], and carbon footprint [14]. However, green walls have a highly variable water demand, from 1 L/m^2 per day in temperate and colder climates [46], up to 20 L/m^2 of water per day in more arid climates [17]. Water requirement is a limiting factor, particularly in arid climates such as Australia and California where these systems are the most effective, but high water demands cannot be easily met on a widespread scale [41]. This highlights the need to switch to different water source (rather than potable) if sustainable and cost effective green wall design is to be achieved.

If green walls could be engineered as water treatment systems, this would eliminate their irrigation requirements. Furthermore, if acceptable quality of treated wastewater is achieved, it could be collected at the bottom of the green wall and reused for toilet flushing and irrigation, transforming green walls into water producers [43], creating additional benefit for these systems. As they are positioned on the side of the buildings, the most convenient source of wastewater for these

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systems would be greywater, which is consistently produced and would not require additional pumping for multi-storey buildings; instead, it can be directly conveyed to green walls (on the same level where it is produced). Simple calculations show that even in arid cities, benefits from such recycling systems would be substantial; e.g. based on the current greywater production and potable water use data for the city of Perth in Western Australia [29], if all light greywater (shower and hand basin) is to be collected and treated from a typical three story residential building (approximately 1.6 ML/year) it would meet both the watering demand of the green wall (0.6 ML/year) and toilet flushing demand for the whole building (0.6 ML/year). Additionally, 0.4 ML/year would be left for watering of surrounding greenery.

The benefits of transforming green walls into greywater treatment system have been recognised by a few researchers [12,37]; [25]; [46], however most studies have relied on a black-box approach, not examining the processes of greywater treatment. The review done by Ref. [38] also points to a great potential of designing green walls as a greywater treating systems, but points to the current lack of scientific literature. This review also highlights the need for more specific parametric studies in this field, that would explore and recommend optimal green wall elements such as media, plants and system design. As the growing media represents the base of every green wall design, understanding and optimising its greywater treatment potential should be the initial step in creating resilient and effective greywater treating green walls.

Previous studies of other vegetated water treatment systems have shown the importance of growing media for sustaining plants and enhancing nutrient removal [11,30,44,48] and selection of optimal media types is generally well understood for constructed wetlands and raingardens; e.g. tightly specified sandy loam was found to give the best performance in stormwater bioretention systems [26]. However, this research cannot be directly transferred to green walls because vertical systems require lightweight media to reduce the load on their supporting structures. Lightweight media is also used for the most green roof designs [47]. Nevertheless, green roofs have never been designed to treat greywater [49], so it is not clear how green roof media would be affected by the high pollutant loads. Furthermore, water contact time and water and nutrient distribution in green wall and green roof systems are significantly different, inhibiting direct transfer of optimal media from one system to the other.

A range of lightweight media suitable for the application in greywater treating green walls was tested by Ref. [43] in a laboratory-scale column study of non-vegetated greywater filters and it was found that dense coco coir achieved effective pollutant removal of total suspended solids (TSS), total nitrogen (TN) and phosphorus (TP), chemical oxygen demand (COD) and *Escherichia coli*, but was prone to physical and biological clogging. In contrast, the same study reported lower removal performance for perlite, but faster infiltration rates and no clogging. Due to the differences in the properties (specifically, water retention capacity and porosity) and pollutant removal mechanisms of these two media [43], suggested combining coco coir and perlite, as a future research step. However, it is not clear how these two media types would interact within a single mix and what proportion of both media would be optimal for effective pollutant removal and infiltration performance.

Properties of filter media, such as porosity, surface area and charge, are directly impacting both aerobic and anaerobic processes occurring inside the media. This, in turn, governs pollutant removal. The higher water retention capacity of coir [21,36], together with its low nitrogen drawdown index (NDI_{75}, see Ref. [4], facilitate greater microbial processing of soluble nitrogen. However, conditions that are conducive to microbial development may result in biological clogging. Additionally, the high density of the coir and its susceptibility to hydraulic compaction are also increasing the risk of physical clogging. The addition of perlite to coir increases aeration and hydraulic conductivity due to its larger particle size [35] and thus reduces the risk of clogging, albeit at the cost of water retention capacity and therefore pollutant removal. However, the point at which addition of perlite to coir starts to significantly impede treatment performance has not been previously defined.

Until now there have been no clear recommendations for the use of effective lightweight media in greywater treating green walls. This study is the first one that offers practical guidelines based on scientific research, on optimal lightweight media mix which is suitable for construction of robust green walls, and are able to be equally effective in sustaining plants and treating greywater inflows for reuse purposes. This was achieved by using non-vegetated laboratory-scale column study to evaluate the effect that different coco coir and perlite mixes have on the treatment performance and clogging rates of the system watered with greywater. Non-vegetated design was chosen in order to understand the pollutant removal performance of the media in isolation from other factors such as plants and pot system design (approach used for development of other vegetated water treatment systems; i.e. [28]. Performance was evaluated across different inflow conditions and system maturation stages. Further understanding of underlying treatment processes has been acquired and presented, alongside practical implications of mixing and using coco coir and perlite. The performance of selected media mix in combination with vegetation will be tested in a future experiment, under Australian arid climate.

2. Materials and methods

2.1. Media properties

Six different perlite and coir mixtures were tested in this experiment (Fig. 1, Table 1). These mixes were selected to give a wide perspective on how media properties are affecting hydraulic and greywater treatment performance, ranging from the highest density mix, 1:3 perlite to coir, to the lowest density proportion, 4:1 perlite to coir. The raw media were characterised for particle density and porosity while bulk density and infiltration rate were measured according to constant head method, after the media was packed into the columns. Both perlite and coir were locally sourced and the perlite was of a medium grade with a particle size of 1–2 mm.

2.2. Experimental column design

As this study focuses only on media performance (excluding the effect of plants in the future green wall design), non-vegetated 100 mm diameter PVC columns were used (Fig. 2), with the total column height

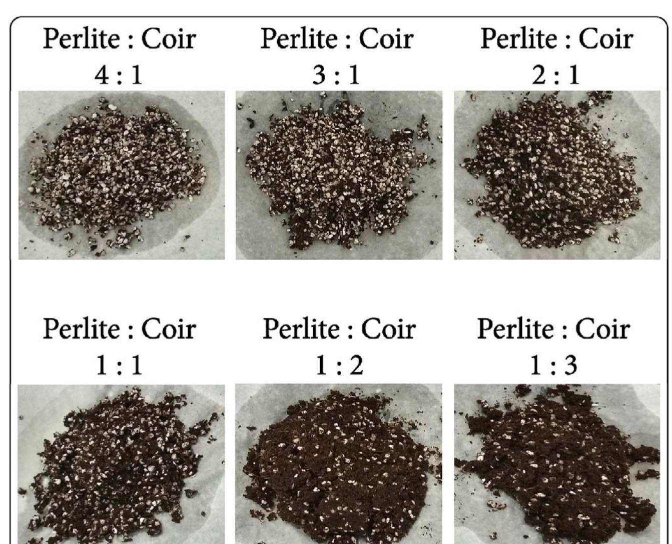

Fig. 1. Perlite and coir mixes and columns used in the study.