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Study on the Application and Sustainable Benefits of Greywater Management Integrate with Green Walls

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Abstract:

In the context of global climate change, population growth and socio-economic development, many cities are facing increasing water stress and water scarcity. Greywater, which makes up a substantial proportion of domestic wastewater, has the potential to be reused for non-potable purposes. Therefore, greywater management has received increasing attention in recent years and combining it with green walls is considered an innovative approach. Based on the perspective of sustainable development and by reviewing a series of existing studies, this paper analyzes the technology, application, and perpetual benefits of using green walls for greywater management. The feasibility of this approach is confirmed by modular and standing green wall facilities and systems that have been commercially applied. Greywater treatment with green walls provides a range of environmental benefits by removing more than half of the major pollutants and meeting local non-potable water quality standards in a cost-effective manner. At the same time, the use of greywater to irrigate green wall plants could benefit their growth to a certain extent, which can also have positive socio-economic benefits. However, the lack of infrastructure, technology, or policy support in some developing or underdeveloped regions may have a negative impact on its application. Nevertheless, in the future, the combination of greywater management and green walls has a relatively wide application and promotion prospects in water-scarce urban areas.

Keywords: Greywater management; green wall; sustainability; environment.

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1. Introduction

In recent years, many cities are facing considerable water stress or risk of water scarcity. Meanwhile, with population growth and socio-economic development, the demand for water and the rate of depletion of water resources are gradually increasing. This situation poses obstacles and challenges to the sustainable development of urban areas and the achievement of sustainability targets. Worldwide, the sustainable utilization, management, and protection of water resources in cities has become a critical issue that needs to be emphasized and advocated. As a result, currently, under the perspective of integrated water management, water demand management (WDM) approaches have been promoted and applied in some countries and regions, aiming to promote the reuse of wastewater in order to solve the shortage of water supply sources to a certain extent. Among them, greywater management is seen as a feasible and potential measure to address the problem at both environmental and economic aspects. This alternative water source mainly comes from household water used for washing and cleaning in bathrooms, lavatories, and kitchens, as well as laundries, and contains less pathogenic pollutants and nitrogen [1]. At present, greywater treatment systems could be categorized as traditional filter-based or chemical treatment measures, versus nature-based solutions (NBS). The NBS is an environmentally and economically valuable measure, and constructed wetlands, green roofs and green walls are regarded as adopting this solution. In densely built-up urban spaces, compared with artificial wetlands and green roofs, green walls do not take up much space and could make relatively full use of the vertical façade to improve the livability of the building and help control the internal temperature [2]. Since green walls consist of plants grown in media-filled pots, it would be regarded as a green technology with high water requirements. Besides, several studies have been conducted to evaluate alternative water sources for irrigation, such as rainwater and greywater. Compared to the volatility and irregularity of rainwater and the subsequent demand for additional storage, greywater could be considered as a more consistent reusable water and irrigation source with relatively yield and higher nutrient content for regions with arid climates [3]. Additionally, other studies focused on the development of green walls as an effective wastewater treatment system, such as utilizing the media to remove pollutants from the process, as well as the effect of pollutants in greywater on the growth of green wall plants [4, 5].

In this paper, a systematic review of methods, techniques, and applications for integrating greywater management with green walls is presented. In addition, the composition, effectiveness and effectiveness of the facilities are compared and analyzed through a series of practical cases. Potential challenges and prospects for future development are assessed with a view to informing further widespread application of this approach.

2. Measures and Tchnologies

2.1 Nature-based Greywater Treatment

As an NBS, the technique of applying green walls to greywater treatment aims to eliminate impurities and purify water by utilizing plants and soils that mimic a range of processes inherent to nature, including adsorption, filtration, and biodegradation [6]. Compared to general drinking water, greywater exists with certain concentrations of contaminant indicators such as suspended solids, BOD5, COD, and organic compounds, as shown in Table 1.

Table 1. Common pollutants and nutrient constituents in urban greywater

Pollutants	Nutrients
Suspended solids (SS)	Nitrogen/organic nitrogen methods, e.g. Urea, amino acids
Biological oxygen demand (BOD5)	Phosphorus, e.g. PO43-
Chemical oxygen demand (COD)	Sulfur, e.g. Sulphate
Ammonia nitrogen (e.g. NH3–N, NH4+)	Salts, e.g. Potassium (K), boron (B), magnesium (Mg), etc.
Total phosphorus (TP)	Other minerals, e.g. Aluminium (Al), sodium (Na), zinc (Zn), manganese (Mn), iron (Fe), etc.

When utilizing a green wall to treat water, the collected greywater would be transported to the roots of the plants. The vertical structure of the green wall makes it possible for a portion of the water to flow from the top down through the plant growth areas throughout the system by gravity rather than consuming additional energy. Through this process, pollutants and organics in the greywater would be available for uptake by the plants from the root zone. Moreover, the presence of symbiotic microorganisms, such as some bacteria, in the root zone of the green wall plants means that some pollutants would be further broken down and transformed through a biological reaction of natural degradation. For example, a biofilm would be formed on the soil surface as a medium during the treatment process [5]. Furthermore, the medium of cultivated plants could also be utilized to remove pollution through a series of processes such as filtration, adsorption, and reaction. A study has shown that slow media represented by rockwool and coconut fibers are hydraulically slow and retain greywater for a longer period, providing enough time for biochemical reaction processes such as denitrification to take place [4]. Compared to the performance of fast media that utilizes physicochemical reactions to remove pollutants, slow media exhibit higher and more consistent potential. Moreover, another study noted that the introduction of materials such as biochar and pumice as a media could be beneficial in further reducing total nitrogen (TN) and TP [7].

2.2 Plants and Media Selection

The ability to be planted vertically and the sustainability of vertical planting are regarded as the primary criteria for selecting plants suitable for the construction and installation of green walls. Ease of cultivation and growth, short plants, moderate or slow growth rate, ease of maintenance, and ability to grow all year round or perennial are regarded as some of the typical characteristics of green wall plants [8]. Based on this, the various resources that allow plants to grow vertically as an important part of a green wall system need to be considered, such as the need for water, nutrients, light, and elevation. Moreover, the water and light requirements of the selected plants within the same green wall system would also influence the specific location in the green wall where they would be grown. For example, some plants that require low light or partial-sun positions would be placed in locations of the green wall that are shaded or protected from direct sunlight. Table 2 lists six species that would be selected for planting in green wall systems, some of which are edible, and those non-edible species would commonly be used for landscape purposes. While combined with greywater management measures, these green wall plants would also be utilized for water treatment. Considering that greywater contains high concentrations of nutrients such as nitrogen, phosphorus, and salts (Table 1), plants suitable for greywater treatment are also required to have the capability to tolerate high nutrient environments or elevated salinity [9].

Table 2. Plant species selected for green walls

Binomial names	Water demand	Light demand	Edibility	In high nutrient environment
Blechnum spicant	High water plant	low light	Non-edible	Tolerable
Calathea orbifolia	High water plant	low light	Non-edible	Non-tolerable
Rosemarinus officinalis	Low water plant	full/partial sun position	Edible	Tolerable
Ruellia tuberosa	High water plant	full/partial sun position	Non-edible	Tolerable
Sedum morganianum	Low water plant	full/partial sun position	Non-edible	Non-tolerable
Thymus vulgaris	Low water plant	Low light	Edible	Tolerable

As for the selection of media, the filtration material not only requires to be lightweight with sufficient nutrient and hydraulic retention, but also have capability to allow sufficient infiltration to prevent clogging of the system, which could affect plant growth and treatment effectiveness. Porosity, permeability, and hydraulic retention of the material are regarded as physical factors. These factors would affect retention time and infiltration capacity of the substrate, even the overall life cycle of the media in a green wall system applied to greywater treatment. Additionally, factors such as the cost, availability, and recyclability of the material would also be taken into account in media selection [7]. Whereas, considering that filter materials can affect the efficiency of green walls in treating greywater to a considerable extent, mixing a variety of media materials is considered to be an effective way to enhance the treatment efficiency, especially some different matrix materials with complementary properties. However, different volume ratios could affect the effectiveness of media in adsorbing and removing pollutants. For example, Prodanovic et al. [10] reflected that when perlite and coir fiber are mixed as media and the volume of perlite is dominant, the ratio is required to be in the range of 2:1 to 3:1, in order to ensure the time for biochemical progress. Table

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3 lists some of the media materials that could be selected for implementing in green wall systems integrated with greywater management functions.

Table 3. Materials of medias for green walls

Type of material	Permeability	Synthetic/un-natural product
Biochar	√	
Coconut fibre	√	
Coffee grounds	√	√
Engineering mineral-based materials	√	√
Foam materials	√	√
Pearlite	√	
Potting soil	√	√
Pumice	√	
Rock wool	√	√
Sandy soil	√	
Vermiculite	√	

2.3 Greywater as Irrigation Source

In some green wall systems, greywater is used as a continuous source of irrigation water to support plant growth. According to Anangadan et al. [5], the growth rate and number of plant stems and leaves irrigated with greywater increased, and the content of minerals and some organic substances in the soil, including sulfates and phosphates, increased. Moreover, greywater could provide and supplement boron, which is lacking in the soil, which means that greywater can improve the nutrient and soil conditions for plant growth in the green wall system. Meanwhile, however, the chemicals in greywater from detergents and bath products may also cause green wall plants to show reduced chlorophyll levels. In some areas, greywater excluding kitchen water is considered as “light greywater”, which on average is less contaminated than normal greywater [11]. That is, the concentration of metal salts and pathogenic bacteria would be lower. Therefore, light greywater could be selected as an alternative water source that is more suitable for irrigating more green wall crops and plants.

3. Applications

3.1 Facilities and Systems

A wide range of commercially available green walls are currently in use. In many cities, green walls are used in a variety of applications, such as building facades, interior facades, and vertical parking lots. Of the several types of green walls, modular and containerized green walls are considered the most appropriate for greywater treatment and reuse [12]. Specifically, modular systems tend to consist of block-designed panels or basin-designed compartments with drip-type water delivery systems, and the support structures for the individual facility modules and equipment are made of rigid plastic materials. Whereas, at this stage, various sizes of panels and compartments are commercially available. The advantage of this type of green wall system is that its large media volume helps to effectively remove suspended solids and pollutants from gray water. Besides, as an example, a pilot installation of a green wall inside an office building in Pune, India, with a modular design in the shape of pots [13]. This design further avoids the interaction effects between plant roots or stems and leaves. Three hybrid materials were selected for the media in this green wall system, a lightweight expanded clay aggregate (LECA), sandy soil, and coir fibers, which were designed to increase the residence time and to improve the greywater treatment performance. Moreover, in the Ghent region of Belgium, a green wall facility called Total Value Wall (TVW) was applied to take on a part of the municipal water treatment and non-potable water reuse functions [14]. This full-size green wall system is used to treat gray water, which can be loaded with about 100 L per day, and the treated water is reused for toilet flushing. Ornamental plants are planted in the media for aesthetic and landscape functions. The selected media is a 2:1:1 mix of lava rock, organic soil, and biochar to balance permeability and pollution removal efficiency. In domestic scenarios, the green wall could be mounted on space-constrained walls in the mode of a modularly designed small bioreactor unit and combined with a slow sand filtration unit for integrated management of household greywater [15].

3.2 Effects and Benefits

Integrating greywater management measures with green walls has shown considerable effectiveness and benefits. The diverse performance and sustainability potential of green walls as a green infrastructure has been further expanded. From the environmental perspective, the effectiveness of green wall plants and media in filtering, adsorbing, and degrading suspended solids and pollutants in greywater is relatively significant. Particularly, biological processes in plant root zones could remove more than 80% of TN, total suspended solids (TSS) and Escherichia coli (E. coli). Masi et al. [13] concluded that the COD and BOD5 removal rates of the green wall utilizing mixed media set up inside the building also exceeded 40%. This means that the green wall system can efficiently treat greywater to a standard that allows for continued reuse while obtaining irrigation. This type of green wall system not only helps to save water, promote and improve water recycling, but could also be used as part of a municipal wastewater recycling system. As a result, greywater could be used as a sustainable source of reclaimed water and alternative water sources. Through the application of this type of green wall system and the promotion of greywater management, about 60% of domestic wastewater originating from households would be recycled, thereby increasing the total amount of local water resources [16]. In some arid climates, the pressure on local water supply would be alleviated, and community resilience and sustainability to climate change and specific weather extremes (e.g., droughts and heatwaves) would be improved, as green walls of a certain size and coverage could also cool buildings and mitigate some of the urban heat island effect [14]. Moreover, the use of greywater to irrigate edible green wall plants can increase the growth rate and the amount of stem and leaf production to a certain extent, which could create further socio-economic benefits. Particularly in urban areas where water resources are scarce, it can not only increase the biodiversity of urban areas and make full use of vertical space, but also increase the native yield of some specific crops and reduce the difficulty of accessibility. Apart from that, the use of greywater as an alternative source of irrigation can further reduce the operating costs of the green wall system, which is conducive to the promotion and sustainable application of relevant measures and technologies. Hence, the effective use of green walls for greywater management would also contribute to the greening of the city in line with the requirements of the 6th, 7th, 11th, and 13th SDG [17].

4. Challenges and Further Implementation

Apart from that, there are also some potential challenges that would be faced during the implementation of greywater management methods integrated with green walls in practice. For example, in the underdeveloped or developing regions, such as in some cities or communities in Africa, the network and facilities may lack proper maintenance. Whereas some of the local infrastructures would face extensive replacement for implementing or renewing the greywater treatment or irrigation system. Besides, the construction of these green walls would require proper technical conditions, specific naturally available or synthetic materials and relatively large spatial scale. However, in these areas, there would not only be a lack of professional and technical support in underdeveloped areas, but also that the local government may not have sufficient funds to support large-scale upgrading or modification of the system, as well as the subsequent maintenance [18]. In such situations, not only the implementation of demand management measures could be generally hampered by a lack of political and consumer support, but also the socio-economic tangible benefits that can be derived from the installation of the green wall systems would also be diminished by the lack of government support and encouragement [19]. For interventions, their successful implementation and effectiveness require despite of both technical and financial support, also policy advocacy would be relatively essential [20]. Moreover, public perceptions of the application and importance of greywater management measures would also influence the construction, promotion, and long-term operation of such green wall systems to a certain extent. On the one hand, at this stage, in addition to their landscape and urban ecological functions, to some extent, the potential and benefits of green walls in greywater reuse have not yet been adequately promoted to various stakeholders, such as the public. Moreover, some people may have some concerns about changing their old water habits and accepting agricultural products cultivated with grey water. Although public education could bring a long-term and sustainable positive impact, it would also take a gradual and challenging process for educating the public and changing their perceptions, behaviors, or lifestyles. Whilst the benefits and feasibility of promoting greywater management integrated with green walls could be assessed and validated from several aspects, there would be complex factors that need to take further consideration if these measures would be implemented in practical application scenarios.

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5. Conclusion

In conclusion, in a green wall system incorporating grey water management practices, the selection of specific green wall plant and medium species, as well as the type of green wall, requires consideration of several different conditions. These conditions are suitable for the adequate removal and degradation of pollutants and for the relatively high nutrient concentrations in greywater. The feasibility and effectiveness of green wall systems for greywater treatment, or the use of greywater to irrigate plants cultivated on it, has been studied and validated, and is being used in a variety of urban buildings. Such green infrastructures could help to sustainably improve environmental and WDM patterns in urban areas, increase resilience to climate change and promote water conservation and recycling. Meanwhile, the application of green infrastructure needs to take into account the local facilities, economic and policy support, and the public's water use habits and awareness, among other factors or challenges. Therefore, in cities where water resources are relatively scarce, greywater irrigation and greywater treatment could be introduced into green wall facilities that are already built or under construction. This paper aims to analyze the specific technologies, applications, and benefits, and provide a reliable reference for the further application and promotion of green walls incorporating greywater management. In the future, it is foreseeable that the number of green wall systems in urban areas would grow and be promoted to a certain extent. By implementing green walls, the sustainable development potential of cities could be enhanced in line with the corresponding sustainable development goals. Furthermore, a range of specific benefits such as water saving, energy saving, and carbon capture could be further quantified.

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