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Purification performance at the entrance and exit of an artificial marsh in duplicate (plant and control) with Horizontal Sub-Area Flow (Al Haouz, Marrakesh, Morocco)

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Abstract

Increasing demand for water for human, industrial and agricultural consumption, coupled with repeated national droughts, have prompted decision-makers to consider wastewater as a valuable water resource that must be reused after treatment. This study is part of the integrated management of water resources in the face of the water shortage affecting our country, by looking at the treatment of greywater from the dwellings of a village in Marrakech. This study focuses on the treatment and reuse of greywater through a planted filter, using a reed (*Phragmites australis*), with horizontal sub-surface flow and another unplanted to determine the purification efficiency of this type of treatment system through the measurement of certain physicochemical parameters of wastewater such as: nitrogen compounds, phosphorus compounds, suspended solids etc. This study provides an overview of the elements relating to the works planned for autonomous wastewater treatment. The results of the analyses obtained during this study have helped us to establish a diagnosis of certain physico-chemical parameters, and to measure the degree of pollution of domestic wastewater, and to draw certain remarks as follows: Human activity in towns and cities is at the root of changes in the degree of pollution of urban wastewater. To achieve near-optimum environmental protection, and for every domestic wastewater reuse project, the State must regulate and opt for environmental impact studies. Economically speaking, local authorities can treat domestic wastewater at very affordable costs.

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Introduction

Today, and tomorrow even more so, water is a raw material of the utmost importance. Yet available stocks are unevenly distributed. We note, for example, that most water reserves are located in the Antarctic polar ice cap.

This implies protecting this resource through effective and efficient treatment, in order to produce clean water for human consumption and other industrial needs, without forgetting to limit pollutant discharges into the natural environment.

The growing demand for water for human, industrial and agricultural consumption, and repeated droughts on a national scale, have prompted decision-makers to consider wastewater as an appreciable and exhaustible water resource that absolutely must be reclaimed after treatment (Mouaouia *et al.*, 2019). The discharge of untreated or inadequately treated water has serious repercussions, such as the disruption and dislocation of the biological system, as well as harmful repercussions on human health and the environment (Abou-Tammame *et al.*, 2021).

It should also be noted that an intensification of nutrient flows can lead to an increase in the concentration of physico-chemical parameters in the environment (Prasanna *et al.*, 2017).

Effective purification systems for greywater treatment include horizontal sub-surface flow filters. This system features simplicity of operation combined with high yields in terms of contaminant reduction and low maintenance (Mouaouia *et al.*, 2018). The efficiency of this system can be optimized by the addition of purifying plants called hydrophytes (Ayaz *et al.*, 2020).

Hydrophytes, which originate in wetlands and are characterized by the development of emergent herbaceous plants, are the most suitable type of plant for use in artificial marshes (Pichura *et al.*, 2022). Among the most commonly used species are *Phragmites australis*, *Typha* spp. *Arundo donax*, *Scirpes* spp. *Eleocharis* spp. *Carex* spp. *Juncus* spp. *Phalaris arundinacea, Glyceria maxima and Cyperus* spp. (Vymazal, 2011).

In this study, we chose to use the reed *Phragmites australis*. This plant is renowned for its ability to tolerate extreme drought conditions and nutrient-poor soils. Its robustness enables it to thrive in unfavorable environments. What's more, its deep roots act as natural filters, able to retain pollutants and undesirable substances present in wastewater. Its use in wastewater treatment offers an economical and ecological solution for regions subject to harsh climatic conditions (Arliyani *et al.*, 2021).

Few experiments have been carried out on sub-surface horizontal flow treatment systems in the Haouze region. The main aim of this project is, on the one hand, to highlight the importance of installing this type of system in this region, and on the other hand, to carry out a comparative study between a non-planted treatment unit and one planted with *P. australis*.

The aim of these types of treatment is to purify grey water from households in a small urban area for reuse in watering green spaces in the city of Marrakech. This was achieved by carrying out a more exhaustive analysis of the purification performance of the two systems by measuring their efficiency on the basis of measured concentrations of 9 physico-chemical parameters at the inlet and outlet of the filters.

Materials and methods

Experimental installation and set-up

Our artificial marsh, which was the subject of the experimental installation (figure 1), is a wetland with horizontal sub-surface flow. We designed and implemented it in duplicate (one planted and the other as a control) in the village of Ait Hammou commune Aghmat in Marrakech (Morocco), with the following geographical coordinates: 31°25'38.9 "N 7°46'35.8 "W. An average annual temperature of 19°C and an annual rainfall of 282 mm characterize the area. The purpose of the plant is to purify and reuse treated grey water for watering green spaces. Our bioreactor is installed in the form of a rectangular tank with the following dimensions: 5.00 m long, 1.00 m wide and 0.80 m deep (figure 2). Three different layers of porous media were used: a drainage layer, a transition layer and a filter layer. The pond is planted with reed (*P. australis*). This species used as a reed in this study was chosen for its qualities. It is a perennial forage plant that thrives in wetlands on well-textured soil rich in organic matter, nutrients and exchangeable elements. In addition, *P. australis* develops a high root density, which is conducive to nutrient uptake, water drainage and substrate oxygenation.

Fig. 1. Filter experimental set-up (planted and control).

Plant growth was monitored by measuring the weekly height of five reed stems using a millimetre-scale tape. To ensure spatial homogeneity, the five stems were selected as follows: one stem per corner (4) and one stem in the center (1) of each reactor.

Sampling methodology

Grey water and treated water samples were taken at the inlet and outlet of the filters (planted and control) by manual sampling using 500ml sterile glass bottles every day (one sample in the morning at the inlet, and a second in the evening at the outlet) over a period of 120 days (from May to August).

These samples are stored at 4°C for physico-chemical and biological analysis: pH, temperature, chemical oxygen demand (COD), suspended matter, nitrogen compounds and phosphorus compounds.

Analysis methods

Analysis was carried out in accordance with Moroccan standards, which are similar to AFNOR standards. The table below explains the different analytical methods used during this study to measure the magnitudes of the various physicochemical parameters of the wastewater samples to be treated through our bioreactor (Table 1).

Results and discussion

The comparison between the two sub-surface horizontal flow treatment systems, one planted with *P. australis* and the other unplanted, showed significant results in terms of water purification. The results obtained are in line with other studies that have shown that sub-surface horizontal flow treatment systems are effective in reducing the nutrient and pollutant content of water (García-Ávila *et al.*, 2019; Vymazal, 2011).

Effect of filters on physico-chemical parameters

The pH measurements show similar mean values for raw water in either a planted filter or a non-planted bioreactor (5.3). Wastewater, on the other hand, shows higher average pH values than those quoted above (7.5). Suspended solids measurements for both planted and unplanted filters show almost identical concentrations. Concentrations range from 64.01 to 934.93 mg/l and 280.99 to 635.58 mg/l respectively, while the wastewater contains quantities higher than those mentioned above (from 1120 to 2360 mg/l). The average purification efficiencies obtained were 77.58% for the planted reactor, and 73.69% for the control.

Table 1. Techniques for the analysis of wastewater samples.

Paramètres	Technique d'analyse	Norme
pH	Electrochemical probe method	NF T90-008
Suspended matter	Membrane filtration with a pore diameter of 0.45 µm	NF T90-105
Total chemical oxygen demand	Potassium dichromate oxidation method	NF T90-101
Total nitrogen Kjeldhal	Kjeldhal method: Mineralization, distillation and titration	NF T90-110
Ammonium (NH_4^+)	Indophenol blue molecular absorption spectrometry	NF T90-015
Nitrite (NO_2^-)	Molecular absorption spectrometry by diazotization	NF T90-013
Nitrate (NO_3^-)	Molecular absorption spectrometry after cadmium reduction	NF T90-045
Total phosphorus	Aluminium molybdate molecular absorption spectrometry in the presence of ammonium vanadate after mineralization	NF T90-023
Phosphate ortho (PO_4^{3-})	Aluminum molybdate molecular absorption spectrometry	NF T90-023

Figure 3 shows the variations in chemical oxygen demand (COD) values in the wastewater at the inlet and outlet of our bioreactor during the treatment trial period. These average concentrations are 1564 mg O_2/l in the raw wastewater at the inlet before treatment, and 121.9 mg O_2/l for the planted filter, and 230.71 mg O_2/l for the control filter (not planted) after treatment. Chemical oxygen demand concentrations are clearly lower in the planted bioreactor than in the control. Average purification efficiencies were 92.43% for the planted reactor, and 83.93% for the control.

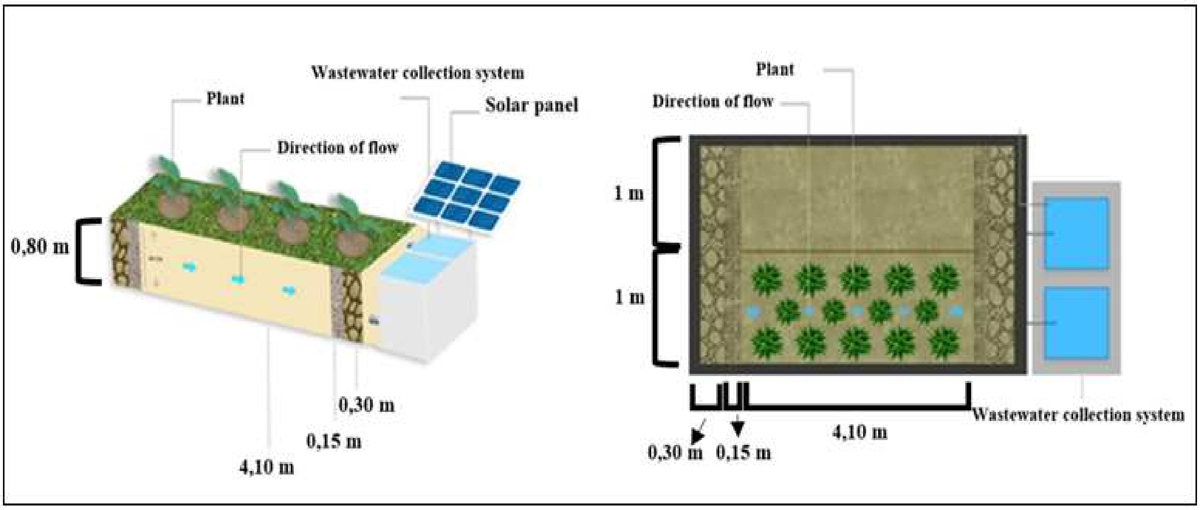

Fig. 2. Experimental set-up for our filters (planted and control).

In particular, the significant drop in pH in both filters is an indicator of the system's effectiveness in reducing wastewater acidity. This drop in filtrates reflects an acidification of the environment due to nitrification, oxidation of organic matter and plant respiration (Brix *et al.*, 2005). On the other hand, the significant decrease in suspended matter content and COD after filtration in both systems is another indicator of the effectiveness of sub-surface horizontal flow treatment systems in removing pollutants from wastewater (Rezaie and Sahlezadeh, 2014).

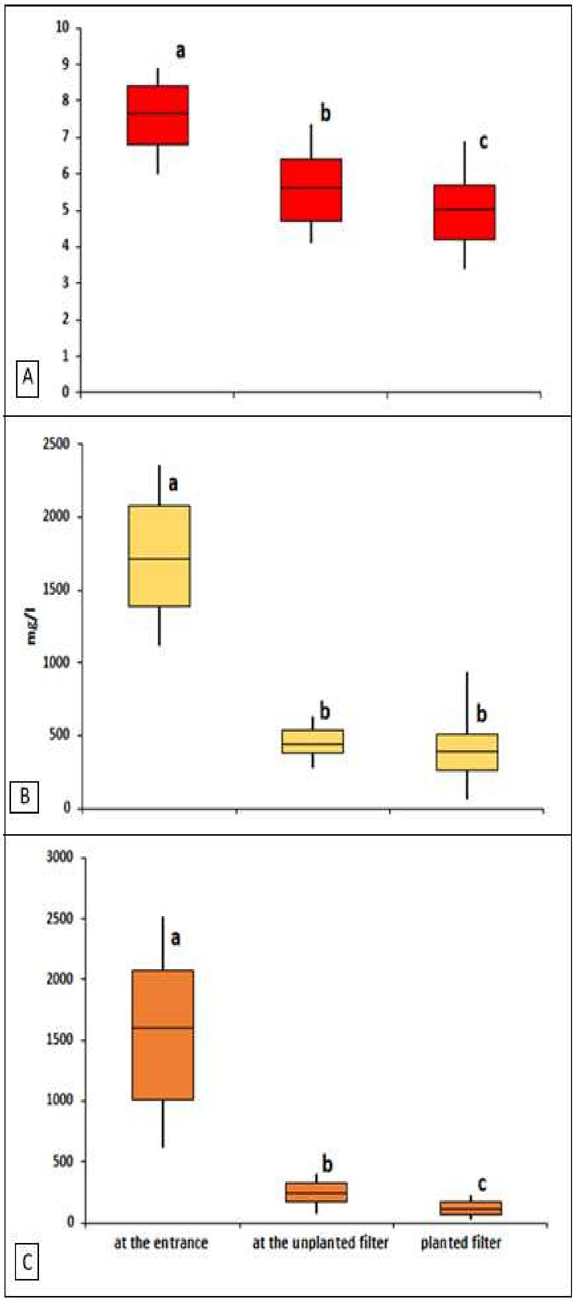

Fig. 3. Variation in pH (A), suspended matter (B) and oxygen demand (C), different letters indicate significant differences between measurement at filter inlet and outlet planted and unplanted filter.

However, this reduction is more significant when using the planted system. The COD reduction in reactors planted with *P. australis* is higher than that reported by Coulibaly *et al.* (2008 a,b) in the range of 62-65%.

This difference in results is probably linked to the type of plants used. These results are in line with other studies that have shown that plants can promote the growth of bacterial microorganisms that contribute to the degradation of organic matter in planted sub-surface horizontal flow treatment systems (Kadlec and Wallace, 2008).

Nitrogen compound content

Analysis of total nitrogen (TN) shows significantly higher concentrations in the raw wastewater than in the treated water, either at the planted filter outlet or in the control reactor (Fig 4). At the filter inlet, mean concentrations are 119.40 mg/l and 465.7 mg/l, between 44.96 and 264.60 mg/l at the planted filter outlet, and between 6.02 and 202.58 mg/l at the control reactor outlet, with mean concentrations of 283.31 mg/l, 112.01 mg/l and 154.96 mg/l respectively. However, TN concentrations are lower at the planted filter outlet than in the control reactor. TN removal in the planted reactor is therefore higher than in the control reactor (TN = 60.46% for the former, and TN = 45.30% for the latter).

Analysis of the ammonium (NH^{4+}) concentrations in the raw wastewater (EUB) at the filter inlet and outlet (either planted with *P. australis* or not planted) shows that the concentration values measured in the filtrates from the various reactors are well below those of the EUB. In the raw wastewater entering our treatment system, the NH^{4+} concentration averages 107.55 mg/l, with minimum and maximum values of 19.2mg/l and 195.9 mg/l respectively. At the reactor outlet, the minimum and maximum values are 2.17 and 23.87 mg/l for the planted filter, with an average NH^{4+} concentration of 12.56 mg/l, and between 18.6 and 71.5 mg/l for the control reactor, with an average of 43.67 mg/l.

In comparison with the two reactors at the outlet, the planted filter achieved a NH^{4+} purification efficiency of 87.58%, compared with 56.86% for the control. Conversely, NO_2^- and NO_3^- concentrations in the filtrates of the planted and control reactors are statistically higher than those recorded in the raw wastewater. In the latter, values range from 0.05 to 0.27 mg/l for NO_2^- and from 0.74 to 12.6 mg/l for NO_3^- respectively. These values are comparable to those of filtrates from the unplanted reactor (control). On the other hand, in the planted reactor filtrates, the respective mean concentrations of NO_2^- and NO_3^- are 0.70 mg/l and 49.82 mg/l.

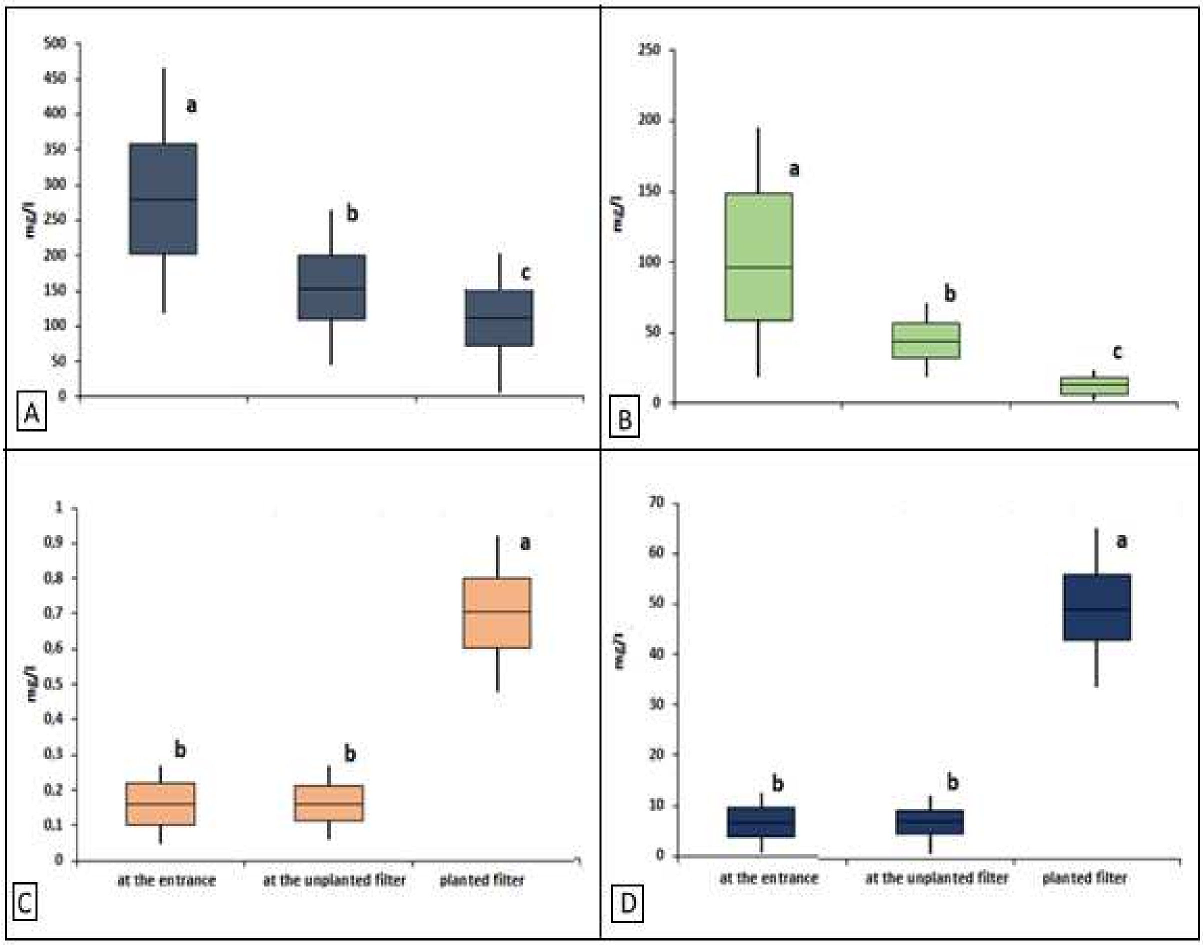

Fig. 4. Variation in total nitrogen (A), ammonium (B), nitrite (C) and nitrate (D), different letters indicate significant differences between measurement at filter inlet and outlet planted and unplanted filter.

The significant decrease in total nitrogen and ammonium content in both filters, with a greater reduction in the planted system, shows that planted sub-surface horizontal flow treatment systems are more effective in reducing the nitrogen content of wastewater (Ennabili and Radoux, 2020). Indeed, several studies, including those by Weaver *et al.* (2003) and Münch *et al.* (2004), have shown that in the planted reactor, the transfer of atmospheric oxygen into the substrate through the root system creates aerobic conditions that increase the redox potential in the anoxic zones and enable nitrification, the products of which are NO_2^- and NO_3^-. Purification efficiencies are relatively higher than those obtained (50-80%) by Tanner *et al.* (2002), Bergheim and Brinker (2003), Maltais-Landry *et al.* (2007, 2009) and Sindilariu *et al.* (2009) (figure 4).

Phosphorus compound content

Figure 5 shows the variations in total phosphorus (TP) concentrations in the wastewater at the filter inlet and at the outlet of the filter planted with *P. australis* and the control filter. The average concentrations are 10.2 mg/l in the raw wastewater, while in the filtrates they are 2.1 mg/l and 6.4 mg/l, respectively at the outlet of the filter planted with *P. australis* and the control filter. The average yields obtained are 79.82% for the planted reactor and

37.36% for the control. These yields are significantly higher in the planted filter than in the control.

The results show that the concentration of ortho-phosphate (PO_4^{3-}) drops considerably at the outlet of the planted filtrates, compared with the concentrations already measured in the raw wastewater at the reactor inlet. This reduction in PO_4^{3-} concentration is much clearer in the planted filter than in the control. In the raw wastewater, values vary between 3.25 and 12.09 mg/l at the filter inlet, with an average concentration of 7.67 mg/l. At the reactor outlet, they fluctuate between 0.37 and 1.92 mg/l in the planted reactor filtrates (mean concentration 0.64 mg/l), and between 1.56 and 7.69 mg/l in the control filtrates (mean concentration 4.62 mg/l). Purification efficiencies were significantly higher in the planted reactor than in the control. They are of the order of 48.63% for the control filter, and 86.07% for the planted reactor.

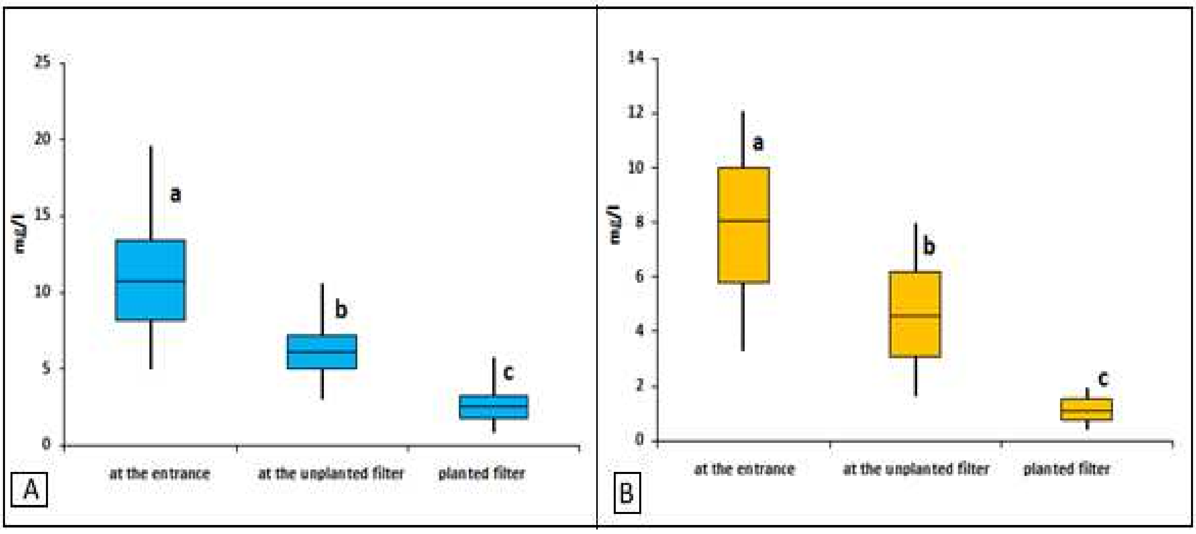

Fig. 5. Variation in total phosphorus (A) and orthophosphate (B), different letters indicate significant differences between measurement at filter inlet and outlet planted and unplanted filter.

The significant decrease in total Phosphorus and ortho-phosphate content in both filters, with a greater decrease in the planted filter, is an indicator of the system's efficiency in removing nutrients from wastewater (Kadlec and Wallace, 2008; Angassa 2017). This is probably due to the combined action of microbial assimilation (Molle, 2003), plant uptake (Hadad and Maine, 2007) and precipitation and adsorption reactions (Bubba *et al.*, 2003) of phosphorus in the reactor substrate.

The results of this study show that horizontal sub-surface flow treatment systems planted with *P. australis* are more effective at removing nutrients from wastewater, reducing suspended solids and chemical oxygen demand, but can promote the growth of nitrifying and denitrifying microorganisms, leading to increased nitrite and nitrate levels in the treated water. These results suggest that planted sub-surface horizontal flow treatment systems can be an effective and economical solution for wastewater treatment. However, further studies are needed to understand the mechanisms underlying these observations and optimize the design and operation of these systems.

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