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Subsurface Flow Constructed Wetlands: the road to treated wastewater and renewed ecosystems

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Highlights:

- Assessment of the optimal performance of a subsurface flow artificial wetland in the purification of contaminants present in wastewater.

Keywords: Artificial wetland; wastewater; water quality

INTRODUCTION

Growing urbanization and the intensification of agricultural activity have caused an increase in the contamination of water bodies due to the discharge of wastewater with high levels of pollutants. A viable solution to this problem is the implementation of artificial wetlands, which take advantage of natural physical and biogeochemical processes to eliminate these pollutants. These wetlands not only contribute to the removal of organic matter and nutrients, but also provide additional benefits, such as ecosystem services and recreational opportunities (Wu et al., 2023). One particular type of these wetlands are subsurface flow wetlands, a system where water flows slowly through a permeable substrate, such as gravel or sand, below the soil surface, allowing for greater retention and filtration of pollutants. This increased retention also provides more time for biogeochemical and biological processes to take place, which increases the effectiveness of treatment (Duque-Sarango & Pinos, 2022; Pérez et al., 2024)..

In this context, the present study aimed to evaluate the optimal performance of a subsurface flow artificial wetland in the removal of organic matter and nutrients from wastewater. An experimental design was carried out involving the manipulation of different hydraulic retention times, together with the inclusion of the plant species *Iris pseudacorus*. Thus contributing to the advancement in the field of wastewater treatment and the search for sustainable solutions for water resource management.

METHODOLOGY

The system structure was sized according to the guidelines of. (Asensi et al., 2019; Pérez et al., 2024; Romero-Martínez et al., 2019) y (Vymazal, 2019). The subsurface flow wetland system used in this study has dimensions of 2 m long, 1 m wide and 0.8 m deep, providing a surface area of 2 m². These dimensions were selected to optimize system performance within the available experimental space.

Based on these dimensions, the organic and hydraulic loads applied to the system during the experiments were calculated. The organic load was 3.0 kg BOD5/m²/day, while the hydraulic load was 0.2 L/min, as recommended by Vymazal (2019) for subsurface flow wetlands under similar conditions.

These parameters made it possible to evaluate the system's ability to treat wastewater at a constant flow rate and to determine its effectiveness in removing key pollutants.

It was adapted with different substrates suggested by (Navarro et al., 2013). A 20 cm layer of coarse gravel (9.5 to 38 mm) was placed at the bottom, followed by a 20 cm layer of volcanic rock, then 5 cm of fine gravel, and finally, at the top, a 15 cm layer composed of a mixture of peat and compost. Each layer was separated by a high-strength geotextile mesh. Fifteen *Iris pseudacorus* plants were arranged in four rows, with a distance between plants of 30 cm. The design incorporates a system of perforated pipes, arranged every 5 cm, with holes of 1 cm in diameter (Jácome et al. (Jácome et al., 2014) (Figure 1). This system was supplied with urban wastewater from the Ucubamba WWTP, Cuenca-Ecuador. Flow and application rates were measured to ensure rigorous control of the experiments. During the first 45 days of operation, a continuous flow with a feed rate of 0.2 L/min was established. This flow was designed to provide adequate hydraulic loading and allow for the development and establishment of biomass in the system (Duque-Sarango & Zagal-Andrade, 2023).. Parameters such as pH, electrical conductivity, temperature, aluminum (Al), calcium (Ca), iron (Fe), ammonia (NH_4^+), phosphorus (P) and chlorine (Cl) were examined, following the guidelines established in "Standard Methods of Water and Wastewater" (Clesceri et al., 2023). (Clesceri et al., 1998).. The BOD_5 was determined by the manometric method.

In terms of biomass, it was observed that the 45-day period was sufficient for the initial growth of *Iris pseudacorus* plants, which showed healthy establishment, suggesting a suitable environment for biological filtration and nutrient removal. Although the system was fed continuously, the operating parameters were adjusted to ensure that flow and application rates were consistent throughout the experiment.

After a period of 45 days, we proceeded to carry out a sampling campaign consisting of three monitoring campaigns of the system. The first sample was obtained by introducing 6 liters of water in a period of 2 minutes, resulting in the output of 4.5 liters of treated water from the system. For the second sample, 2 liters of water were introduced at 4-minute intervals, generating a total volume of 3.5 liters. The third sample was obtained by introducing 2 liters of water every 10 minutes. These measurements made it possible to establish the retention times necessary for the proper functioning of the system.

RESULTS AND CONCLUSIONS

Table 1 shows encouraging results on the effectiveness of the treatment system in improving water quality. A significant reduction in several key parameters is highlighted: turbidity decreased by 70%, indicating efficient removal of suspended particulate matter; BOD_5 showed a 72.3% reduction, suggesting efficient biological activity in organic matter degradation; TSS and ST varied in reducing values by 71% and 65%, respectively, indicating efficient removal of suspended matter and total solids during treatment. In addition, a significant decrease in iron, calcium and aluminum concentrations was observed, with removal percentages of 53.3%, 80.0% and 63.6%, respectively, suggesting the formation of precipitates or adsorption during treatment. Although phosphorus removal is relatively low (2.8%), it still represents a significant removal of this nutrient. The ammonia concentration in the outlet water also decreased by 40.8%, suggesting effective ammonia nitrogen removal during treatment.

With a hydraulic load of 0.2 L min^{-1} , the results showed that the organic matter removal rate measured as BOD was higher. This finding is of great relevance in the context of wastewater treatment, since organic matter is one of the main pollutants present in this type of water. A higher organic matter removal rate means a higher efficiency in wastewater purification, which leads to a significant reduction in pollution and, therefore, to an improvement in the quality of the treated water.

In summary, the results presented reveal a remarkable success of the treatment system in improving water quality. Significant reductions in multiple parameters were observed, including turbidity, BOD_5, TSS and ST, as well as Fe, Ca and Al concentrations. These findings highlight the importance of carefully considering operational parameters, such as hydraulic loading, to maximize the efficiency of wastewater treatment systems and their positive impact on the environment and public health.

Figure 1. Subsurface flow wetland design.

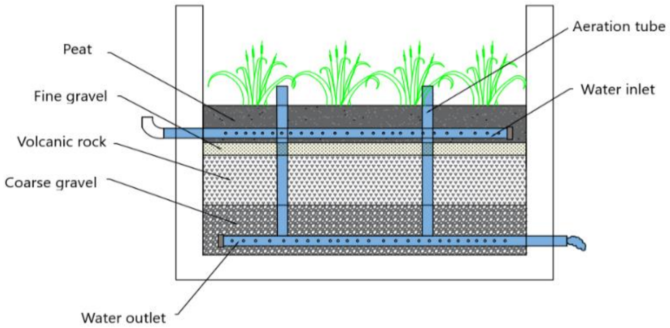

Table 1. Raw water characteristics and removal percentage

Parameter	Unit	Incoming water	Removal (%) outlet water
Conductivity	µs cm^{-1}	636 ± 87	-
pH	-	7.27±1.2	-
Temperature	°C	17±1.5	-
Turbidity	FTU	21±11	70.0
BOD_5	mgO_2 L^{-1}	265±54	72.3
Total solids (TS)	ppm	2216±345	65.0
Total suspended solids (TSS)	ppm	1748±285	71.0
Non-volatile suspended solids (NVSS)	ppm	340±45	-
Iron	ppm	0.15±0.05	53.3
Calcium	ppm	6.0±2.4	80.0
Aluminum	ppm	0.055±0.014	63.6
Phosphorus	ppm	0.72±0.15	2.8
Ammonia	ppm	1.74±0.45	40.8

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