Hydraulic Behavior of a Full-Scale Partially Saturated Vertical Flow Constructed Wetlands: Wastewater Production and Flow Rate

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Highlights:

- Monitoring of Hydraulic Behavior in a New Full-Scale PS-VFCW System.
- Flow variations observed across different days of the week and throughout the months.
- Effluent flow patterns in PS-VFCW units with varying saturation levels.
- The data collected provides valuable insights for the installation of new systems, contributing to the advancement of decentralized wastewater treatment solutions.

Keywords: Partially Saturated Vertical Flow Constructed Wetlands; Decentralized Wastewater Treatment; Hydraulic Behavior.

INTRODUCTION

Decentralized wastewater treatment plays a crucial role for the universalization of sanitation and the achievement of the United Nations Sustainable Development Goal number 6 (Clean Water and Sanitation) (UNITED NATIONS, 2021), particularly in developing countries such as Brazil (Tonetti et al., 2018). Vertical flow constructed wetlands (VFCW), particularly partially saturated ones (PS-VFCW), represent a promising technology in this context, offering a nature-based solution that is both highly efficient and has low operational and maintenance costs.

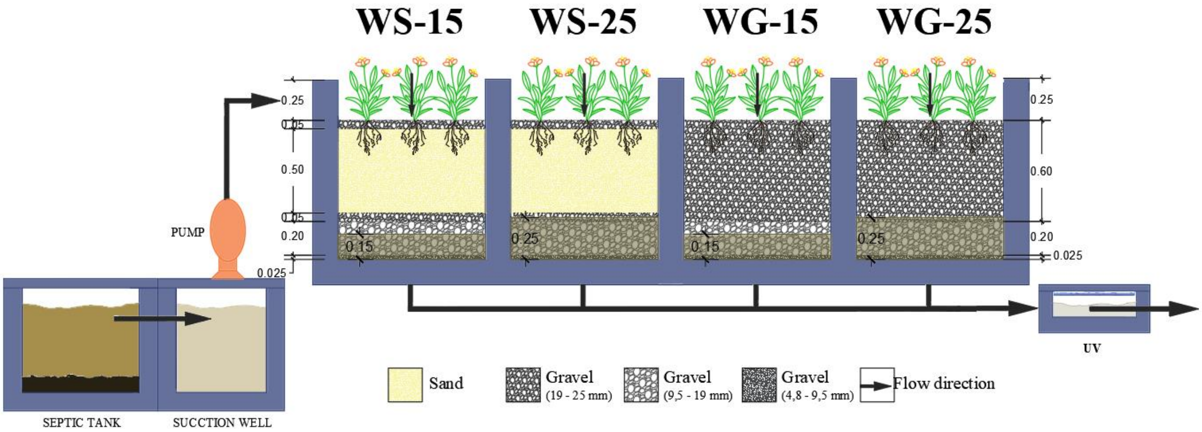
To facilitate the dissemination of this technology, it is essential to understand its inherent aspects, such as the hydraulic behavior of the system and the effluent production from the community it serves. Therefore, over the period of five months, right after the operation start of a system employing VFCW-PS (full-scale), the effluent production from the student residences at UFSM *campus* in Frederico Westphalen (Rio Grande do Sul, Brazil) was monitored, along with the monitoring of influent and effluent flow rates. The objective of this study is to present the preliminary data on the hydraulic behavior of this system and the effluent production, as well as challenges and future perspectives for system monitoring.

METHODOLOGY

The system started operation in September 2023 and serves approximately 72 people and consists of preliminary treatment (larger solids and sand retention), septic tank, suction well, four units of PS-VFCW (designated as WS-15, WS-25, WG-15 and WG-025), and ultraviolet radiation disinfection

(Figure 1). The PS-VFCW units nomenclature refers to their predominant supporting medium, sand (S) or gravel (G), and the level of partial saturation, either 0.15 m or 0.25 m. Each PS-VFCW were transplanted with *Canna x generalis* and has surface area of 23.80 m² and

Figure 1. Representative diagram of the system (dimensions in meters).



Wastewater is applied intermittently in batches, regulated by a level controller that activates the pump once the required level is reached. Thus, the number of batches per day varies according to the wastewater production and the school period (vacations, holidays, etc.). An electronic system was installed in December 2023 and remotely records pump activation data, registering the number of daily batches. Inflow rates are monitored by electromagnetic flow meters to ensure equal inflow to each unit. The outflow rates were manually measured using a beaker and a stopwatch during a single batch, starting precisely at pump activation and continuing for 158 minutes until the next batch. This work presents effluent hydraulic outflow data from the two gravel-based PS-VFCW units ($WG_{0.15}$, and $WG_{0.25}$) as well as the results of remote pulse monitoring during the first five months of operation.

RESULTS AND CONCLUSIONS

Each unit receives 0.3 m³ batch^{-1} in average. So far, wastewater generation is highest on Mondays, Tuesdays, and Saturdays. In December 2023, the average was 5 pulses day^{-1} with a gradual decline throughout the month as the vacation period began and students returned to their hometowns. By February 2024, the number of pulses dropped significantly, with no pulses recorded on some days, averaging 0.6 pulses day^{-1}, representing a decrease of 88% compared to December 2023. In March 2024, the wastewater generation increased once again with the students' return for the new semester (Figure 2). This illustrates the importance of monitoring effluent production when designing new systems that must withstand flow variations without compromising efficiency or functionality.

The campaign recorded the effluent flow rate (Figure 3) during a single batch from units WG-15 and WG-25, both with gravel as the supporting medium but differing in saturation level: 0.15 m and 0.25 m, respectively. A similar behavior of the units is observed: a rapid increasing in the flow rate, after the start of the batch, reaching a maximum flow rate at the end of the batch (approximately 7 minutes), followed by a constant decline. The maximum peak flow rate values differ with approximately 0.10 L s^{-1} between the units, with higher values for WG-15. Considering that the gravel in both units has very similar characteristics (mean diameter between 9.5 and 19 mm), this difference can be explained by Stevin's Theorem, since unit WG-15 has a higher water column above the saturation level, the pressure exerted increases the velocity, consequently, the flow rate. The permanence of the wastewater presents the same behavior in both units, approximately 50% of the incoming volume is drained within 20 min after the start of the batch, and the volume reaches 90% after 124 min.

Figure 2. Mean wastewater production on each day of the week (A) and the variation in the number of batches per week (B) from December 2023 to April 2024.

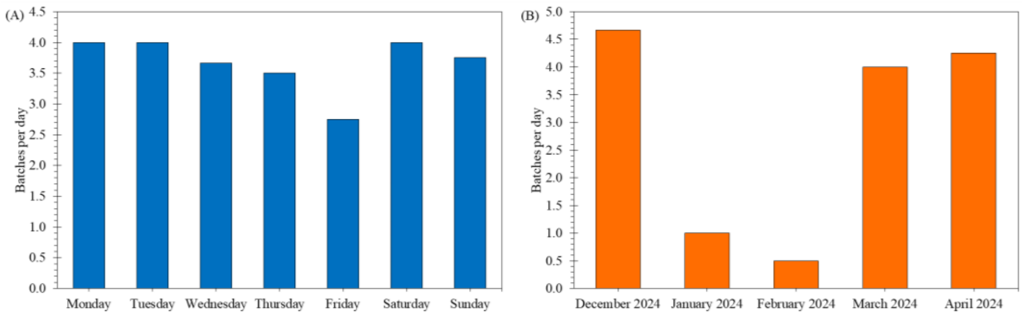
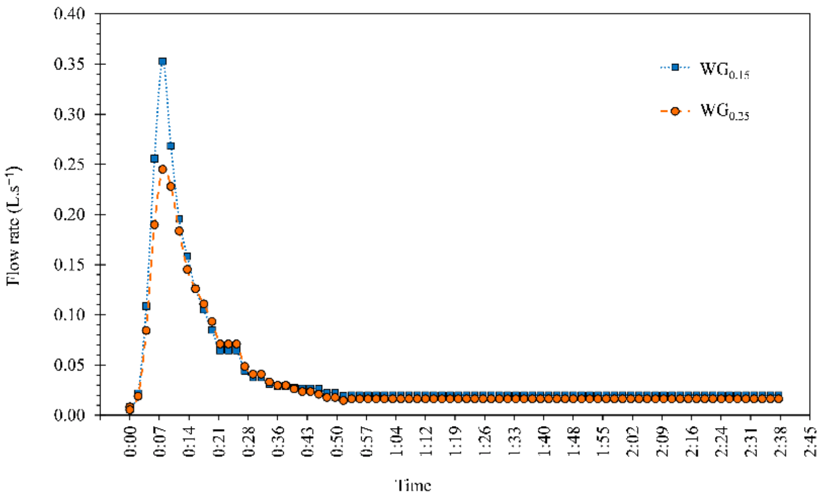


Figure 3. Effluent flow rate in units $WG_{0.15}$ and $WG_{0.25}$.



Real-scale studies such as this one are critical for the advancement of decentralized wastewater treatment. Ongoing hydraulic monitoring, along with physicochemical and microbiological analyses, will help correlate pulse frequency with removal efficiency. Long-term monitoring will also reveal trends in outflow behavior, filter clogging, system lifespan, and operational challenges. Ultimately, this will enable the development of a robust design framework for new PS-VFCW installations in similar contexts, based on long-term effluent production patterns observed at student housing facilities.

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