Vertical flow constructed wetlands for decentralized wastewater treatment: Insights from microbial removal efficiency in two real scale systems.

Ferreira, Fernanda Daniela Gonçalves*, Silva, Janaina Casado Rodrigues da*, Haiml, Camila***, Sezerino, Pablo Heleno** and Magri, Maria Elisa*

*Universidade Federal de Santa Catarina, Campus Trindade, Depto Engenharia Sanitária e Ambiental, Grupo RReSSa - Recuperação de Recursos em Sistemas de Saneamento. Florianópolis/SC, Brasil.
*Universidade Federal de Santa Catarina, Campus Trindade, Depto Engenharia Sanitária e Ambiental, GESAD - Grupo de Estudos em Saneamento Descentralizado. Florianópolis/SC, Brasil.
**Rotária do Brasil, Florianópolis/SC, Brasil.

Highlights:

- We evaluated the microbial removal efficiency of two constructed wetland systems.
- The saturated wetland was more efficient in removing bacteria.
- The non-saturated wetland had better removal of bacteriophages.
- Bacteriophages proved more resistant to elimination than bacteria.
- Results show the potential of constructed wetlands for enhancing water quality.

Keywords: Constructed wetlands; wastewater treatment; microbial removal; water quality.

INTRODUCTION

The presence of adequate sanitation is fundamental to safeguard public health and improve the overall well-being of individuals. Its absence is one of the main contributors to the prevalence of diseases, representing a significant challenge for public health, especially among children under the age of five in the Global South (WHO, 2018). The main pathogens that pose notable contamination risks include bacteria, viruses, protozoa, and helminths - enteric organisms excreted in the feces of infected individuals. These pathogens spread predominantly through the fecal-oral route, whether through contact with contaminated objects, consumption of contaminated water or food, or exposure to polluted bathing waters (WHO, 2018). Removing human pathogens from wastewater is an important factor related to human health, especially for the resource recovery approach. Constructed Wetlands are environmentally friendly systems that can potentially reduce chemical pollution and pathogens from wastewater (Wu, 2016). This study aims to evaluate the microbial removal efficiency of two vertical flow constructed wetland systems (saturated and non-saturated) under real-scale conditions, providing crucial insights into the differential performance of these systems regarding microbial and organic matter removal.

METHODOLOGY

Wastewater treatment plants studied

Two real scale systems were used in this study. The system 1 is a saturated vertical flow constructed wetland, located in the municipality of Palhoça, Santa Catarina State. The plant was designed for a multi-residential site with a maximum occupancy of 2,200 people. The system consists of an anaerobic reactor followed by the constructed wetland and a chlorination tank (Fig 1). This system began operating in 2006 and it has a surface area of 3,141 m². The macrophyte used is *Cyperus papiros*. the system is filled with 10 cm of gravel in the bottom and 50 cm of coarse sand (d10 = 0.3 mm and U = 4.84). The system is divided into four quadrants and feeding occurs alternately in two quadrants every 30 days. The average flow is 230 m³/day and the organic loading rate 148 gCOD/m². day.
System 2 is a vertical flow constructed wetland located at Florianópolis/SC in a Department store with a maximum expected occupancy of 714 people. The system is composed of a septic tank followed by the constructed wetland, phosphorus chemical precipitation and a chlorination tank (Fig 2). This system has a surface area of 35.91 m² and is filled with a sand layer in between two gravel layers. The average flow is 4.9 m³/dia and the organic loading rate is 67 gCOD.m². day.

Sampling

We collected influent and effluent samples from the constructed wetlands for evaluation of the removal efficiency of microbial indicators once a month in the two systems, from September 2022 to December 2023. Effluent samples were specifically taken from the outflow of the wetlands before entering the chlorination tank. No samples were collected or analyzed from the post-chlorination tank (Fig 1 and 2). Samples were analyzed for total *E. coli, enterococcus,* and viral indicators bacteriophages ΦX and MS2. Herein we call system 1 - saturated vertical flow constructed wetland S1-SVF and system 2 - vertical flow constructed wetland S2-VF.

Figure 1: System 1.

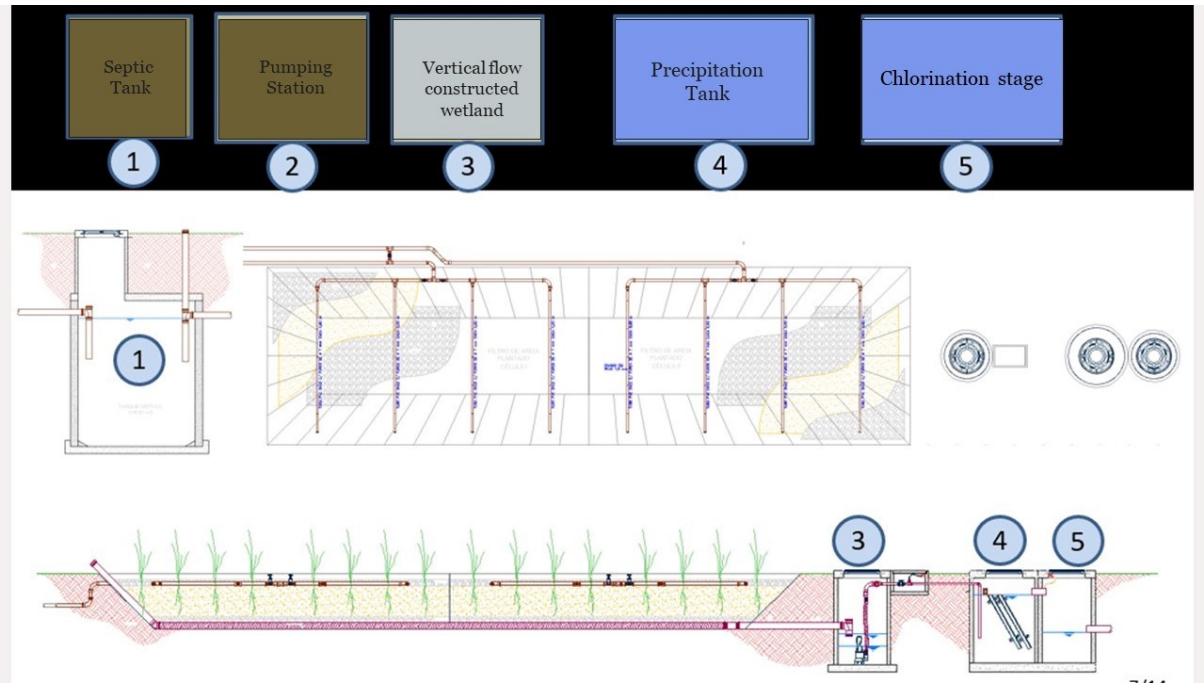
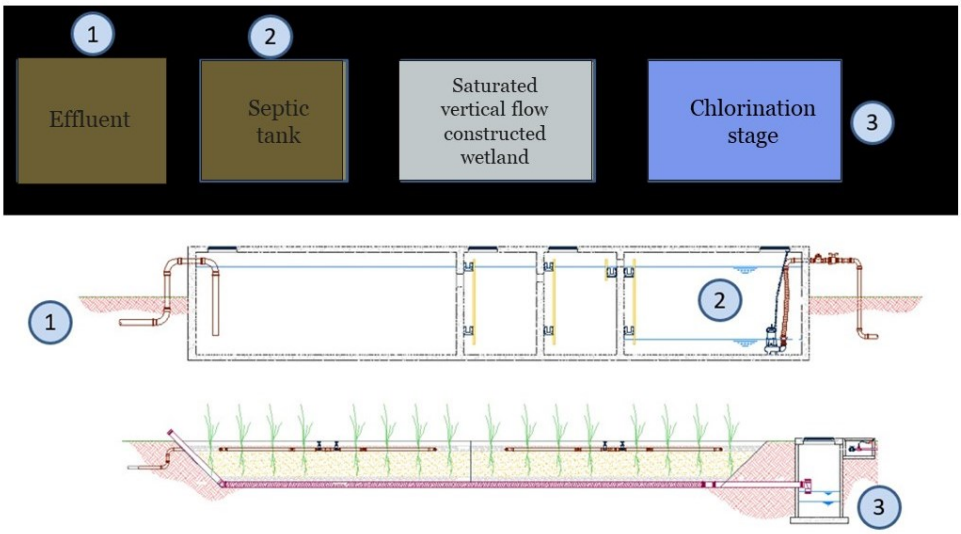


Figure 2: System 2.



Data analysis

The results of the enumeration of the tested micro-organism were expressed in CFU and PFU per ml and were log10 transformed. The mean and standard deviation were calculated using excel software.

RESULTS AND CONCLUSIONS

Average data for the 16 months of analysis for all the microorganisms tested are in table 1 for the S1-SVF and in table 2 for the S2-VF. Additionally, data of Chemical oxygen demand (COD) in inflow and outflow, as well as the efficiency of COD removal has been presented for each system. The technological arrangements have the potential for removing pathogenic indicators until approximately 1.6 log units (e.g. Enterococcus species for S1). Additionally, system 1 (S1-SVF) presented an efficiency of 93.8% in COD removal. The system 2 (S2-VF) shows less reduction of the bacteria *E. coli* and COD removal compared to the system 1. The efficiency in COD removal in system 2 was 74.7%.

In system 1, it was observed that bacteriophages were more resistant to elimination than bacteria. However, system 2 showed that the bacteriophage ΦX was less resistant to removal than bacteria *E. coli.*The saturated wetland was more efficient in removing bacteria and COD than the non-saturated one, and the opposite was detected for bacteriophages.

The results obtained from the present study highlight that constructed wetlands can achieve high organic matter removal, with better efficiency in the saturated wetland, even operating with more than twice the organic loading rate, in comparison to the free vertical flow. Constructed wetlands also contributed to the removal of pathogens, with better results for bacteria than virus indicators in general. Other sequences of barriers should be evaluated if the intention is the recycling of effluent.

Table 1 - Average and standard deviation microbial data and COD for System 1.

System 1 - Saturated vertical flow constructed wetland			
	Inflow	**Outflow**	**Removal Efficiency**
***Escherichia coli* (CFU.mL^{-1})**	4.73 ± 0.49	3.31 ± 0.60	1.421
***Enterococcus* (CFU.mL^{-1})**	4.05 ± 0.71	2.82 ± 0.12	1.227
ΦX (PFU.mL^{-1})	2.96 ± 0.50	2.96 ± 0.50	0.001
MS2 (PFU.mL^{-1})	2.6 ± 0.88	2.48 ± 0.66	0.116
pH	7.13 ± 0.37	6.40 ± 0.43	-
Chemical oxygen Demand (mg/L)	1011±1477	62±16	93.8%

Table 2 - Average and standard deviation microbial data and COD for System 2.

System 2 - Vertical flow constructed wetland			
	Inflow	**Outflow**	**Removal Efficiency**
***Escherichia coli* (CFU.mL^{-1})**	4.27 ± 0.61	3.90 ± 0.72	0.364
***Enterococcus* (CFU.mL^{-1})**	4.09 ± 0.58	2.48 ± 0.14	1.617
ΦX (PFU.mL^{-1})	3.24 ± 0.33	2.04 ± 0.75	1.200
MS2 (PFU.mL^{-1})	2.83 ± 0.65	2.63 ± 0.54	0.202
pH	7.56 ±0.55	7.05 ± 0.45	-
Chemical oxygen Demand (mg/L)	490±183	124±68	74.7%

REFERÊNCIAS

Rampuria, A., Gupta, A. B., Kulshreshta, N. M., & Brighu, U. (2021). Microbiological analysis of two deep constructed wetlands with special emphasis on the removal of pathogens and antibiotic-resistant bacteria. Water, Air, & Soil Pollution, 232(5), 174.

World Health Organization (WHO). (2018). Guidelines on Sanitation and Health. Geneva: WHO.

Wu, S., Carvalho, P. N., Müller, J. A., et al. (2016). Total environmental sanitation science in constructed wetlands: A review on the removal of human pathogens and fecal indicators. Science of The Total Environment, 541, 8–22. https://doi.org/10.1016/j.scitotenv.2015.09.047

Zhong, X., Teng, X., Tang, B., Lin, X., Chen, J., Zhao, R., Wu, Q., & Huang, X. (2024). Constructed wetland treating mine drainage wastewater: Performance and microbial mechanisms. Journal of Water Process Engineering, 60, 105244. https://doi.org/https://doi.org/10.1016/j.jwpe.2024.105244