IWA 17th SWWS AND 9th ROS
10th–14th November, 2024
Curitiba-Brazil

Technological matrix for selecting constructed wetlands arrangement for reclaiming water

Ribeiro, T.*, Sousa, A. R.* and Sezerino, P. H.*

* GESAD – Decentralized Sanitation Research Group, Department of Sanitary and Environmental Engineering, Federal University of Santa Catarina, Florianópolis, Santa Catarina 88040-900, Brazil.

Highlights:

- The potential for reusing treated wastewater by the WC-FSS ecotechnology in Brazil is evident.
- The context, the required area and flow rate have proven to be determinants for technology selection.
- Source segregation of generated wastewater is important for the quality of the produced reuse water.

Keywords: Constructed wetland; Water reuse; Resource recovery.

INTRODUCTION

Wastewater treatment through Nature-Based Solutions (NbS) stands out for its low maintenance and operational cost, and applicability in regions where centralized systems are economically unfeasible (PINNINTI et al., 2021). Among NbS, constructed wetlands (CW) have emerged as a consolidated alternative, being studied in Brazil since the 1990s (SILVA; SEZERINO, 2021). The effluents generated in these systems have low turbidity and organic matter content, but face challenges in removing nutrients, such as nitrogen and phosphorus compounds. Thus, the effluent takes on the role of water with potential for reuse, aligning with the principles of circular economy and the strategic practices of the 2030 Agenda. In this context, the aim of this study was to categorize WC systems in the Brazilian territory and evaluate the treated effluent quality in relation to current legislation, in order to develop a technological matrix that assists in choosing the most suitable technological arrangement to enable effluent reuse.

METHODOLOGY

A Systematic Literature Review was conducted, using the search string ("constructed wetland" OR "treatment wetland") AND ("reuse") AND NOT ("industrial") in the Web of Science and Scopus databases. From there, the methodology and results of publications were analyzed, selecting works that provided information on system configurations, criteria, and design parameters (population equivalent, applied flow rate, hydraulic loading rate), as well as the performance achieved by constructed wetlands in wastewater treatment (physicochemical and microbiological characterization). In the end, 50 articles studying Subsurface Flow Constructed Wetlands (SFCW) were chosen (SOUSA, 2023).

RESULTS AND CONCLUSIONS

The total of 65 wastewater treatment systems were mapped across the North (1 rural), Northeast (2 urban, 2 rural, and 1 peri-urban), Midwest (1 urban and 2 rural), Southeast (8 urban, 5 rural, and 2 peri-urban), and South (10 urban, 29 rural, and 2 peri-urban) Brazilian regions. Six main macrophyte genre were used (24% *Cyperus* spp., 22% *Typha* spp., *15% Canna indica* L., 10% *H. coronarium*, 5% *Equisetum* sp., 5% *Cymbopogon* sp., and 19% others), along with four main bed media materials (53% sand, 35% gravel, 5% pebble, 2% soil, and 5% others). There were also variations in the hydraulic retention time (HRT), with 22% of the systems having HRT > 5 days, 17% with 3 < HRT ≤ 5 days, 44% with 1 < HRT ≤ 3 days, and 17% with HRT ≤ 1 day. Thirteen different technological arrangements were observed. The configuration of Septic Tank (ST) followed by WC accounted for 26 out of 65 systems, with 6 in urban settings and the remainder in rural settings. Anaerobic Baffled Reactor (ABR), Anaerobic Filter (AF), Sequencing Batch Reactors (SBR), Upflow Anaerobic Sludge Blanket (UASB), Biological Filter, Polishing Pond (PP), Decanter, and Stabilization Pond were also identified. Horizontal Constructed Wetlands (HCW), Vertical Constructed Wetlands (VCW), and Hybrid Systems (HS) were observed, distributed across urban settings (8 HCW, 11 VCW, and 2 HS), rural settings (24 HCW, 13 VCW, and 3 HS), and peri-urban settings (2 HCW, 2 VCW, and 1 HS).
To assess effluent quality, the systems were divided according to the generating source, and their average values were calculated and compared with current Brazilian legislation regarding treated effluent reuse. Thus, the effluents were classified into 5 categories, as shown in Table 1.

Table1. Average values classified according to relevant Brazilian legislation.

	Urban Reuse								Agricultural Reuse			
	pH	[1]BOD	[1]TN	[1]NH_4^+	[1]NO_3^-	[1]TP	[2]TC	[2]EC	pH	[1]BOD	[2]TC	[2]EC
Ra	7.1	41.2	76.9	41.7	5.4	6.9	7.29E+05	9.52E+04	7.1	41.2	7.29E+05	9.52E+04
Rb	7.2	84.2	40.7	63.7	7.6	7.2	6.68E+03	2.41E+06	7.2	84.2	6.68E+03	2.41E+06
Rc	6.7	21.4	13.8	8.7	10.5	1.5	3.13E+04	1.74E+04	6.7	21.4	3.13E+04	1.74E+04
P	6.8	47.7	25.5	-	-	1.6	-	3.45E+03	6.8	47.7	-	3.45E+03
Ua	7.5	34.0	8.4	18.5	7.0	0.3	469.0	7.08E+03	-	-	-	-
Ub	7.5	74.0	8.4	18.5	7.0	0.3	1.00E+04	1.57E+05	-	-	-	-
Uc	6.9	24.0	10.6	37.1	10.8	3.4	2.95E+06	1.0E+04	-	-	-	-

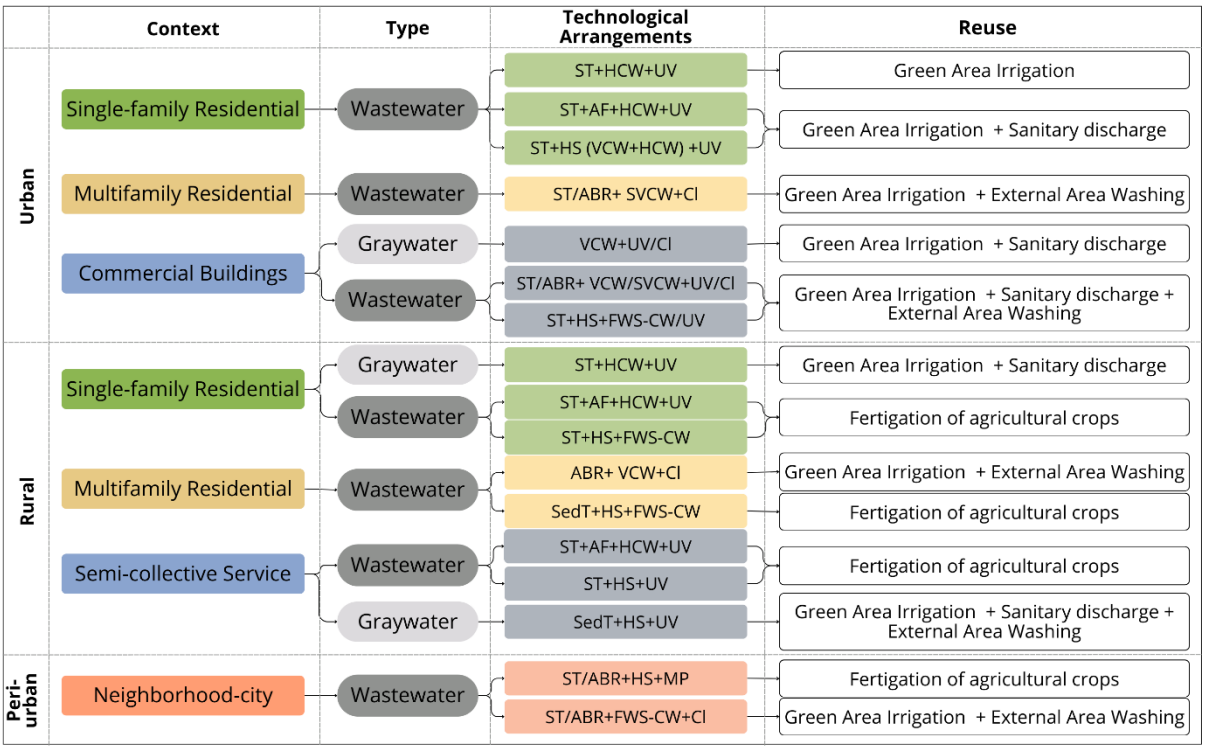
Meet all | Meet some regulations | Meet regulations for restricted use only | Specify case | Does not meet

Note: Ua: single-family residential in urban setting; Ub: multi-family residential in urban setting; Uc: commercial building in urban setting; Ra: single-family residential in rural setting; Rb: multi-family residential in rural setting; Rc: semi-collective services in rural setting; B: neighborhood-city; BOD: Biological Oxygen Demand; TP: Total Phosphorus; TC: Thermotolerant coliforms; EC: *Escherichia coli*. [1]$mg.L^{-1}$ [2]NMP $.100mL^{-1}$

The potential for reusing treated wastewater by the SFCW ecotechnology in Brazil is evident, with 43% of the units allowing urban reuse and 67% meeting standards for agricultural reuse. Based on Table 1 and current Brazilian legislation, removal intervals necessary for each scenario and reuse were generated. Subsequently, the technological matrix of Figure 1 was structured aiming to guide the choice of technological arrangements enabling resource recovery and circularity. It includes arrangements composed of technologies consolidated in the national territory (ST, ABR, HCW, and chlorination) and common technologies in systems aimed at wastewater reuse (sedimentation tanks, HS, and UV radiation).

The context, the required area and flow rate have proven to be determinants for technology selection. For primary treatment, low flows can be met by ST, while ABR serves high values. Regarding CW, HCW is suitable for simplified and single-family contexts, VCW is preferable for commercial buildings, HS for rural areas, and Saturated Vertical-flow Constructed Wetlands (SVCW) for multifamily, commercial, or peri-urban contexts. Chlorination is recommended for disinfection in commercial, multifamily, and peri-urban systems, while UV is preferable for rural single-family scenarios. Source segregation of generated wastewater is important for the quality of the produced reuse water. It is also essential to assess the technology's insertion context and adjust it for required sizing and operation.

Figure 1. Technological matrix to assist in the selection of technological arrangements for generating reused water in the Brazilian context.



Note: ST: Septic Tank; HCW: Horizontal Flow Constructed Wetland; VCW: Vertical Flow Constructed Wetland; UV: Ultraviolet Radiation; AF: Anaerobic Filter; HS: Hybrid System (HCW+VCW); ABR: Anaerobic Baffled Reactor; SVCW: Saturated Vertical-flow Constructed Wetland; Cl: Chlorination; FWS-CW: Free Water Surface Constructed Wetland; SedT: Sedimentation Tank; MP: Maturation Pond.

ACKNOWLEDGMENTS

To the Federal University of Santa Catarina (UFSC) for the infrastructure and to the Coordination for the Improvement of Higher Education Personnel (CAPES) for financial support.

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