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Technical Article

Considerations on design and implementation parameters of domestic wastewater treatment by subsurface flow constructed wetlands

Considerações sobre parâmetros de dimensionamento e implantação de wetland *construída de fluxo subsuperficial no tratamento de esgoto doméstico*

Lis Eveline Athaydes Fadanelli[1]*, Alceu Gomes de Andrade Filho[1], Giovana Kátie Wiecheteck[1], Maria Magdalena Ribas Döll[1]

ABSTRACT

Constructed wetlands might be an alternative for communities away from urban centers and not served by a domestic wastewater treatment system. The purpose of this study was to provide instructions for the implementation of subsurface flow constructed wetland systems. To that end, we gathered information regarding the construction aspect, plants, and operational parameters used in systems which already operate in the country and the respective efficiency of these sets after previous treatment. The system in real scale proposed by Oliveira *et al.* (2005) was prominent among those that presented the highest efficiency. It was preceded by upflow anaerobic reactor built in brick, with macrophyte of the *Typha* genre, crushed stone at the entry and exit of the system, and sand in its intermediate portion. It required 1.04 m^2 surface area per inhabitant in humid temperate climate and hot summer, 1.71 m^3 d^{-1} flow, and one-day hydraulic detention. The considerations presented here might help the construction of this kind of system, regarding dimensional and operational criteria.

Keywords: constructed wetlands; sewage; wetlands; decentralized treatment.

RESUMO

As *wetlands* construídas podem ser uma alternativa para comunidades afastadas de centros urbanos que não são atendidas por rede de tratamento de esgoto. Visando à orientação para implantação do sistema de *wetlands* construídas de fluxo subsuperficial, foi levantada uma série de informações a respeito dos aspectos construtivos, das plantas e parâmetros operacionais utilizados em sistemas já em funcionamento no país e a respectiva eficiência do conjunto, após um tratamento precedente. Entre os sistemas que apresentaram melhor eficiência, destacou-se o de Oliveira *et al.* (2005) em escala real, precedido por reator anaeróbio de fluxo ascendente, construído em alvenaria, com a macrófita do gênero *Typha*, brita na entrada e saída do sistema e areia na parte intermediária, com uma área superficial de 1,04 m^2 por habitante de clima temperado úmido com verão quente, vazão de 1,71 m^3 d^{-1} e tempo de detenção hidráulica de um dia. A elaboração das considerações apresentadas neste trabalho pode auxiliar na construção desse tipo de sistema, construído nos critérios de dimensionamento e operação.

Palavras-chave: sistema de alagados construídos; esgoto sanitário; áreas alagadas; tratamento descentralizado.

INTRODUCTION

Constructed wetlands have been presented as an alternative of decentralized sewage treatment, simulating a natural wetland environment, with basic ecological mechanisms (DORNELAS; MACHADO; VON SPERLING, 2009) allied to principles of Civil and Sanitary Engineering. According to Costa *et al.* (2003), who evaluated artificial wetlands in real-pilot scale at the Paraíba Federal University, the system had low cost and was easy to operate and maintain.

These systems can be used as secondary or tertiary treatment composed by substrate, typical plant species, and microorganisms. The microfauna community structure and bacterial removal are clearly affected by vegetation and flow type (PEDESCOLL *et al.*, 2016) and can be used as a tertiary treatment of emerging contaminants, including pharmaceuticals, personal care products, plasticisers, flame retardants, surfactants, and certain pesticides (MATAMOROS; RODRÍGUEZ; BAYONA, 2017).

[1]Universidade Estadual de Ponta Grossa – Ponta Grossa (PR), Brazil.
*Corresponding author: lis_eveline@hotmail.com
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Substrate creates empty spaces which serve as flow channels, making wastewater flow more easily, according to its permeability, in addition to giving support to plants. This support, along with the roots, provides the ideal place for nutrient removal and formation of microbial biofilm. Macrophytes — plants with specific characteristic to grow in damp places — incorporate air through the leaves and transfer it to rhizomes and roots, which send oxygen to the substrate, promoting the formation of a microbial biofilm, and capturing, through the roots, nutrients and other substances from the effluent that feeds the system (GANSKE; ZANOTELLI, 2008). The microbial biofilm developed in the rhizosphere of the real-pilot scale, comprising roots and substrate, consists of microorganisms that degrade organic matter, making the nutrients available to macrophytes (COSTA *et al.*, 2003; PEDESCOLL *et al.*, 2016).

Constructed wetlands are classified according to their flow into surface and subsurface. In the surface flow, the effluent flows above the support medium, while in the subsurface flow, the wastewater flows below the substrate surface. Toniato (2005) concluded that the subsurface flow wetland requires a smaller area than the surface flow wetland for system implementation and does not expose sewage flow to the environment, reducing the chances of human or animal contact and preventing the proliferation of vectors such as insects as well as the release of bad odors. In addition, subsurface flow wetland is more efficient.

Subsurface flow wetlands can be subdivided into vertical and horizontal flow. In the vertical flow, the effluent to be treated is distributed in the support layer surface, being gradually drained next, and going through all the layers of the constructed bed vertically (LANA *et al.*, 2013). On the other hand, in the horizontal flow, the effluent goes through the filling material and macrophyte roots horizontally (MATOS; VON SPERLING; MATOS, 2018).

Olijnyk *et al.* (2007) pointed out that the area/inhabitant ratio greatly influences the efficacy and system lifetime, and that other parameters such as temperature, applied loads, and hydraulic retention time must be taken into consideration. Toniato (2005) cited that the effluent detention time needed is proportional to the organic load applied. However, the system treatment capability tends to decrease with the reduction in temperature. More sunlight makes the plant develop faster, leading to an increase in water loss through evapotranspiration, reducing the volume of wastewater discharged after treatment.

There are many options and design parameters according to the region of implementation of this alternative and self-sustaining technology as a simplified domestic wastewater treatment, which might confuse the designer, hindering a comparative analysis and a trend towards standardization (SEZERINO *et al.*, 2015).

This study aimed at elaborating practical and safe considerations for the implementation of domestic wastewater treatment systems using subsurface flow constructed wetlands, based on comparisons of efficiency and performance of configurations reported in the scientific literature.

METHODOLOGY

The study was based on theoretical background. We surveyed theses, dissertations, papers in journals, reports, and projects already published by several authors, focusing on constructed wetland treatment systems aimed at treating domestic wastewater. We compared vertical and horizontal flows using the data collected and classified all information according to flow direction to present the results.

Other important variables used to select the technology with the best overall performance were: identification of systems that preceded the constructed wetlands, construction aspects and dimensions, which made possible to establish the relation between the area needed to treat the wastewater generated per inhabitant (m^2 $inhab^{-1}$), later used to calculate the system implementation area (A), filling materials, and operational parameters (hydraulic detention time, applied load, and regional climate).

Whenever this relation was not present in the written material analyzed, we needed to consider average standard households, according to NBR 7229 (ABNT, 1993). The next step was to relate the system entry daily flow (Q) to the daily contribution per inhabitant (N) who would be favored by a constructed system, according to Equation 1. With the dimensions presented and the height fixed at one meter (H = 1.0 m), we could estimate the relation of area per inhabitant (m^2 $inhab^{-1}$), Equation 2.

$$N = \frac{Q}{C} \quad (1)$$

In which:
N: number of inhabitants contributing to the wetland unit (inhab.);
Q: flow of the contribution (m^3 d^{-1});
C: wastewater contribution per inhabitant (m^3 $inhab^{-1}$ d^{-1}).

$$A / inhab = \frac{\left(\frac{V}{H}\right)}{N} \quad (2)$$

In which:
A/inhab: Constructed wetland area per inhabitant (m^2 $inhab^{-1}$);
V: volume (m^3);
H: height (m);
N: number of inhabitants contributing to the wetland unit (inhab.).

Based on the information gathered, the system selected was that which presented the best performance regarding the efficacy of biochemical oxygen demand (BOD) removal, chemical oxygen demand (COD), pathogens, nitrogen, and phosphorus, allied to the smaller implementation area, calculated using Equation 3.

$$A = Nx\ (A/inhab) \quad (3)$$

In which:

A: necessary area to implement the wetland (m^2);

N: number of inhabitants contributing to the wetland unit (inhab.);

A/inhab: constructed wetland area per inhabitant ($m^2\,inhab^{-1}$).

Lastly, we elaborated the considerations for the construction of wetlands based on the previously selected system.

RESULTS AND DISCUSSION

Diagnosis of the previous treatment of constructed wetlands

Among the treatment systems that preceded the horizontal flow constructed wetlands reported in the scientific literature, 28% were septic tanks and 20% were anaerobic reactors (Figure 1A). According to Von Sperling (2013), BOD removal by anaerobic rectors ranges from 60 to 80%, information corroborated by Costa *et al.* (2013) who noted a BOD removal efficiency of 72% over four years, during which an upflow anaerobic sludge blanket (UASB) reactor was monitored. Septic tanks presented BOD removal efficiency between 30 and 60%. These technologies are well established, conventional, and easy to build, making them economically viable (AZEVEDO NETO, 1977). This might explain the widespread use of these systems as treatments preceding wetlands to remove part of the organic matter, despite the existence of more efficient technologies such as anaerobic reactors.

Figure 1B presents the alternatives of preceding systems used for vertical flow constructed wetlands, indicating the septic pit as the most used for this flow, followed by septic tank. Septic pits are also affordable systems and easy to build, leading them to be largely adopted in regions with no sewage collection and treatment at their disposal. However, their low COD removal efficiency — between 30 and 40% — requires them to be used in association with other technologies that complement the treatment.

Construction aspects of constructed wetlands

Traditional building materials (mortar, concrete, bricks) are commonly used in the implementation of constructed wetlands. In addition, waterproofing materials are largely employed, due to the need to guarantee the sealing of system walls, which, according to Dornelas, Machado and Von Sperling (2009), is essential to retain the substrate that supports the macrophyte and bacterial biofilm growth and prevent soil or groundwater contamination through percolation.

Figure 2A and 2B show the materials used, respectively, in horizontal and vertical flow constructed wetlands, as reported in the literature.

The frequent (37%) use of plastic canvas was observed as the only material for the implementation of vertical flow constructed wetlands (Figure 2B). This might be justified by the fact that the effluent reaches the lower part of the system almost totally treated, reducing the impact

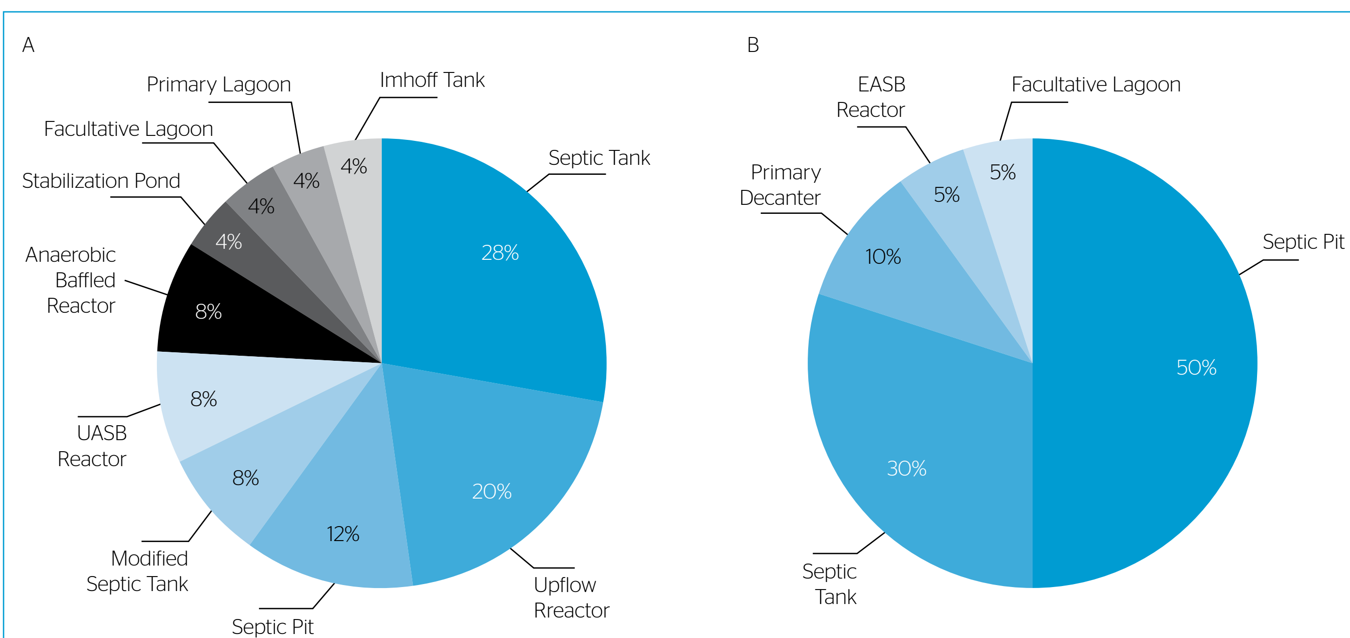

Figure 1 – Distribution of the technology used as treatment preceding the horizontal (A) and vertical (B) flow constructed wetlands in the evaluated works.

of possible contamination through leakage if the plastic canvas is torn by some sharp material. This fact added to the low cost of plastic canvas makes its use attractive.

Regarding the filling material or support medium, the use of gravel or some alternative material with similar granulometry was identified in 67% of the systems under study (Figure 3A), at the entry and exit points.

Costa *et al.* (2003) explained that the use of a support with such characteristics is essential as it facilitates the affluent distribution all over the bed, reducing the current impact on the biofilm, promoting more even effluent distribution, and increasing the assimilation of pollutants by roots and microorganisms. The intermediary part used finer material such as sand, due to the need to reduce the effluent speed of the primary treatment by the system, increasing the contact time with microorganisms that will act in the decomposition of the organic matter present. Cano, Gomes and Nolasco (2011) evaluated a real-pilot scale and explained that the smaller the area of the filtering material

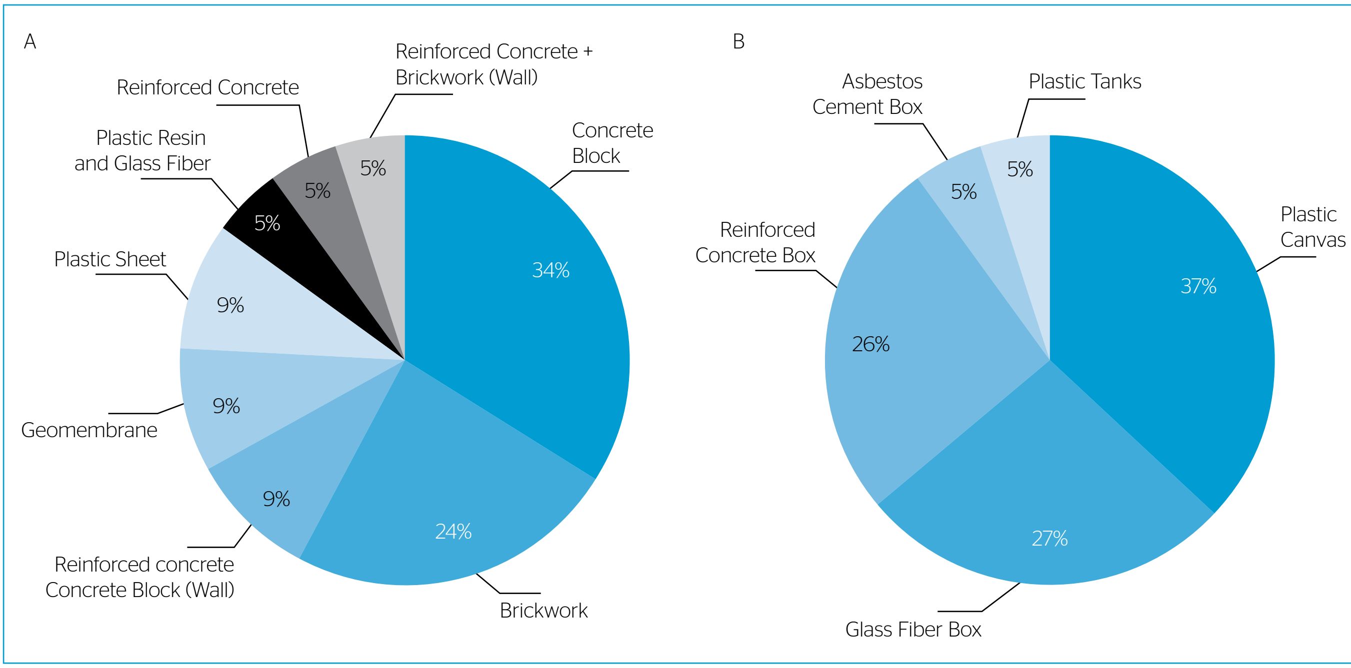

Figure 2 – Distribution of materials used to construct horizontal (A) and vertical (B) flow wetlands in the evaluated works.

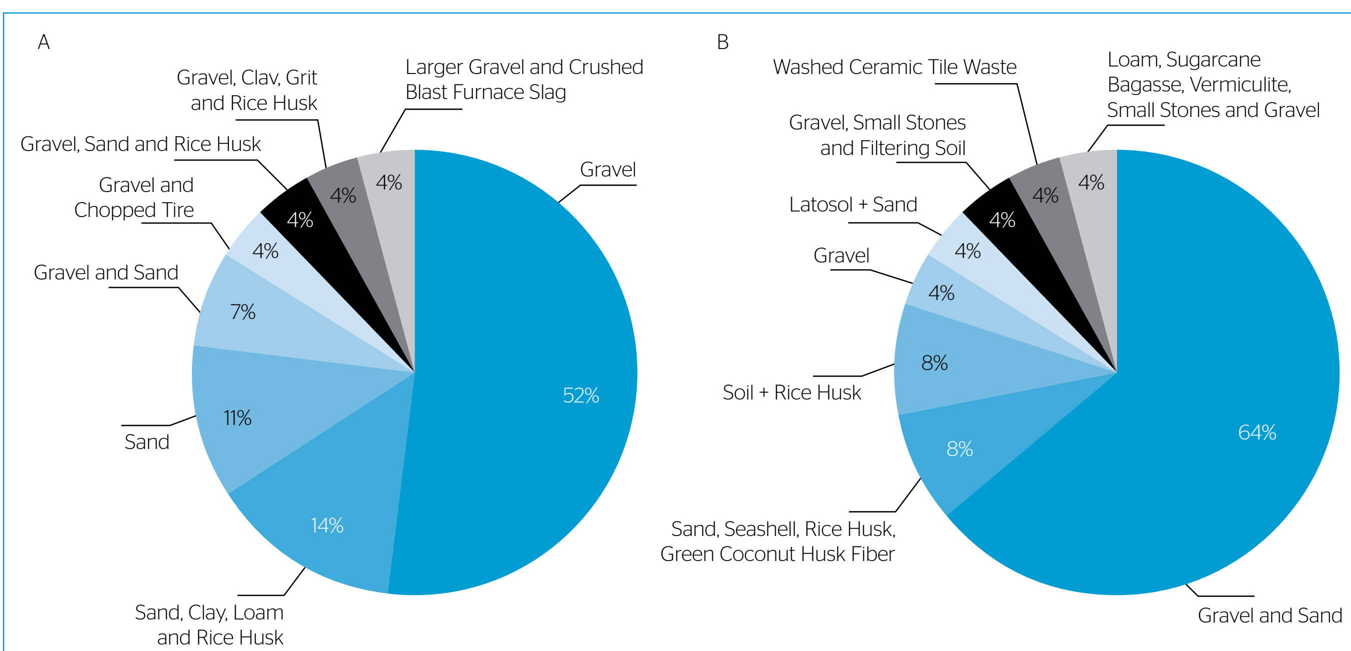

Figure 3 – Substrate used to construct horizontal (A) and vertical (B) flow wetlands in the evaluated works.

the better the filtering result, therefore, improving the removal of solids, which will get stuck in the filtering material.

In horizontal affluent distribution systems, the substrate must be placed in series, blocks, or bands throughout the wetland profile. In most vertical systems under analysis, the substrate was distributed in layers (Figure 3B). According to Zanella (2008), who worked in real scale wetlands, the layers should be installed in the longitudinal length of the wetland area with constant height, which would make the affluent go through all the different sizes that form the substrate, guaranteeing reduced impact of the wastewater entry and percolation speed, and providing the necessary contact time with microorganisms. Vertical flow needs materials of larger granulometry, such as gravel, in places where the distribution pipes are installed to prevent the fine material from clogging the pipelines.

Macrophytes grown in constructed wetlands

The choice of which plants to use in constructed wetlands should be related to their tolerance to water saturated environments, their growth potential, climate conditions in the implementation area, and planting and maintenance costs (regular trimming, reuse, etc.) (DORNELAS; MACHADO; VON SPERLING, 2009).

The species *Typha* has been the most used in horizontal flow projects (Figure 4A). This plant is very vigorous, producing a great number of rhizomes per hectare, is quite abundant all over Brazil, and can stand high temperatures. Another relevant factor is its tolerance to high concentrations of heavy metals (BIANCO; PITELLI; PITELLI, 2003). On the other hand, systems using plants from the families *Commelinaceae* and *Asteraceae* presented the best adaptation and performance among horizontal flow systems. It is noteworthy that systems with these plants operated longer with hydraulic detention time than the other systems under evaluation (TONIATO, 2005).

Tölke *et al.* (2011) explained that several species from the family *Commelinaceae* present ornamental potential, are easy to grow, and have a good development in the shade. The family *Asteraceae* has plants with spontaneous vegetation and environmental adaptation ability, which makes their use in constructed wetlands viable (NAKAJIMA; SEMIR, 2001).

In the vertical flow (Figure 4B), despite the predominant use of the species *Zantedeschia aethiopica*, the plants *Oryza sativa L.* and *Colocasium antiquorum*, *Zantedeschia aethiopica* and *Colocasium antiquorum* had the best performances. These plants, which belong to the family *Araceae*, predominate in tropical and sub-tropical regions (CORRÊA *et al.*, 2005). Species from the family *Araceae* are not frequently found in cold regions and present better development at 16 and 30°C, except for the *Zantedeschia aethiopica*, which resists to temperatures below 0°C (SANTOS, 2011).

The *Zantedeschia aethiopica* is an ornamental plant that can be used in constructed wetlands to produce commercial flowers, resulting in a harmonious landscape effect, without reducing system efficiency. Nonetheless, it is highly susceptible to plagues and diseases, unlike the *Colocasium antiquorum*. The need for abundant water to grow successfully and its great adaptability to different climate conditions make *Oryza sativa L.* suitable to be used in constructed wetlands (MAIER, 2007).

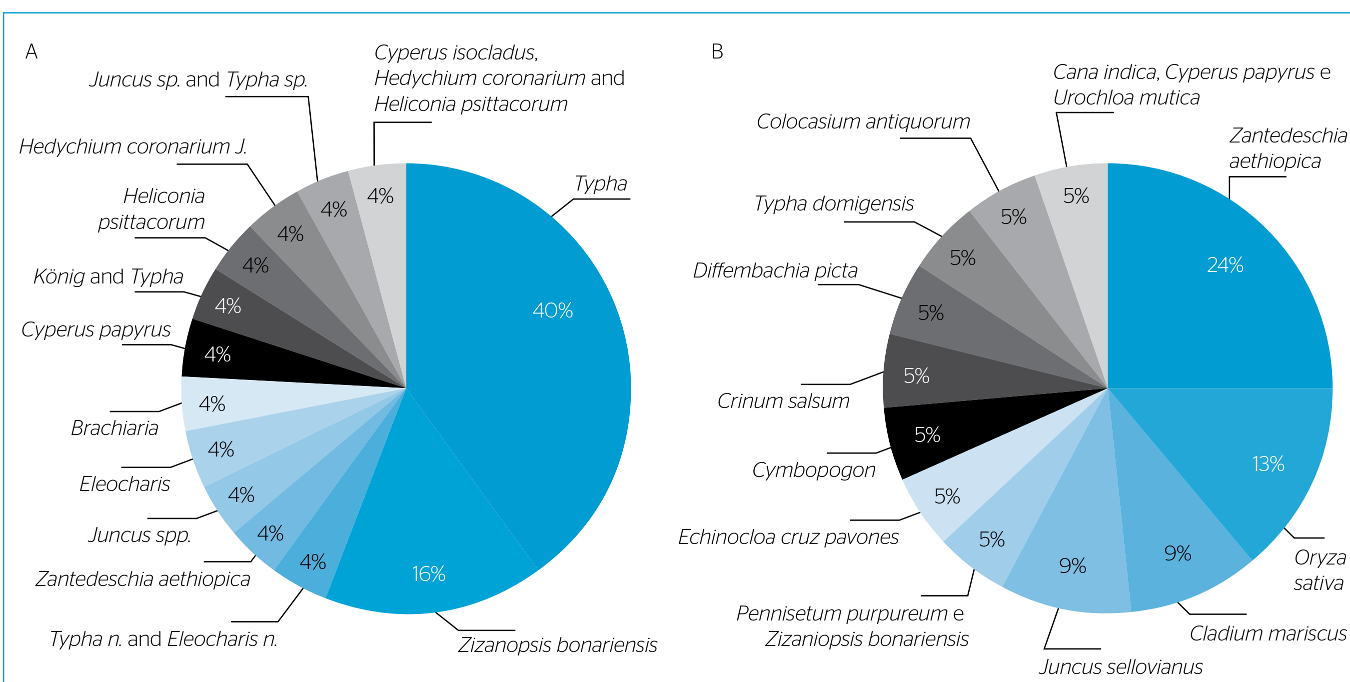

Figure 4 – Types of plants used in horizontal (A) and vertical (B) flow constructed wetlands in the evaluated works.

Performance parameters of constructed wetlands

Applied hydraulic load

Platzer *et al.* (2007) applied the hydraulic load rates suggested by Chernicharo *et al.* (2001) (146 and 205 mm.d^{-1}) on a pilot scale. However, this band is considered high compared to the 2 to 30 mm.d^{-1} hydraulic load rate. Platzer *et al.* (2007) noticed that the applied hydraulic load influenced substrate clogging due to the high content of organic load found in the system entry area. In addition, the effluent went through the system without appropriate treatment due to lack of time. Recently, Matos, Von Sperling and Matos (2018) evaluated the influencing factors for the clogging in horizontal subsurface flow constructed wetlands. They indicated that the material should be as inert as possible, being less subject to wear and, therefore, the release of inorganic solids that contribute to clogging the pores of constructed wetlands.

Hydraulic retention time

The hydraulic retention time (HRT) needed to reach good levels of organic matter decomposition varies according to the organic load applied. Results obtained by Olijnyk *et al.* (2007) confirmed that, among real scale systems with the same characteristics, the most efficient was the one with the longest HRT — 3.1 days — compared to 1.4, 1.6, and 1.7 days.

Climate

Chernicharo *et al.* (2001) affirm that the macrophytes to be used in a constructed wetland system must be selected according to the ideal temperature for development. The authors suggest temperatures ranging from 10 to 30ºC for *Typha* sp. and 16 to 26ºC for *Juncus* sp., for example.

Efficiency

The quality of treatment by constructed wetlands depends on their efficiency in relation to the standard set by Resolutions CONAMA n. 430 (BRAZIL, 2011) and n. 357 (BRAZIL, 2005). All horizontal flow wetlands and most of the vertical ones are within the 60% minimum BOD removal percentage, which shows that this technology can be adopted as an alternative in the treatment of domestic wastewater.

In general, BOD and COD removal in horizontal flow constructed wetland treatment ranged from 61 to 96% and 55 to 96%, respectively. The system in real scale evaluated by Ganske and Zanotelli (2008) consisted of septic tank and wetlands constructed with gravel, rice husk, coarse sand (in Portuguese, *saibro*), and gravel as substrate, in a region of humid temperate climate with hot summer. The system presented higher efficiency in these conditions, with 96% of BOD and COD removal. However, the authors of this system did not identify the macrophyte used, the area per inhabitant ratio, and the HRT.

Subsequently, Toniato's (2005) real scale system proposed the same previous treatment. It was constructed at a 2.57 m^2 inhab^{-1} ratio, in tropical savannah weather with dry winter, using gravel as substrate, plants of the families *Commelinaceae* and *Asteraceae*, and HRT of 6.15 days, reaching 93% of BOD removal and 95% of COD removal. This research also presented the best performance regarding nitrogen removal with 85% efficiency.

In all works evaluated, BOD and COD removal percentages in treatments using vertical flow constructed wetlands ranged from 48 to 99% and 46 to 99%, respectively.

Maier (2007) obtained greater BOD and COD removal, both resulting in 99% efficiency. The real scale wetland was constructed with layers of gravel n. 2 and sand, using the plant *Colocasium antiquorum*, after septic tank, in humid temperate climate with hot summer, without identifying the area per inhabitant ratio or HRT. Silva (2007) obtained the same BOD removal performance in bench scale as Maier (2007), with a system installed after a primary decanter, using a mixture of Red-Yellow Oxisol with washed sand at a 1.0:1.5 ratio to support the cultivation of *Oryza sativa* L., in a tropical savannah climate with dry winter season, and a 4.38 m^2 inhab^{-1} ratio. Unfortunately, the author did not present information about the HRT.

The mechanism of organic matter removal from results by Oliveira *et al.* (2005) indicates that macrophytes help to increase the performance due to the root zone formation, which also provides better filtration, the establishment of microorganism diversity, and oxygen incorporation in this region, contributing to organic matter degradation reactions.

Furthermore, the roots in constructed wetlands contribute to greater microbial activity, lower carbon immobilization, and rapid mineralization by microorganisms, which can prevent the fast clogging of the substrate soil. Microorganisms (aerobic, facultative, and anaerobic) convert organic matter into energy for cellular synthesis and transform organic compounds, mineralizing nutrients or forming humic substances in soil (SILVA; BERNARDES; RAMOS, 2015).

Regarding ammoniacal nitrogen removal, Oliveira *et al.* (2005) found a possible biological oxidation of nitrogen for the forms most usable to plants (root absorption) and microorganisms.

Pathogen removal in horizontal flow constructed wetlands varied from 40 to 99.99%, and more than 85% of the systems had a removal percentage over 90%. Sousa, Van Haandel e Guimarães (2001) reached 99.99% efficiency in the system preceded by a UASB reactor using the plant *Juncus* spp. and washed coarse sand as substrate. Pathogen removal in vertical flow constructed wetlands ranged between 74 and 99.95%, and Silva's (2007) bench scale system also presented the best performance with 99.95% efficiency.

Disinfection is one of the most affected parameters with high HRT. Higher HRT promotes greater pathogen removal capability via natural decay of fecal microorganisms exclusive of the intestinal tract. The physicochemical and biological systems involved in the wetland disinfection process are ultraviolet radiation, predation, high pH, dissolved oxygen, algal toxins, tropical climatic conditions (temperature, solar radiation), sedimentation, and filtration (SEZERINO *et al.*, 2005b).

However, Teodoro *et al.* (2017) indicated that even with the pathogen reduction reported in several studies in the literature, an effective disinfection process is recommended after the wetlands, since most of the biological indicators used were coliforms and *Escherichia coli*, microorganisms easily destroyed and very sensitive to the adverse conditions of wetlands.

Accordingly, Teodoro *et al.* (2017) tested heterogeneous photocatalysis processes to disinfect gray water after passing through a wetland system. The authors observed that with lower flow and longer HRT, direct ultraviolet radiation significantly increased disinfection for coliforms, (60%) enterococci (58%), and *Pseudomonas aeruginosa* (57%) as indicator microorganisms.

The percentage of nitrogen removal in the horizontal flow varied between 4 and 85%, while the phosphorous removal percentage ranged between 28 and 96%. Monteiro (2009) pointed out that nutrient removal in the secondary treatment was not sufficient in relation to nitrogen and phosphorous concentration, and a tertiary treatment was necessary to reduce such concentrations. Dornelas, Machado and Von Sperling (2009) obtained 44% working with a real system, while Costa *et al*. (2015) reached 70% in phosphorous removal performance. Nitrogen removal was higher in vertical flow systems than in horizontal ones, varying between 27 and 94%. Silva's (2007) system also had the best performance in removing this nutrient, with 99.5% efficiency.

The inefficiency of some systems under evaluation might be related to construction and operation failures caused by low-quality material, sloppy techniques, and neglected construction processes and operation.

Considerations for the implementation of constructed wetland systems

Selection of constructed wetlands with the best general performance

Table 1 shows the constructed wetland systems with the best general performance among the Brazilian works evaluated.

Table 2 was elaborated considering this selection and aiming at summarizing the construction and operational characteristics as well as the preceding treatment that influenced the efficiency of the systems selected.

Based on the data presented in Table 2, we calculated the superficial area (A) necessary for implementation as exemplified, considering a population of a hundred inhabitants (Table 3). The population would be equivalent to a residential condominium with 25 units with 4 inhabitants each.

The studies by Ganske and Zanotelli (2008), Maier (2007), and Van Kaick, Macedo and Presznhuk (2008) evaluated real scale wetlands but did not provide dimension data. Therefore, despite their good efficiency results for the parameters under analysis, it was not possible to calculate the area needed per inhabitant, and, thus, we will not discuss these data. Despite the good results in the vertical flow system, only Silva (2007) presented data that enabled us to calculate the superficial area.

The wetland in bench scale proposed by Silva (2007) used a mixture of red-yellow latosol with washed medium sand at a 1.0:1.5 ratio, which is not advisable since this material is collapsible when subjected to infiltration, hampering the effluent flow and promoting clogging. Consequently, it should not be considered to elaborate implementation guidelines.

According to the calculation presented in Table 3, the wetland configuration that required the smallest superficial area to obtain the best performance was built by Oliveira *et al.* (2005) in real scale with horizontal flow. It also presented satisfactory efficiency results as shown in Table 1. Therefore, from this point on, the system proposed by Oliveira *et al.* (2005) will be used to elaborate the construction guidelines presented in this study.

Considerations on the implementation of wetlands in real scale as proposed by Oliveira et al. *(2005)*

Previous treatment

Oliveira *et al*. (2005) installed an upflow anaerobic reactor for the treatment that preceded the wetland, without identifying the HRT.

Table 1 – Constructed wetlands that presented the best general biochemical oxygen demand (BOD), chemical oxygen demand (COD), pathogens, nitrogen, and phosphorus removal efficiency.

Flow	BOD (%)	COD (%)	Pathogens	N (%)	P (%)	Reference
Vertical	99.0	99.0	99.80	80.5	91.0	Maier (2007)
Vertical	99.0	n.i. [1]	99.95	94.0	99.5	Silva (2007)
Vertical	98.0	98.0	99.00	n.i. [1]	n.i. [1]	Van Kaick, Macedo and Presznhuk (2008)[2]
Vertical	97.0	95.0	99.00	n.i. [1]	n.i. [1]	Van Kaick, Macedo and Presznhuk (2008)
Horizontal	96.0	96.0	98.80	78.5	59.0	Ganske and Zanotelli (2008)
Horizontal	93.0	95. 5	No removal	85.5	82.5	Toniato (2005)
Horizontal	92.0	89.0	94.59	50.0	n.i. [1]	Olijnyk *et al.* (2007)
Horizontal	91.0	81.5	99.66	65.5	64.0	Oliveira *et al.* (2005)

[1]Not informed; [2]different systems were presented in the same work and are shown separately in this table.

However, since a wide variety of systems can be used in the previous treatment (anaerobic filter, septic tank or pit, as shown in Figure 1), there are no restrictions regarding the type of previous treatment to the constructed wetlands. The only requirement for the wetland is the existence of a previous efficient treatment. However, Sezerino *et al.* (2015) indicated the use of decant-digester units as septic tanks, compartmentalized anaerobic reactors, UASB, or anaerobic ponds as a secondary treatment before the wetland in Brazil.

Sezerino (2006) recommended a maximum load of 16 g d^{-1} m^{-2} of suspended solids applied to the transversal section to maintain more than 65 and 80% in COD and SS removal, respectively, and to prevent system clogging.

Construction aspects

According to the results shown in Table 2, the area necessary to implement a 1.0 m deep system is 1.04 m^2 $inhab^{-1}$. For a 0.9 m deep system, as the one presented by Oliveira *et al.* (2005), the area needed is 1.15 m^2 $inhab^{-1}$. A slight slope in the lower part of the system should be considered to keep the effluent flow through gravity (VAN KAICK, 2002).

The material used to close the system construction must be defined according to the needs of the implementation site since this material is inert and not reagent to the liquid under treatment. It is advisable to build the wetland with civil engineering traditional materials as they are easy to find and guarantee system isolation. Almeida, Pitaluga e Reis (2010) suggested the construction of reinforced concrete floors and brick walls in real scale (14 x 29 cm, horizontally placed on pierced

Table 3 – Superficial area (A) calculated as necessary to implement a constructed wetland to serve a population of a hundred inhabitants.

Flow	A (m^2)	Scale	Reference
Horizontal	257	real	Toniato (2005)
Horizontal	109	real	Olijnyk *et al.* (2007)
Horizontal	104	real	Oliveira *et al.* (2005)
Vertical	438	bench	Silva (2007)

Table 2 – Characteristics of constructed wetlands with the best overall efficiency.

Horizontal flow				
Reference	Ganske and Zanotelli (2008)	Toniato (2005)	Olijnyk *et al.* (2007)	Oliveira *et al.* (2005)
Previous treatment	Septic Pit	Septic Pit	Septic Tank	Upflow anaerobic reactor
Dimensions (m)[2]	n.i.[1]	15.00 x 5.50 x 0.50	12.00 x 6.00 x 0.70	5.00 x 3.00 x 0.90
Filling material	Gravel n. 4, rice husk, clay, and grit	Gravel n. 2	Layers: coarse sand, clay, loam, and rice husk	Entry and exit: Gravel n. 1. Intermediary portion: medium sand
Relation area/inhabitants	n.i.[1]	2.57	1.09	1.04
Climate	Cfa	Aw	Cfa	Cfa
Plant	n.i.[1]	*Commelinaceae and Asteraceae*	*Zizanopsis bonariensis*	*Typha domingensis* Pers.
HRT (d)	n.i.[1]	6.15	3.1	1.0
Q ($L.d^{-1}$)	n.i.[1]	2088	n.i.[1]	1710
Vertical flow				
Reference	Maier (2007)	Silva (2007)	Van Kaick, Macedo and Presznhuk (2008)	Van Kaick, Macedo and Presznhuk (2008)
Previous treatment	Septic Pit	Primary Decanter	Septic Pit	Septic Pit
Dimensions (m)[2]	5.00 x 1.00[2]	0.26 x 0.87[2]	1.00 x 1.00 x 1.00	n.i.[1]
Filling material	Gravel n. 2 and sand	Mixture of red-yellow Latosol with washed medium sand at a 1.0:1.5 ratio	Gravel and sand	Gravel and sand
Relation area/inhabitants	n.i.[1]	4.38	n.i.[1]	n.i.[1]
Climate	Cfa	Aw	Cfb	Cfb
Plant	*Colocasium antiquorum*	*Oryza sativa* L.	*Cladium mariscus*	*Typha domingensis*
HRT (d)	n.i.[1]	n.i.[1]	n.i.[1]	n.i.[1]
Q ($L.d^{-1}$)	n.i.[1]	40	n.i.[1]	n.i.[1]

[1]Not informed; [2]area x height.

brick) and waterproofing plaster. Plastic canvas can also be used on the ground and covering the walls as a way of waterproofing.

The support material or substrate must comprise sand in the intermediary area and gravel at the system entry and exit, distributed in blocks, following the criteria of placing a support medium with higher draining capability on the entry and a finer material on the intermediary site. Such distribution can be considered the most suitable for horizontal flow constructed wetlands, based on the real system proposed by Oliveira *et al.* (2005). Nevertheless, the author did not specify the dimension of the blocks.

Among the macrophytes, we strongly recommend the species *Typha* sp. because this kind of plant is vigorous, resistant to high temperatures and high concentration of heavy metals, and easily found all over the country. However, it is important to make the adaptation of these plants easier by using macrophytes from natural environments with similar conditions to those existing in the constructed wetland implementation site. The use of exotic plants should be avoided not to make the system more expensive, unless they have landscaping or ornamental purposes, as proposed by Zanella (2008).

The plants should be trimmed regularly, and the remains removed to prevent decomposition and accumulation of organic matter that could stifle new plants and change effluent characteristics. Other plant cultural practices, planting, and cultivation must follow specific technical recommendations not covered here.

a) *Operational parameters:* Oliveira *et al.* (2005) applied a 114 mm d^{-1} hydraulic load rate to have a good performance in the constructed wetland. This value might be considered high when compared to the construction criteria defined by Chernicharo *et al.* (2001) — more recent in the literature used —, in which the hydraulic load rate should range from 2 to 30 mm d^{-1}. Therefore, despite the good efficiency of the system with this value, it is advisable to reduce the load rate to prevent clogging risks. Intermittent flows might damage the system, so a constant flow is also desirable (SILVA, 2007).

Clogging of the filling material results from the deposition of suspended solids from the facultative pond effluent, and the growth of the adhered biofilm leads to an operation with alternating supply of the wetlands. Thus, we recommend the use of two units (of equal treatment capacity) in parallel (SEZERINO *et al.*, 2005a) to reach the required efficiency.

The 1-day HRT adopted by Oliveira *et al.* (2005) had good efficiency results. However, when compared to a HRT between 2 and 7 days — as defined in the construction criteria by Chernicharo *et al.* (2001) —, it seems advisable to adopt a longer hydraulic detention time than that by Oliveira *et al.* (2005).

Oliveira *et al.* (2005) implemented a wetland in real scale with humid temperate climate with hot summer. In colder climate regions, the microbial activity in these systems will be reduced. For this reason, the flow should be reduced and/or the HRT increased. Sites with higher sun exposure will have better plants, development of decomposing microorganisms, and evapotranspiration losses. Therefore, they can have their size or HRT decreased to obtain the same efficiency. The system installed in high-temperature conditions will present greater efficiency regarding organic matter and pathogen removal.

CONCLUSIONS

The systems with the best performance were those with vertical flow, presenting higher efficiency, in general, when compared to those with horizontal flow. However, the lack of information prevented the elaboration of considerations for their implementation.

Among the constructed wetlands with higher efficiency and known implementation data, the system presented by Oliveira *et al.* (2005) was prominent. It required a smaller area to obtain good efficiency results and can be considered a starting point to design the implementation of horizontal flow constructed wetlands.

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