

Undergrad Works

Efficiency of pollutant removal in a hybrid constructed wetland with *Hedychium coronarium* J. König: a sustainable alternative for poor communities

Eficiência na remoção de poluentes por sistema alagado híbrido com *Hedychium coronarium* J. König: uma solução para comunidades de baixa renda

Brennic Menezes Amaral¹, Douglas Pires Alcântara¹, Eva de Melo Ferreira¹,
Karla Alcione da Silva Cruvinel¹

¹ Universidade Federal de Goiás. Goiânia, GO, Brazil

ABSTRACT

Wastewater treatment in developing countries is a problem of access and efficiency. Individual wastewater treatment systems are important when the sewage collection network does not reach the whole community. Therefore, the treatment efficiency should be evaluated when considering systems design and the prevention of environmental negative impact. Wetland's systems are often used as final treatment for wastewater polishing. This work proposes a wastewater treatment using a hybrid system consisting of septic tank, anaerobic filter, and a wetland system using plants as tertiary treatment. Samples were collected to evaluate biochemical oxygen demand (BOD), chemical oxygen demand (COD), turbidity, apparent colour, total solids, total phosphorus (TP) and nitrogen. In two points analysed the contaminant removal was a result of septic tank set with the anaerobic filter. The efficiency of the system was recognized to improve the quality of the final effluent, showing as an excellent alternative to countries with lack of collective structures for the treatment of domestic sewage.

Keywords: Contaminants; Greywater; Sustainability; Sustainable communities; Water reuse

RESUMO

O tratamento de águas residuárias em países em desenvolvimento é um problema de acesso e eficiência. Os sistemas individuais de tratamento de esgoto são importantes quando a rede de coleta não chega a toda a comunidade. A eficiência do tratamento deve ser avaliada ao considerar o projeto dos sistemas e a prevenção do impacto ambiental negativo. Os sistemas de tratamento de esgoto são frequentemente

utilizados como tratamento final para o polimento de águas residuárias. Este trabalho propõe um tratamento de esgoto utilizando um sistema híbrido composto de fossa séptica, filtro anaeróbico e um sistema de zonas úmidas utilizando plantas como tratamento terciário. Foram coletadas amostras para avaliar a demanda bioquímica de oxigênio (DBO), demanda química de oxigênio (COD), turbidez, cor aparente, sólidos totais, fósforo total (TP) e nitrogênio. Em dois pontos analisados, a remoção de contaminantes foi resultado do conjunto de fossas sépticas com o filtro anaeróbico. A eficiência do sistema melhorou a qualidade do efluente final, mostrando como uma excelente alternativa aos países com falta de estruturas coletivas para o tratamento de esgoto doméstico.

Palavras-chave: Contaminantes; Águas cinzas; Sustentabilidade; Comunidades sustentáveis; Reuso da água

1 INTRODUCTION

Wastewater systems are critical to poor communities. They protect residents from waterborne contamination. Conventional wastewater treatment has contributed substantially to the progress in health and environmental protection (KÜMMERER *et al.*, 2018), but in Brazil it is not available in all the cities, where 36 municipalities in the country's 100 largest cities have less than 60% of the population with sewage collection (TRATA BRASIL, 2019).

Unfortunately, maintaining enough pollutants removal is not a priority for all governments, being important to remove dirt from the population's field of vision. Wastewater treatment plants (WTPs) have received considerable attention over the past decades because it act as a barrier to prevent micropollutants (MPs) from entering the environment. Intensive sampling and analysis efforts have been made globally to improve understanding of the occurrence, behaviour, and fate of MPs in WTPs (BEN *et al.*, 2018).

In the face of the emerging concern for environmental preservation and governmental regulations that are becoming more stringent the development of innovative, sustainable, environmentally friendly, and low-cost processes for efficient treatment of tannery wastewater has gained the interest of researchers in clean technologies (ASSEFA *et al.*, 2019). The performance of systems for wastewater treatment for the safe release of the effluent (e.g., for the protection of human health and the environment) is the primary role. Research studies have

evaluated the performance of these systems with respect to their ability to remove potentially harmful constituents (DIAZ-ELSAIED *et al.*, 2017).

One solution for the wastewater treatment in poor communities is the constructed wetlands (CWs). CWs, as an increasingly popular option for wastewater treatment, has been used for over fifty years (XU *et al.*, 2019). CWs comprise a suite of recognized eco-technologies that are designed and constructed to mimic and manipulate the simultaneous physical, chemical, and biological processes occurring in natural wetlands for wastewater treatment purposes.

Besides the water quality improvement, CWs also provide a multitude of other functions, such as biodiversity, habitational, climatic, hydrological, and public use functions (WU *et al.*, 2018). Furthermore, playing an important role in the environmental plan to achieve both federal, state regulatory compliance for effluent discharges (XU *et al.*, 2019), and have been used effectively for the inactivation of bacterial indicators (KALIAKATSOS *et al.*, 2019).

CWs are categorized according to its hydrology to the free water surface (FWS) CWs and the subsurface flow (SSF) CWs. FWS systems are like natural wetlands, with shallow flow of wastewater over-saturated substrate (KALIAKATSOS *et al.*, 2019). For the construction of such systems, it would be economically feasible to use naturally available materials and local vegetation as filler agents. Elimination of pathogenic germs takes place in the filter body and root zone area of CWs, which can exceed the elimination capacity of conventional, biological wastewater treatment plants.

Selection of the substrates and macrophytes is therefore a crucial aspect while designing CWs (SHINGARE *et al.*, 2017). CWs, composed of low-cost materials and ecological plants, serve the simultaneous nitrification, anammox and denitrification process with conducive conditions. The packing substrates and plant surfaces can provide immense interface for the attachment of microorganisms associated to nitrogen cycle (CHEN *et al.*, 2019).

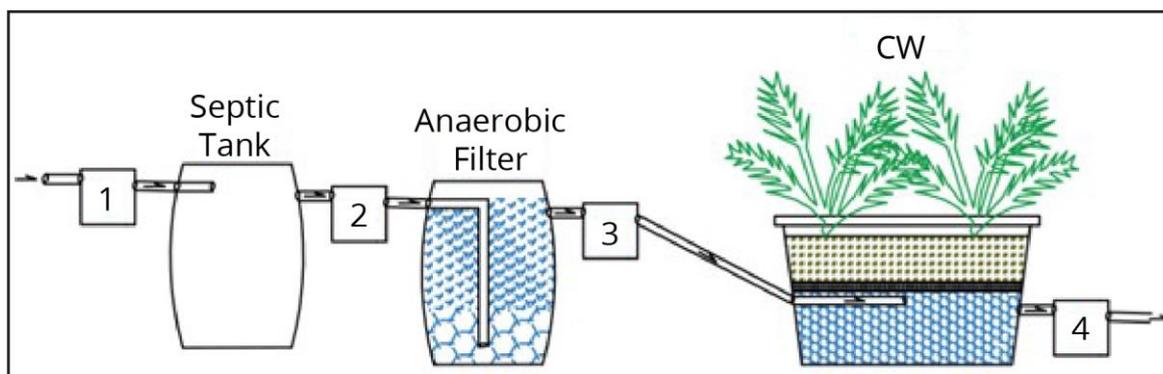
Considering the importance of CWs technology to developing countries, the main goal of this work is to propose a wastewater treatment using a hybrid system consisting of septic tank, anaerobic filter, and a wetland system using plants as tertiary treatment in Brazil.

2 MATERIAL AND METHODS

A hybrid wastewater system was designed, consisting of a septic tank, anaerobic filter, and CW, with inspection boxes between the system units. The unevenness of the site was used, using gravity for the sewage flow in the system. The sizing has prioritized the use of materials to run an efficient and cost-effective system.

To analyse the economic viability of the system implementation, the budget was initially executed using plastic bottles such as for the septic tank and anaerobic filter and a water tank for the CW (Figure 1), and in second moment using masonry tanks for all units. The volume for the septic tank was 240 L, considering the size of the plastic drums.

Figure 1 – Hybrid constructed wetland used (n. 1-4 is the monitoring points)



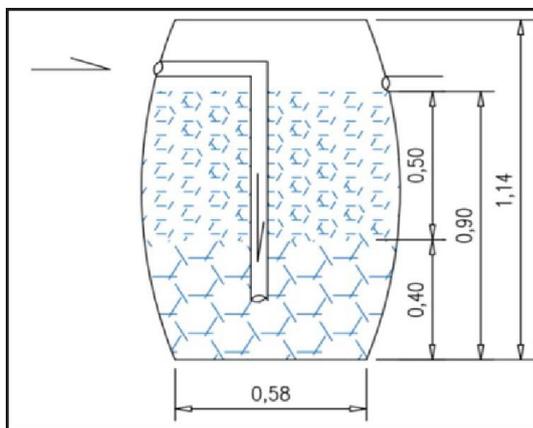
Source: Authors, 2021

The hydraulic detention time was 0.75 days (18 hours), meeting the economic and constructive criteria. Wastewater consisting of soluble materials and with

considerable suspended solids content may cause problems related to undesirable filling of the bed interstices that may hinder the passage of water.

One of the main problems related to the durability and functionality of anaerobic filters is closely linked to filter bed clogging (CRUZ *et al.*, 2013). To minimize this possible problem and extend the life of the filter, a 40 cm layer of crushed stone was used at the bottom, with a particle size ranging from 64 mm to 170 mm, followed by gravel number 4 in the rest (Figure 2).

Figure 2 – Anaerobic filter dimensions (cm)



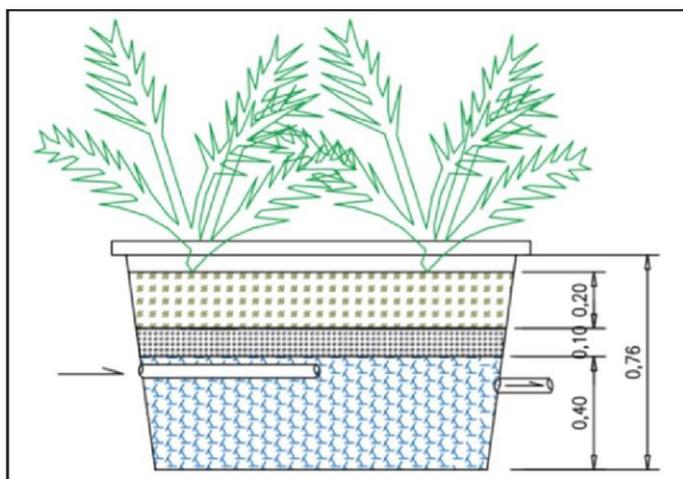
Source: Authors, 2021

Mota and Sperling (2009) indicate the subsurface flow efficient for septic tank effluent treatment besides having a satisfactory landscape structure. The CW was dimensioned following the literature, in which the authors adopted the per capita area ratio as the sole criterion. The relationship varies according to the characteristics of the effluent studied by each author. According to the technical literature, the range of 1 to 5 m² per person is the most usual (SEZERINO *et al.*, 2004).

The choice of substrate followed the recommendations described in a literature review, which emphasizes that the substrate must have a large contact surface area, function as a filter medium, support medium for the development of microorganisms and root fixing medium (PITALUGA, 2011). A 1000 L water tank with a 1.82 m² surface area was used as material for the wetland unit. It was filled

at the bottom (40 cm) with gravel n. 4, followed by a 10 cm layer of sand and ending with 20 cm of soil, forming the area for fixing the plants. The species *Hedychium coronarium* J. König) was inserted in the project implementation region, meeting the criteria of efficiency and adaptation to the local climate of Brazilian savannah, Figure 3 (ALMEIDA *et al.*, 2007).

Figure 3 – CW's dimension (cm)



Source: Authors, 2021

Figure 4 – Plants in the first month of transplantation (A) and after three months (B)



Source: Authors, 2021

The construction of the system involved the excavation of the holes to accommodate the system, the water box, and the inspection boxes, later the accommodation of the gravel in the filter and as a filter bed of the cultivated bed. The species chosen for the cultivated bed facilitated the consolidation of the system, being found around the construction site and transplanted (Figure 4). The effluent water level remains below the support medium without insect proliferation, controlling odour by isolating the effluent from animals and human contact.

The wastewater samples were made after three weeks of stabilization, in the boxes number one, three and four, representing the non-treated wastewater at the system entrance, the effluent before entering the constructed flooded and the treated effluent. The sampling occurred fortnightly between April, May and June and were subjected to laboratory analysis, according to Standard Methods for the Examination of Water and Wastewater (APA) for BOD, COD, pH, total solids, alkalinity, colour, turbidity, ammonia total nitrogen and phosphorus.

Based on the results, characteristic values of pollution parameters in sewage from the three different treatment stages were determined, including average, minimum and maximum values, and medians. The relative frequency of occurrence of the characteristic concentration levels of the tested parameters in the sewage flowing into the treatment plant was determined (Table 1).

Table 1 – Descriptive statistics for the indicator values in the treated wastewater

	Turbity (uT)	Colour (Uc)	Total solids (mg/L)	BOD (mg/L)	COD (mg/L)	Total P (mg/L)	Total N (mg/L)	Alkalinity (mg CaCO₃/L)	pH
First sampling									
S1	37	7010	2160	988	2958	47,5	148,4	1240	7
S2	12	650	417	128	380	12	21	340	7
S3	20	1311	561	97	440	8	25	486	6
Septic tank + filter	67	90	80	87	87	74	85		
CW	-65	101	34	24	15	29	-15		
Total efficiency	45	81	74	90	85	82	83		

Note: S1 – before the flow; S2 – after the septic tank; S3 – after the anaerobic filter

Continued...

Table 1 – Conclusion

	Turbidity (uT)	Colour (Uc)	Total solids (mg/L)	BOD (mg/L)	COD (mg/L)	Total P (mg/L)	Total N (mg/L)	Alkalinity (mg CaCO ₃ /L)	pH
Second sampling									
S1	259	4650	1760	524	5840	45	123	886	7
S2	130	1110	568	144	397	11	61	520	7
S3	102	720	480	53	245	9	50	606	7
Septic tank + filter	49	76	67	72	93	75	50		
CW	21	35	15	63	38	18	18		
Total efficiency	60	84	72	89	95	80	59		
Third sampling									
S1	940	6950	3253	1130	2300	33	85	852	7
S2	267	1390	576	162	322	6	53	516	6
S3	112	303	605	26	127	6	70	652	7
Septic tank + filter	71	80	82	85	86	81	37		
CW	58	78	-5	84	60	3	-31		
Total efficiency	88	95	81	97	94	81	18		
Fourth sampling									
S1	356	5874	1002	505	1165	13	67	865	7
S2	249	1530	843	351	631	6	65	612	7
S3	61	225	518	74	277	5	50	686	7
Septic tank + filter	30	74	15	30	45	50	2		
CW	75	85	38	78	56	24	23		
Total efficiency	82	96	48	85	76	62	25		
Total efficiency	69	89	69	90	87	76	46		

Note: S1 – before the flow; S2 – after the septic tank; S3 – after the anaerobic filter

3 RESULTS AND DISCUSSION

For evaluation of treatment performance of CWs, current research is mainly focused on the measurement of the rate of removal of pollutants such as total nitrogen TN, TP, ammonium nitrogen (NH₄⁺-N) and on determination of COD. Water depth, plant spacing, and layout of inland outlet are the main factors affecting the efficiency of pollutant removal. These design parameters displayed

significant influence on hydraulic performance and negligible effect on treatment performance (Guo et al., 2019). In a study which investigated hybrid CWs, the system had organic and biogenic pollutant removal efficiencies like those obtained in systems using classic plant species such as reed and willow (MARZEC *et al.*, 2019).

Plants are essential for the system functioning and are responsible to reduce the velocity of particle flow, which is beneficial to particle dissolution and solute adsorption; transport gas and solutes between plant leaves, stems, and roots; absorb organic pollutants; and release O₂ into the rhizosphere. Within wetland systems, plants, coupled with microorganisms, employ physical, chemical, and biological processes to purify polluted water (IJAZ *et al.*, 2015).

In the plant-bacteria association, plants assimilate nitrogen to promote growth and provide ideal attachment sites for microbial communities and regulate bacterial nitrification and denitrification by oxygen and organic compound release in the root zone (PENG *et al.*, 2014; WU *et al.*, 2017). For example, common reed (*Phragmites australis*), willow (*Salix viminalis*), giant miscanthus (*Miscanthus giganteus*), Jerusalem artichoke (*Helianthus tuberosus*), Virginia mallow (*Sida hermaphrodita*), Manna grass (*Glyceria maxima*), and marsh lily (*Hedychium coronarium* J. König) can be used as species (JÓŹWIAKOWSK *et al.*, 2019).

It has been widely recognized that CWs are a reliable treatment technology for various wastewaters after years of study and implementation. The current study indicates that advances in the design and operation of CWs have greatly increased contaminant removal efficiencies (WU *et al.*, 2015). In a study developed for two years, water flow, temperature, pH, O₂ and target indicators were monitored over a period of two years, after the first year of vegetation establishment. Different from the research made in Brazil, one control system with aeration was used. At 28 days, there was a reduction in colour in the aerated system combined with vegetation.

No significant effect on colour reduction was obtained for either aeration or vegetation alone. The parameter pH could affect the colour of the water. However,

no relationship between colour and pH was observed in this investigation. This could be because pH was higher than expected during the monitoring period in all mesocosms (SVENSSON *et al.*, 2015).

In a hybrid system consisted of a serially operated horizontal sub-surface flow constructed wetland (HSSF-CW) and a vertical sub-surface flow constructed wetland (VSSF-CW), operated at five periods each lasting about four months, temperature was one of the factors to influence the system efficiency. The authors explain that temperature should be considered as a determining factor in constructed wetland treatment of domestic wastewaters in terms of the removal of N, for example. Higher temperatures can accelerate the treatment process.

The whole treatment system including anaerobic pre-treatment achieved on average up to more than 95% organic matter and 90% nitrogen removal. This resulted in effluent COD concentrations below 20 mg/L with a specific wetland surface area of only about 1 m² per person. Comparison of Period I (during summer with an average influent water temperature of 23 ± 4 C) and Period II (during winter with an average influent water temperature of 16 ± 2 C) showed that removal efficiencies of organic matter (COD and BOD₅), total nitrogen (TN) and suspended solids (TSS) were all higher in the summer period compared to the winter period (AYAZ *et al* 2015).

The ammoniacal nitrogen in the beginning of the system was 143 mg/L, going to 79 mg/L in the 4th sampling, showing the efficiency of the CW studied. In constructed wetlands, the main processes of nitrogen removal by microorganisms are ammonification, nitrification, and denitrification. Denitrification is a chemical reaction in which denitrifying bacteria reduce the nitrate or nitrite produced in the system. Nitrification occurs under aerobic conditions, while denitrification occurs under hypoxic conditions since denitrifying bacteria are heterotrophic facultative anaerobic microorganisms.

Constructed wetlands can provide both anaerobic and aerobic micro-environments to ensure efficient nitrogen removal (DING *et al.*, 2018). Turbidity, total

solids and BOD increased in the third sampling, at the first point, right after the anaerobic filter. This could be improved by an aeration system but increasing the costs with energy and with the project construction.

Apparent colour may be related to turbidity due to particulate matter. The first sampling shows a reduction in colour and turbidity from point one to point two, and subsequently at point three the values increased. This ascendancy of the colour and turbidity values in point three of analysis one may be justified due to the stabilization process of the system.

Suspended particles were present in the cultivated bed substrate. The system was still being "washed" by the tributary during sample collection for the first sampling. In fourth sampling the result for colour increased from point two to three, requiring further study, since the other parameters analysed in this work did not identify any result that explains such ancestry. The average efficiency in colour removal and turbidity were 89.4% and 69.3%, respectively.

Turbidity and total solids in the third sampling showed a very high value at first point compared to the other analyses, but at second, the values fell and were closer to the other analyses and may judge that the system is capable of absorb sporadic events of high turbidity and total affluent solids. In the third sampling, there was an increase in the total solids value from second to third point. This fact can be presupposed by the results of nitrogen and phosphorus analysis, which pointed an increasing from the second to third point, as these substances are in the form of suspended or dissolved solids. An average efficiency of 69.1% was observed for total solids removal in the system. The sump + filter set presented its best efficiency in the third sampling (82.3%) and the flooded constructed in fourth sampling (38.6%).

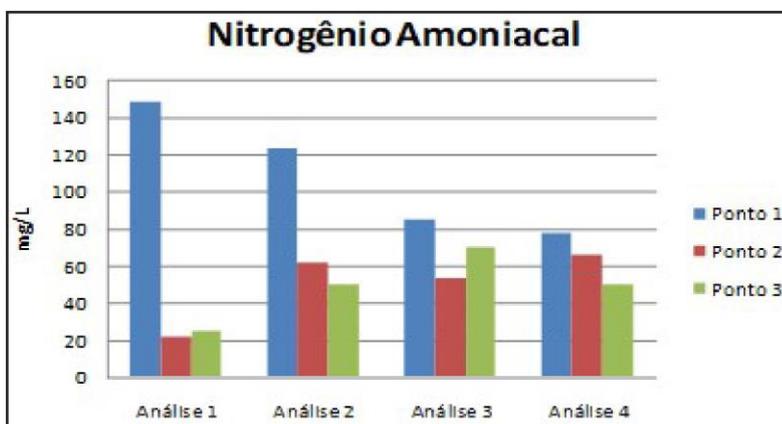
In the sampling at the first point, the COD increase from point two and three. This can be explained because of colour and turbidity, where the stabilization phase of the system caused a slowdown. Particles from the root zone substrate, if the chemical composition of the sand and gravel dust can increase COD values.

BOD was removed during all the collected analyses, especially in first sampling, indicating a rapid stabilization of the system before the removal of organic loads.

The high values of organic and inorganic load pointed out in the first and second sampling the efficiency of the system in the treatment of tributaries with high rates of variation of COD and BOD. In addition, COD removal achieved an average efficiency of 86% and BOD 89% on the overall system. The septic tank and filter set obtained the best efficiency in sampling 1 (87.0%) and the CW was more efficient in third sampling (84.0%).

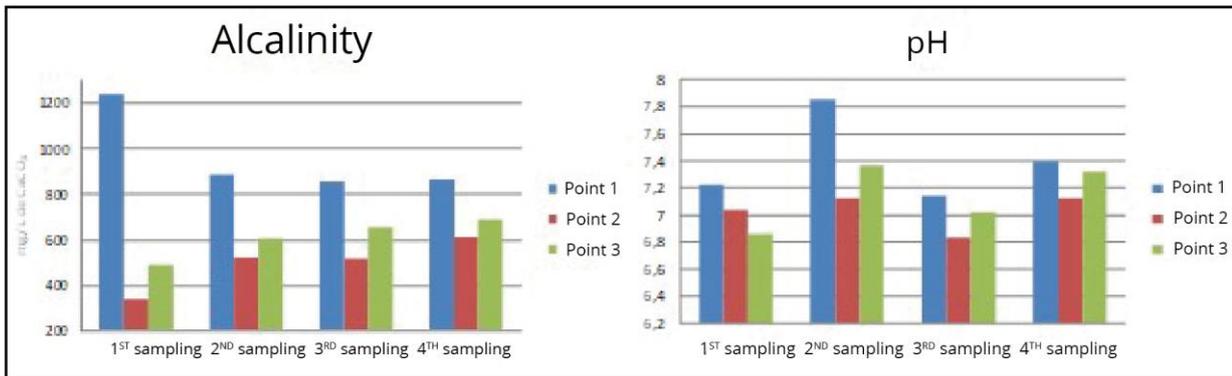
The result of the ammonia nitrogen concentration between the analysed points obtained significant variations, mainly regarding the removal efficiency in the system, as well as in the concentrations of the points two and three that did not obey the reduction logic, being observed in the first, second and third sampling (Figure 5). Valentim (2003) and Almeida (2007) explain the increase in ammonia nitrogen from point two to three through experiments that showed the same behaviour where plants cannot release enough oxygen for ammonia nitrogen oxidation. The hydrolysis of the particulate matter coming from the root-fixing substrate and retained in the CW generates the nitrogen and increase its concentration. It was also observed in relation to points two and three the elevation of pH and alkalinity as shown (Figure 6).

Figure 5 – Frequency of ammoniacal nitrogen values



Source: Authors, 2021

Figure 6 – Alkalinity and pH level in the samples



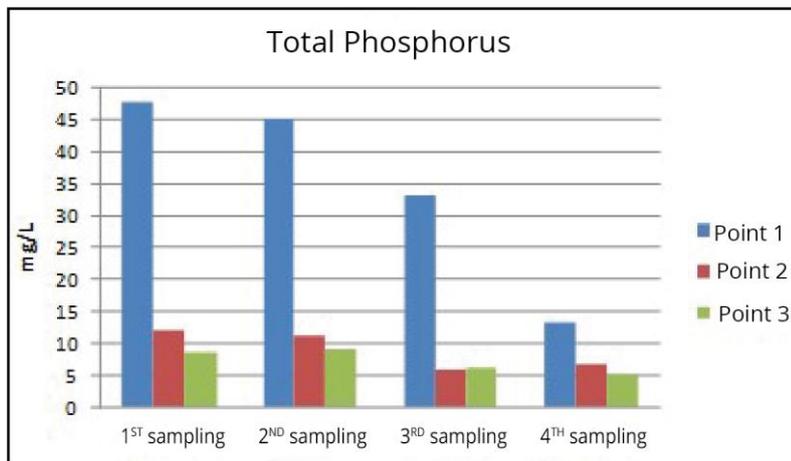
Source: Authors, 2021

For the conversion of 1 mg of ammonia nitrogen to nitrite and nitrate, 4.57 mg of oxygen and 7.14 mg of CaCO₃ of alkalinity to bicarbonate are consumed (METCALF AND EDDY, 2005). Through the analysis can be observed the nitrification deficiency in the CW by the difficulty of the plants to release enough oxygen for such reactions, with no H⁺ release or alkalinity consumption (Valentin 2003). Therefore, the removal of ammonia nitrogen by the root zone in the second, third and fourth sampling may also be largely due to the adsorption of this nutrient by the substrate biofilm (gravel and sand).

At the third sampling, the increase in concentration is explained by Valentim (2003) through the mobilization of nitrogen. The root system of plants that failed to sprout after transplantation and eventually decomposed, releasing nitrogen and other substances in the water present in the plant constructed flooded, if the constructed flooded system is still in the stabilization phase.

The hybrid system obtained 69.3% of efficiency removal, while the septic tank + filter set presented its best efficiency in third sampling (71.6%) and the flooded constructed in fourth sampling (75.4%). Total phosphorus showed a linear and gradual removal behaviour between points one, two and three (Figure 7). Adsorption and precipitation along with plant consumption are the main forms of phosphorus removal from natural systems (VALENTIN, 2003).

Figure 7 – Total phosphorus in the samples



Source: Authors, 2021

The system obtained an average phosphorus removal efficiency of 76.6%, a value lower than that found by Pitaluga (2011) of 93.9%, operating only the CW of vertical flow with the marsh lily, showing the best yield of the plant when subjected to this type of flow. It is also worth addressing the issue of costs involved in project implementation. When comparing these costs involved in the construction of the system using the alternative material adopted with a standard masonry system, there is an approximate reduction of 67% in the final value of the entire work.

Replacing bricks and concrete with pellets in the septic tank and anaerobic filter and water tank in the CW, considerably reduced material costs. In addition, the use of these alternative materials required a professional workforce with basic knowledge of hydraulics to identify a suitable location for the gravity flow of the domestic effluent, allowing it to pass through all the wastewater treatment units.

In a system with five years of monitoring, the CW had a high efficiency of removal of organic pollutants and total suspended solids, and a lower efficiency of elimination of biogenic compounds, e.g., total nitrogen and total phosphorus. The removing of organic pollutants in the research period was 98.8% for BOD₅ and 97.6% for COD (MARZEC *et al.*, 2019).

To develop a region, managers (usually local governments) need to expand industrial production; however, these decisions inevitably lead to increased

industrial waste such as wastewater, waste gas, and solid waste. The contamination carrying capacity of the natural environment, however, is limited; when pollution emissions exceed the carrying capacity upper bound, the ecosystem can be seriously damaged or destroyed (NI *et al.*, 2018). Sanitation in most of the tropical areas, especially in small municipalities and rural areas, deals with much the same issues: high population growth, limited skilled human and financial resources, no sludge management solutions, as well as highly varying fluxes brought by tropical rain patterns (LOMBARD-NATUNE *et al.*, 2018).

The system studied in the present research is a good option for rural communities. When considering sanitation in Brazilian poor communities, the problems linked with wastewater treatment are primarily related to the lack and/or stagnation of “cesspit”, hole, well, or septic tank/ swallow-hole systems. Additionally, in most properties with septic tank/swallow-hole systems, the location (proximity to water bodies and groundwater) is not regulated, and the construction of these systems rarely follows specified guidelines. Several trends in the implementation of sustainable processes address the possibility of recovering materials, energy, and nutrients. This potential to recover resources is important in sustainable sanitation and particularly in wastewater treatment (LUTTERBECK *et al.*, 2017).

3 CONCLUSIONS

The studied system presented satisfactorily average efficiency in some parameters, such as 90.8% in BOD removal and 87.9% in COD removal. Turbidity, apparent colour, and total solids obtained efficiencies of 69.3%, 89.4% and 69.1% respectively.

The average phosphorus removal efficiency was 76.6% and that of Nitrogen 46.3%. The high efficiencies are largely due to the septic tank and anaerobic filter assembly, where considerable removal of some parameters from point one and

two has been identified. The constructed flooded system was very efficient in removing BOD and COD, with efficiencies of up to 76.9% and 60.6%, respectively.

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Authorship contributions

1 – Brennic Menezes Amaral:

Graduated in Environmental and Sanitary Engineering
<https://orcid.org/0000-0003-1021-4689> • brennic96@gmail.com

Contribuição: Data Curation

2 – Douglas Pires Alcântara:

Graduated in Environmental and Sanitary Engineering
<https://orcid.org/0000-0002-8380-9053> • dpallcantara@gmail.com

Contribuição: Data Curation

3 – Eva de Melo Ferreira

Ph.D. in Environmental Science
<https://orcid.org/0000-0002-1115-8976> • emferreira.sci@gmail.com

Contribuição: Writing – review & editing

4 – Karla Alcione da Silva Cruvinel

Ph.D. in Environmental Sciences
<https://orcid.org/0000-0002-5110-565X> • karlaalcione.ufg@gmail.com

Contribuição: Supervision

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