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Constructed wetlands as post treatment of a decanter digester followed by an anaerobic filter

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ABSTRACT

The amount of wastewater has increased due to the considerable expansion of higher education institutions. When wastewater is released without treatment or with inefficient treatment, it causes significant water pollution. In this context, this study evaluated the performance of Constructed Wetlands as a post-treatment of a decanter digester followed by an anaerobic filter, operated with effluent from the Federal University of Mato Grosso, Cuiabá Campus, Mato Grosso State. Four wetlands were constructed to develop the research: planted with *Typha domingensis*, planted with *Heliconia psittacorum*, planted with *Pontederia parviflora*, and not planted. The following physicochemical parameters were analyzed: Color, Turbidity, pH, Temperature, Total Solids, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen, Sulfate, Nitrate and Nitrite. The results show an organic matter removal efficiency with mean removal results: 70% BOD_5 for TCW, HCW and PCW; and COD 76% for PCW. The mean removal of total phosphorus was 78% for PCW and 92% NO^{-2}, as macronutrients. Analysis of variance ANOVA shows significance in the results of TDS, SO_4 and COD removal.

Keywords: biotechnology, horizontal subsurface flow, macrophytes, wastewater.

Wetlands construídos como pós-tratamento de um decanto-digestor seguido de um filtro anaeróbio

RESUMO

Com a crescente expansão das Instituições de Ensino Superior (IES), aumentam-se a quantidade de águas residuais, quando a mesma é lançada sem tratamento ou com tratamento ineficiente contribuem de maneira significativa para poluição dos recursos hídricos. Neste contexto, o objetivo deste trabalho foi avaliar o desempenho de Wetlands Construídos (WC) como pós-tratamento de decanto-digestor seguido de filtro anaeróbio, operados com efluente da Universidade Federal de Mato Grosso *Campus* Cuiabá-MT, no que se refere à remoção de nutrientes e matérias orgânicas. Para o desenvolvimento da pesquisa foram construídos quatro wetlands, sendo eles: WCT - plantado com *Typha domingensis*, WCH - plantado com *Heliconia psittacorum*, WCP plantado com *Pontederia Parviflora*, e WCB - não plantado. Foram analisados os parâmetros físico-químicos de cor, turbidez, pH, temperatura, Sólidos Totais (ST), Sólidos Totais Dissolvidos (STD), Demanda Bioquímica de Oxigênio (DBO_5), Demanda Química de Oxigênio (DQO), nitrogênio total, fósforo, sulfato, nitrato e nitrito. Os resultados obtidos mostram uma eficiência de remoção de matéria orgânica com resultados médios de remoção: de DBO_5 70% para WCT, WCH e WCP; e de DQO 76% para WCP. A remoção média de fósforo total 78% para WCP e NO^{-2} 92%, como macronutrientes. A análise de variância ANOVA mostra significância nos resultados de remoção de STD, SO_4 e DQO.

Palavras-chave: águas residuais, fitorremediação, fluxo horizontal subsuperficial, macrófitas.

1. INTRODUCTION

Wastewater from universities (WU) contains pollutant loads that, if discarded without treatment, can degrade water resources. This occurs when the pollutants are in contact with different processes of water use at universities, leading to water contamination, and thus changing chemical, physical and biological patterns (Santín *et al.*, 2016; Freitas *et al.*, 2016).

Wastewater treatment plants (WTPs) are responsible for restoring water quality standards to return it as naturally as possible to watercourses (Meneses *et al.*, 2015). In order to reduce impacts caused to the environment by sanitary sewage at universities, the water goes through wastewater treatment procedures in WTPs that can efficiently remove the dissolved particles, suspended and organic loads that are added to the wastewater (Morrison *et al.*, 2016; Wagner and Da Costa, 2015).

The Federal University of Mato Grosso is located in the Barbado Stream Basin in the city of Cuiabá, Mato Grosso state, a tributary of the Cuiabá River, and has a decanter digester as wastewater treatment, which comprises wastewater storage tanks. These tanks have active sludge inside with bacterial colonies capable of degrading organic matter through anaerobic biological processes such as hydrolysis, acidogenesis, acetogenesis, methanogenesis and sulfidogenesis. This wastewater treatment system, although simple and cheap, is inefficient in terms of organic matter removal (Chernicharo, 2019).

The aim of a Constructed Wetland (CW) is to treat both raw and post-treatment wastewater, thus ensuring greater efficiency in the removal of organic fats and macronutrients. A CW can operate in two ways: with the flow free flow where the macrophytes are floating or emerging (Toscano *et al.*, 2015); or with subsurface flow (Rodríguez and Brisson, 2015).

CWs are commonly used in countries such as Chile, Spain and Canada (Vera *et al.*, 2013, Casas-Ledón *et al.*, 2017, Caselles-Osorio *et al.*, 2017), mainly in post-treatment, because they have plants that have the capacity to absorb macronutrients (N and P), which are released in the process of decomposing matter, as well as in the nitrification process that occurs in bacteria related to the roots of plants (according to Li *et al.*, 2015).

This study evaluated the efficiency of a CW as post-treatment of a decanter digester followed by an anaerobic filter on an experimental scale.

2. MATERIAL AND METHODS

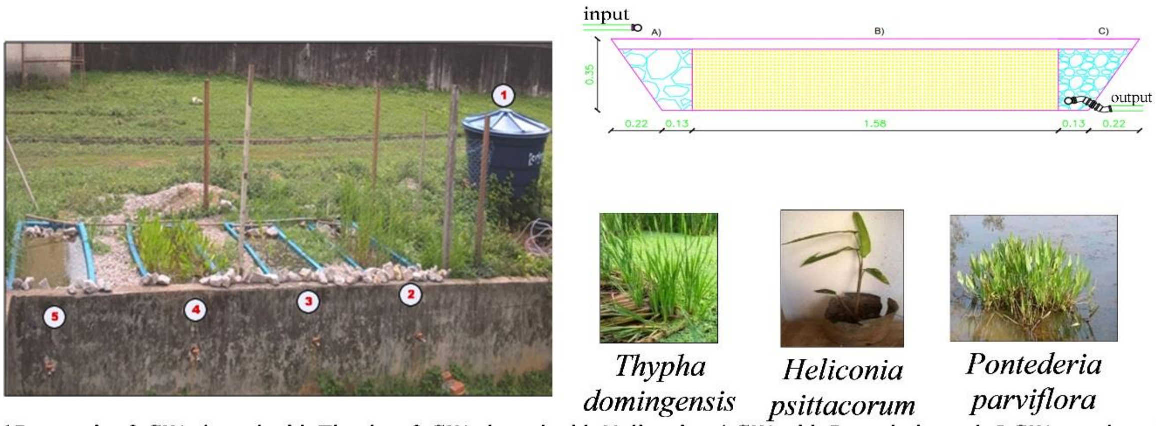
The methodology was developed in three stages: I) designing and constructing the experiment in a pilot scale of the CW; II) monitoring the physico-chemical parameters of the WTP; and III) monitoring the physicochemical parameters and CW biomass growth.

The experiment was carried out at the WTP at the Federal University of Mato Grosso, Cuiabá Campus, located between the geographic coordinates 21S 600022.00m E and 8274119.00m S. The climate in the city of Cuiabá is characterized as continental tropical, with two distinct seasonal seasons, one rainy (October-March) and the other dry (April-September). It has an annual precipitation of 1.262 mm and an average temperature of 25, 91°C (INMET, 2018).

The wastewater treatment system is formed by a lift station that receives the WU, from the sanitary station of the university, and from the *Jardim América* neighborhood. It is then pumped to the WTP, which is comprised of a Decanter Digestor, where the degradation of organic matter occurs anaerobically. This is followed by a biofilter, which retains part of the dissolved solids of the system, and then finally the Drying Bed (DB).

The treated effluent from the WTP was moved by a peristaltic pump to a reservoir of 1 m^3 made of polyethylene, then by gravity to CWs, which were fed continuously in a subsurface form with controlled flows in each CW, at a flow rate of 50 liters / 10 days. The internal volume of the tanks used in the CW implantation was 0.45 m^3, made of high-density polyethylene, with a surface length of 2.20 m and a depth of 1.84 m, a surface width of 0.71 m, and a bottom measuring 0.33 m, respectively. The substrate filling consisted of a sequence of filter layers: hand stone, washed sand and gravel N°. 02.

Four wetlands were constructed, with three different species of macrophytes in separate planted CWs and one unplanted CW; those that were planted had a density of 10 rhizomes per CW, divided into the following: one was planted with *Typha domingensis* (TCW), one planted with *Heliconia psittacorum* (HCW), one planted with *Pontederia Parviflora* (PCW), and one was not planted (NCW) in order to obtain the block of the treatment tanks (Figure 1).



1Reservoir; 2 CW planted with Thypha; 3 CW planted with Heliconia; 4 CW with Pontederia; and 5 CW not planted. A) stone hand; B) sand; C) gravel N° 2

Figure 1. Constructed Wetland.

Sampling was carried out from October 2017 to February 2018, and six points were monitored at the WTP: Gross Effluent - Point 1 (P1) - Landfill and Treated Effluent - Point 2 (P2) - Biofilter Output, considering the flow of the system structure. The other four samples at the output of each CW, occurring over a period of 150 days, complied with the Hydraulic Detention Time (HDT) of 5 and 10 days. The samples were collected using collector tubes installed in each CW tank at the following sampling points: TCW, HCW, PCW and NCW.

Samples were analyzed considering the following parameters: Total Dissolved Solids - TDS (mg /l), Total Phosphorus - TP (mg/l), Sulphate - SO_4 (mg/l), Nitrate – NO^{-3} (mg/l), Nitrite - NO^{-2} (mg /l), Total Nitrogen - TN (mg/l), pH, Biochemical Oxygen Demand - BOD_5 (mg/l) and Chemical Oxygen Demand - COD (mg/l).

After collecting the concentration results of the TDS, TP, SO_4, NO^{-3}, NT, NO^{-2}, BOD_5 and COD parameters, they were submitted to Equation 1 to each CW to obtain the Removal Efficiency.

$$RE = \frac{Conc(P2) - Conc(CW)}{Conc\ (P2)} \times 100 \tag{1}$$

At where:

Conc (CW)$\neq$ 0

2.1. Biomass

Every 10 days, four plants from each treatment were collected and separated into roots, leaves and stems. Afterwards, the roots were washed in running water and distilled to remove soil. The vegetal material was placed individually in paper bags, properly identified and then dried in a forced ventilation oven at 70ºC for 48 hours. Finally, the material was weighed to calculate the dry mass of the leaves, roots and stems of each plant.

Statistical analyses of the results from the laboratory analyses were performed by the paired ANOVA test that evaluated the variance of the results, as well as the standard deviation between them. Significant differences in water quality between wet and dry plant species were evaluated using a completely randomized analysis of variance with significance of 5% and 10%. To prove the variance test, the correlation test was used to determine the relationship between the parameters.

3. RESULTS AND DISCUSSION

Dissolved Oxygen inside the WTP and CW varied between 0.91 and 7.24; the WTP output was lower than the standards established by CONAMA (Brazilian National Council for the Environment) due to the anaerobic system where the pH rises and DO decreases (Figure 2). The CWs had a higher oxygen insertion at the beginning of the experiment, decreasing after the month of January. This variation is related to plant respiration and biofilm development using DO in the decomposition of organic matter (Pelissari *et al.*, 2014).

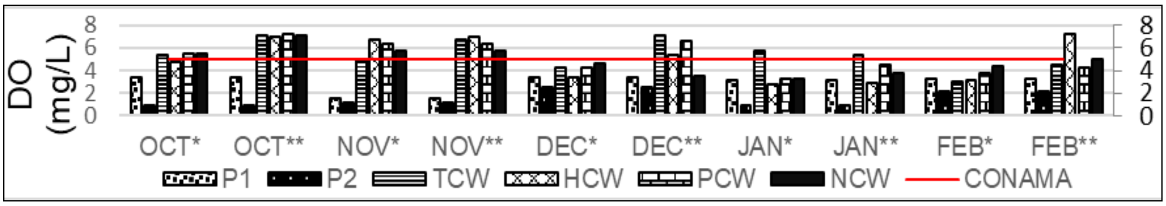


Figure 2. Dissolved Oxygen Variation.

The results of pH and CW in the WTP varied between 8.95 and 6.81, within the range established by CONAMA (Figure 3), and the most alkaline result was recorded in the HCW in the HDT on October 10th, and the most acidic result was recorded in the TCW in the HDT also on October 10th. These values correspond to those of Caselles-Osorio (2017), who states that plant root growth can influence plant pH by acidifying the medium with carbon production due to respiration (Kadlec *et al.*, 1996; Vymazal, 2007).

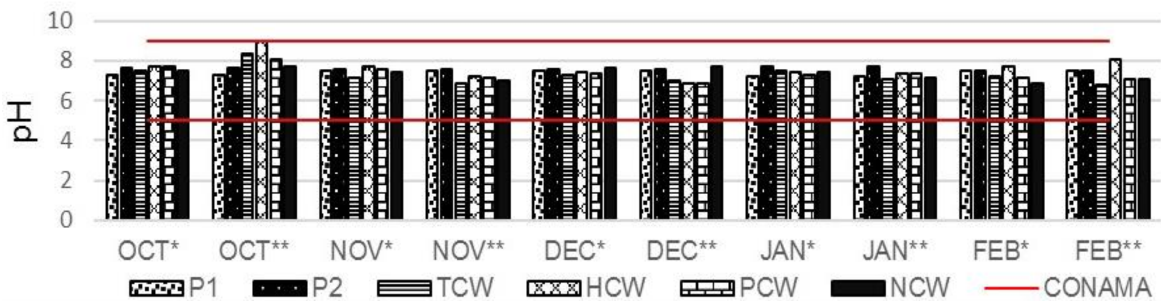


Figure 3. pH variation.

The CW removals were calculated in relation to P1 following the research sample; therefore, the average removal efficiency of the TDS in the HDT of 5 days was highlighted by the PCW, with 51%. The others had close values, which were 48%, 50% and 46% for TCW, HCW and NCW, respectively. In the 10-day results, the efficiencies of all CWs rose. The PCW had the best result, with a value of 73%, while the other TCW, HCW, NCW obtained 71%, 72% and 61%, respectively. These values show that there was increased efficiency in the TDS, similar to those of Sehar *et al.*, who obtained efficiency values between 42% and 74%, in their experiment at a 20-day TDH. In the present study, it was observed that the removal of TS is related to sorption in the filter medium, absorption by the plants (Figure 4) (Sezerino *et al.*, 2015).

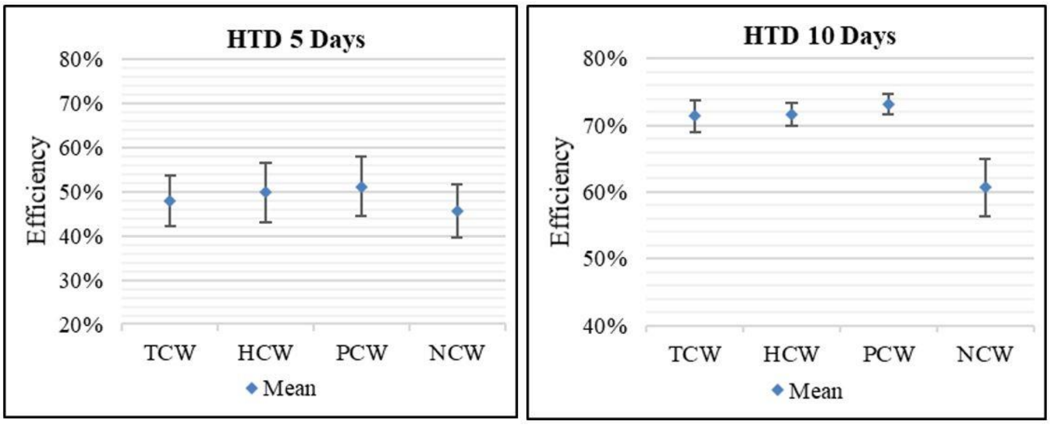


Figure 4. Total Dissolved Solids efficiency.

Phosphorus in the CW had a great variation mainly in the months of November 2017 and February 2017, but the CW behaved efficiently in both concentrations. The average phosphorus efficiencies in the HDT of 10 days were 49%, 45%, 78% and 41%, for TCW, HCW, PCWP and NCW, respectively.

The P is part of the macronutrients that the plants absorb to use in their metabolic compositions, comparing the phosphorus concentrations with Abou-Elela and Hellal (2012) and Leto *et al.* (2013) who obtained a result of 62% removal and 47.9% with a concentration of 0.4 mg/l and 4.2 mg/l. The PCW obtained better removal results, while TCW, HCW and NCW obtained results of efficiency lower than both (Figure 5).

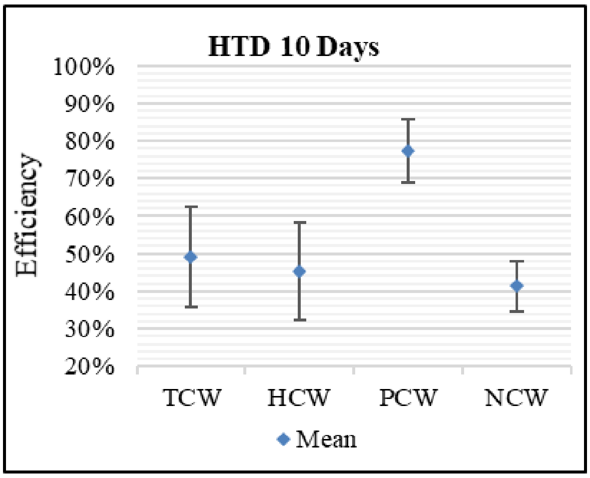


Figure 5. Phosphorus efficiency.

The mean sulphate efficiencies in 5 days of HDT were 60%, 59%, 65% and 35% for TCW, HCW, PCW and NCW, respectively; and in 10 days of HDT were 95%, 99%, 95% and 93% for TCW, HCW, PCW and NCW, respectively. These results show that in the planted CWs, there was higher sulphate removal efficiency compared to the non-planted ones. This may be related to oxygen in the available plant roots (Figure 6).

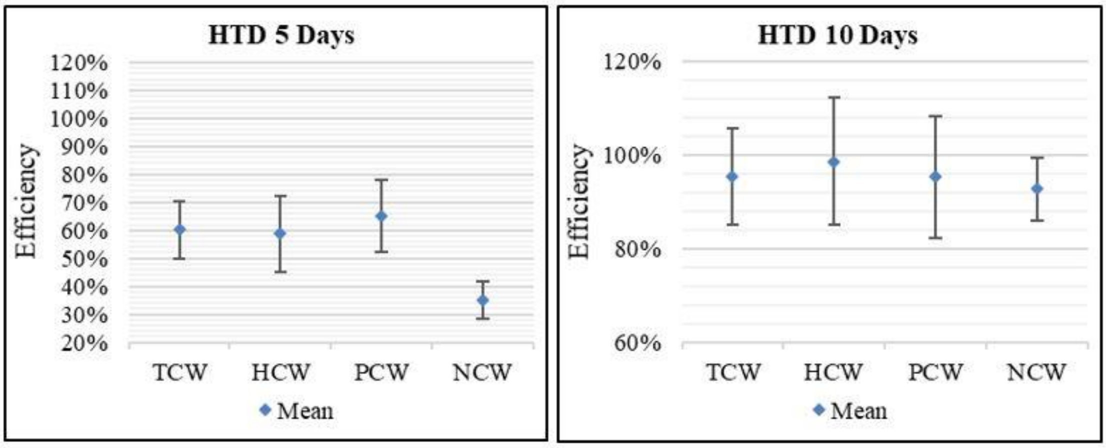


Figure 6. Sulphate efficiency.

The mean efficiency of NO^{-2} in the HDT of 5 days was: 68%, 57%, 61% and 66% for TCW, HCW, PCW and NCW, respectively; for 10 days, it was 92%, 88%, 89% and 78%, for TCW, HCW, PCW and NCW, respectively. The mean NO^{-3} removal in the HDT of 5 days was 66%, 66%, 67% and 57% for TCW, HCW, PCW and NCW, respectively; for 10 days it was 86%, 75%, 82% and 67 for TCW, HCW, PCW and NCW, respectively. The removal of NO^{-3} and NO^{-2} occurs due to the absorption of nutrients by plants and the release of oxygen forming N_2 (Sehar *et al.*, 2014). Maine *et al.* (2006) obtained results of 88% and 85% concerning the removal of NO^{-3} and NO^{-2}, in WC planted with *Typha domingensis* and *Panicum elephantipes* (Figure 7).

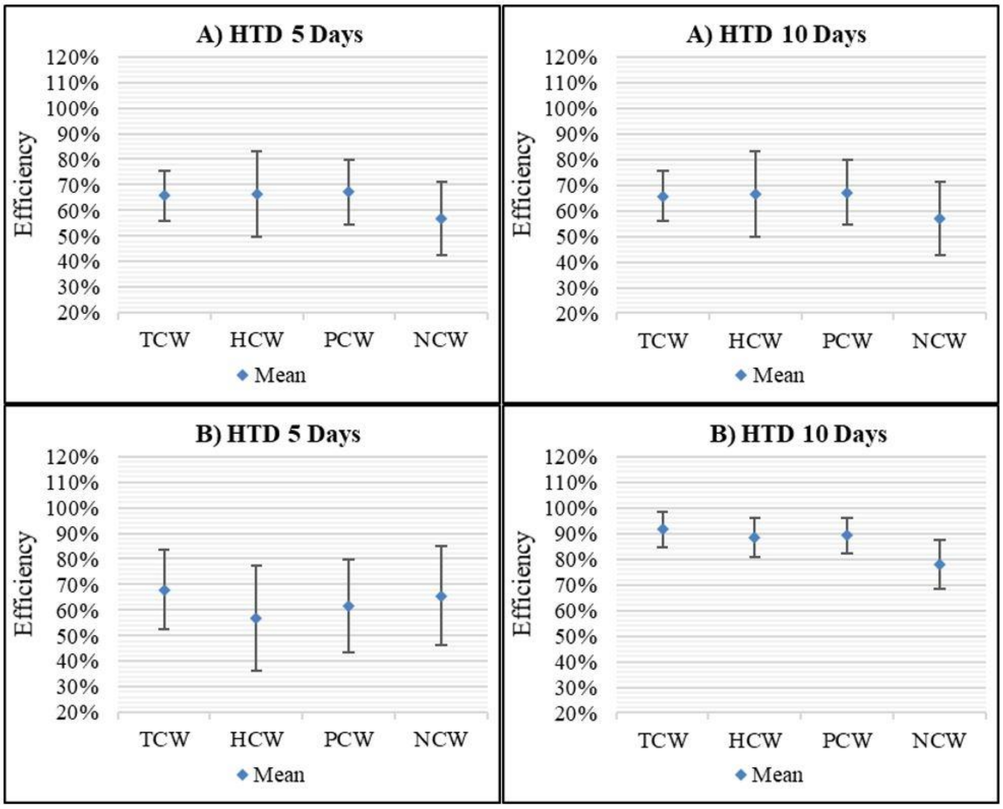


Figure 7. Efficiency of Nitrite and Nitrate.

The mean total nitrogen efficiency results in the HDT of 10 days were 52%, 42%, 34% and 31%, for TCW, HCW, PCW and NCW, respectively. The maximum removal in the PCW was the one that stood out, as it had 60% in October 2017. Hsu et al. (2011) obtained a result of Total Nitrogen removal in a natural wetland which is close to the results of the present study. However, in an experiment similar to this one, Rodríguez and Brisson (2015) managed a removal of 97% (Figure 8).

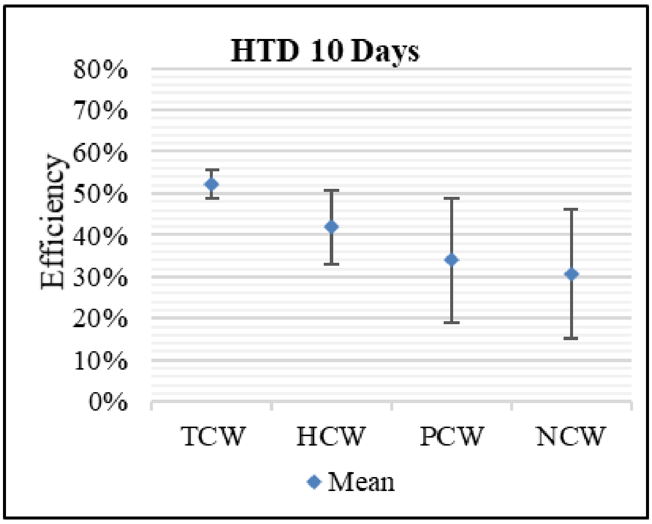


Figure 8. Total Nitrogen Removal.

The BOD_5 obtained the mean efficiency for the HDT of 5 days, which was less than 50%. The CW that had the best mean efficiency was HCW with 45%, then PCW with 44%, TCW with 42% and NCW with 38%. However, the results of the 10-day analysis were the same for all planted CWs at 70%, and the NCW was 66%. The 5-day and 10-day HDT efficiency values, despite being effective in maintaining lower load effluent within the limits of CONAMA 357/05, these same results in the HDT of 5 days are lower than those of Sohsalam *et al.* (2008); Vera *et al.* (2013) and Abou-Elela and Hellal (2012); and the efficiency result in the HDT of 10 days are equal to these authors. BOD_5 removal occurs due to deposition and filtration, while organic compounds were degraded aerobically and anaerobically by heterotrophic microorganisms, depending on the concentration of oxygen in the bed (Figure 9).

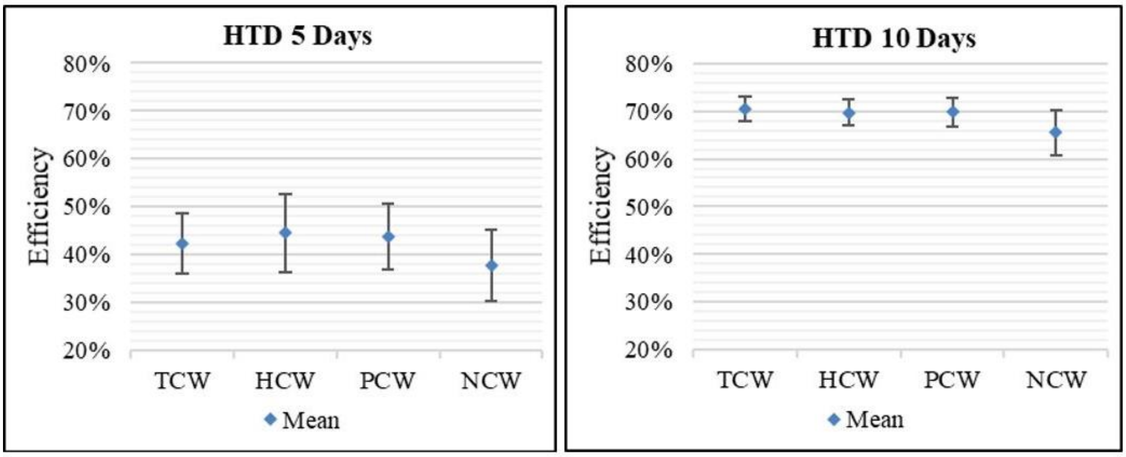


Figure 9. BOD_5 efficiency.

The mean COD removals for TCW, HCW, PCWand NCW were 42%, 34%, 47% and 29%, respectively, in the HDT of 5 days. In the HDT of 10 days, the values were close, ranging from 76% to 69%. The COD values were similar to those of Ansola *et al.* (2003), Caselles-Osorio *et al.* (2011) and Ebrahimi *et al.* (2013), who had mean values of efficiency of 79%, 75% and

72%. These studies found a greater efficiency in planted CWs due to the assimilation of the plant to organic materials and macro nutrients found in the wastewater (Figure 10).

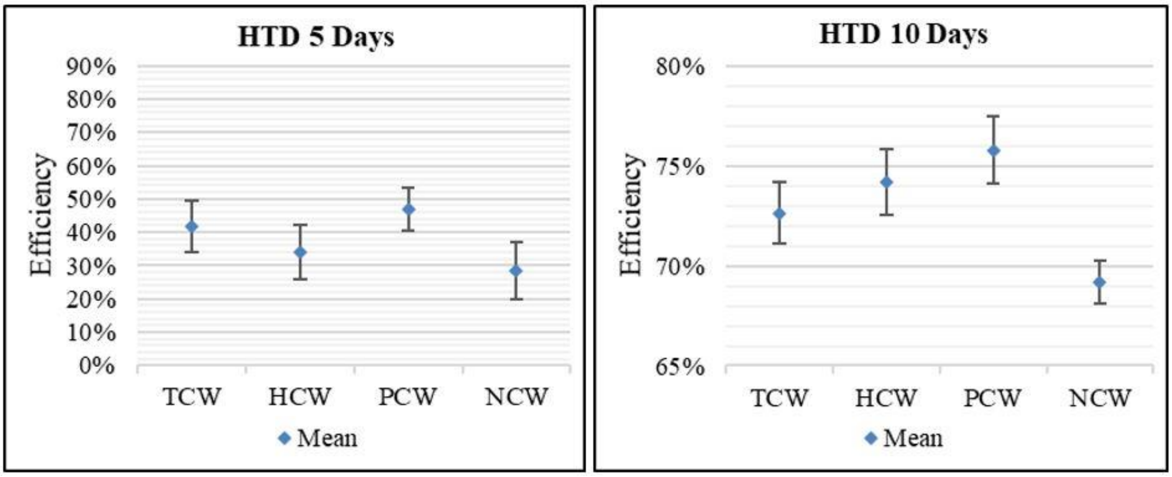


Figure 10. COD efficiency.

3.1. Development of macrophytes

The macrophytes were planted in their young stage and accompanied by their growth in height (cm) and weight (g). The result shows the growth variation between plants from the young to the adult stages. Among the macrophytes, *Typha domingensis* and *Pontederia parviflora* evolved in the analyzed period; however, *Heliconia psittacorum* had a low adaptation to the wetland system implanted (Figure 11).

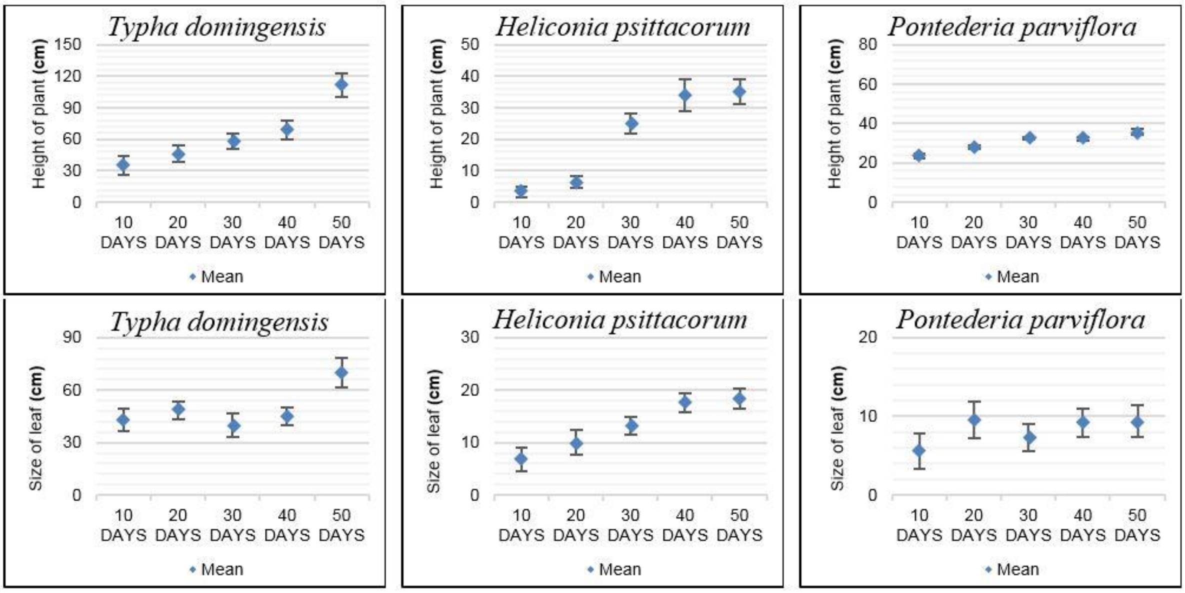


Figure 11. Total Nitrogen Removal.

The average height of the *Typha domingensis* plant in October 2017 was 35.2 cm, and in February 2018 it had an average size of 111.2 cm. In addition, *Heliconia psittacorum* obtained an average height in October 2017 of 3.36 cm, and in February 2018 it was 35.2 cm. The *Pontederia parviflora* species reached 23.55 cm at the beginning of the period, and at the end 35.6 cm (Figure 12).

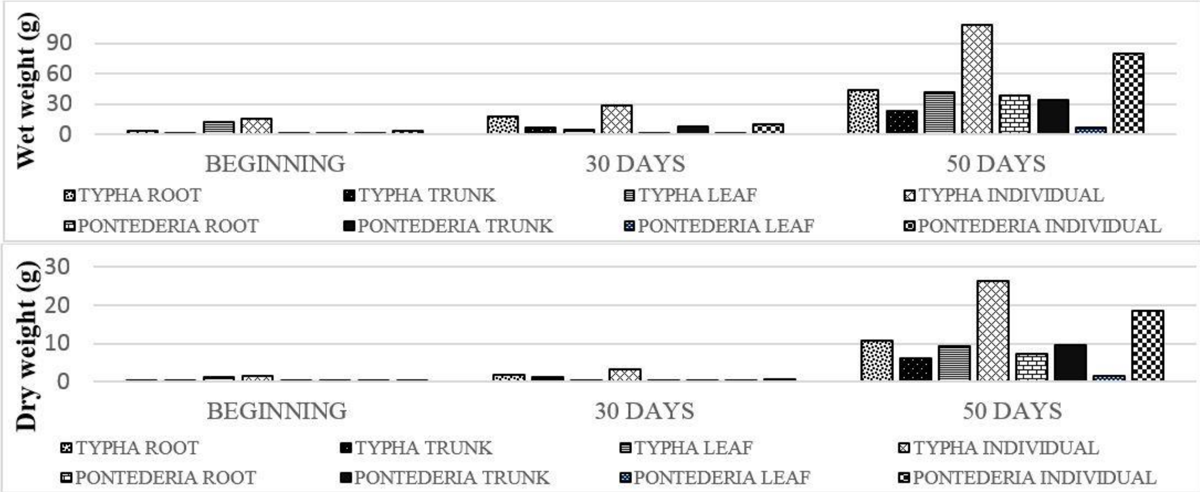


Figure 12. Macrophyte growth.

The mean growth of the leaf of the *Typha domingensis* species was initially 43.05 cm, reaching 72.02 cm; compared to Lorenzen *et al.* (2001), Typha domingensis had similar growth, and in its experiment the final size was 97 cm. On the other hand, the species Heliconia psittacorum had an average increase of 6.74 cm, and at the end of the studied period reached 18.40 cm, compared to Cerqueira *et al.* (2008). These species showed considerable development, since species presented average growth of 97.1 cm. The average leaf length of the *Pontederia parviflora* started at 5.70 and ended at 9.45 cm. The biomass growth was measured in the *Typha domingensis* and *Pontederia parviflora* species, comparing the beginning and end period of 50 days. In the first plant there was an individual increase in its wet weight of 92.53 g and in the dry weight of 24.60 g, compared to the second. Regarding the *Pontederia parviflora* species, the individual wet weight was 76.36 g and the dry weight was 18.15 g. In this plant biomass analysis, we were not able to determine the weight of the *Heliconia psittacorum*.

3.2. Statistical Analysis

The static ANOVA test was performed for 5 and 10 days of HDT, with a significance of 5% for all parameters. The COD, SO_4 and TDS, both for 10 days of HDT, were significant at 10%, according to ANOVA.

4. CONCLUSION

To sum up the experiment, it was concluded that the wetlands present a greater concentration removal in the CWs (TCW, HCW and PCW) than in the non-planted ones. Among those planted, PCW was the one that most stood out in the removal of organic matter and macronutrients. It was the CW that obtained the highest result in 7 of the analyzed parameters in the HDTs of 5 days and 10 days.

Plant growth was fast, as the *Typha domingensis* and *Pontederia parviflora* species flowered at the end of five months, and also multiplied in individuals. However, *Heliconia psittacorum* showed a slower evolution with little productive adaptation.

The parameters such as COD, SO_4 and TDS had a significance of 5% in the ANOVA test, proving that HDT in the CW can be efficient in the removal of these pollutants even with the variation of the input load.

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