Tratamiento de aguas residuales por humedales artificiales tropicales en Tabasco, México

Treatment of water waste by wetlands artificial tropical in Tabasco

Tratamento de águas residuais por zonas húmidas artificiais em Tabasco tropical, México

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Resumen

En las dos últimas décadas, los humedales artificiales han incrementado mundialmente su desarrollo para el tratamiento de aguas residuales. En el presente estudio, doce humedales artificiales tropicales de flujo subsuperficial (HAFS) fueron diseñados y operados específicamente para el tratamiento de aguas residuales domésticas. La eficiencia de remoción de contaminantes básicos (DBO_5, DQO, SST, NT, PT, Turbiedad y Color) fue evaluada bajo tres tratamientos: 1) *Pontederia cordata* (HAFS-Tule), 2) *Phragmites australis* (HAFS-Carrizo) y 3) grava como prueba testigo (HAFS-Grava). Para el HAFS-

Tule, se obtuvieron las más altas eficiencias de remoción entre 81.10 % y 95.44 %. Para el HAFS- Carrizo, se encontraron eficiencias de remoción en un rango de 53 a 89 %; mientras que el HAFS- Grava presentó las eficiencias más bajas (34-72 %). Los datos experimentales fueron analizados estadísticamente por aproximaciones de Kruskal Wallis y ANOVA. Los tratamientos mostraron diferencias estadísticas altamente significativas ($p<0.001$). Desde el punto de vista del costo de operación, la actual vegetación nativa probó ser satisfactoria para el tratamiento de agua residual en una región tropical de México.

Palabras clave: humedales artificiales, flujo subsuperficial, eficiencia de remoción. México, 86039.

Abstract

In the last two decades, the wetlands have increased worldwide its development for the treatment of wastewater. In the present study, twelve tropical surface flow constructed wetlands (CW) were designed and operated specifically for the treatment of domestic wastewater. The efficiency of removal of Basic pollutants (BOD_5, COD, SST, NT, PT, turbidity and colour) was evaluated under three treatments: 1) *Pontederia cordata* (CW-Tule or Tule pond), 2) *Phragmites australis* (CW-Reed or reed-bed) and 3) gravel as test control (CW-Gravel or gravel wetland). For the CW-Tule, the highest removal efficiencies were obtained between 81.10% and 95.44%. For the CW-Reed, has found efficiencies of removal in a range of 53 to 89%; while the CW-Gravel presented efficiencies more low (34-72%). The data pilot were analyzed statistically by approximations of Kruskal Wallis and ANOVA. Treatments showed highly significant statistical differences ($p<0.001$). From the point of view of the cost of operation, the current native vegetation proved to be successful for the treatment of waste water in a tropical region of Mexico.

Key words: constructed wetland (CW), surface flow, efficiency of removal. México, 86039.

Resumo

Nas últimas duas décadas, as zonas húmidas artificiais em todo o mundo têm aumentado o seu desenvolvimento para o tratamento de águas residuais. No presente estudo doze zonas húmidas escoamento subsuperficial tropical construídos (sfaw) foram projetados e operados especificamente para o tratamento de esgoto doméstico. A eficiência de remoção de poluentes básicos (DBO 5, DQO, SST, NT, PT, turbidez e cor) foi avaliado em três tratamentos: 1) Pontederia cordata (sfaw-Tule), 2) Phragmites australis (sfaw-Carrizo) e 3) cascalho como prova de testemunho (sfaw-Grava). Para sfaw-Tule, foram obtidos os maiores eficiências de remoção entre 81,10% e 95,44%. Para HAFS- Carrizo, eficiência de remoção foram encontrados numa gama de 53-89%; enquanto o HAFS- Grava apresentou a menor eficiência (34-72%). Os dados experimentais foram analisados estatisticamente pelo abordagens Kruskal Wallis e ANOVA. Os tratamentos mostraram diferenças estatísticas altamente significativas ($p<0.001$). Do ponto de vista de custo operacional, a vegetação nativa atual mostrou satisfatório para tratamento de águas residuais em uma região tropical do México.

Palavras-chave: alagados construídos, fluxo de subsuperfície, eficiência de remoção. México, 86039.

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Introduction

In general, the water waste households are the fluids from dwellings or residences, commercial and institutional buildings, that affects to some extend the quality of the of water the source or body of water receiver when contains features that it make unacceptable (Romero Rojas, 1999). In this sense, the pollutants associated with untreated wastewater promote depletion of dissolved oxygen measured as demand biochemistry of oxygen (BOD_5) and Chemical oxygen demand (COD), introducing Solids Suspended Total (SST) unpleasant looking and nutrients of Total Nitrogen (NT) and Phosphorus Total (PT) that cause the eutrophication, in addition to chemical that exert toxicity (ammonia, metals, organic), emerging chemicals and pathogens (bacteria and viruses). Therefore, it is imperative to treat wastewater to prevent pollution of surface water or even groundwater (R. Mihelcic and Beth Zimmerman, 2012).

In this context it is necessary to analyze the existing techniques of wastewater treatment to apply criteria such as: ecological, economic, technical and social, seeking the most appropriate solution and forgetting current and routinary approaches based almost exclusively on conventional debugging (Seoánez Calvo, 1999). One of these techniques is the constructed wetlands (CW) since they require little operational staff and in the wastewater treatment process involves elements that are provided by nature (CONAGUA, 2013).

> The main mechanisms of removal and transformation occurring within the surface flow constructed wetlands towards contaminants, are the bioconversion by facultative and anaerobic bacteria located all over the wetland, aerobic bacteria associated in the plants roots and surface detritus, filtration, sedimentation, nitrification/denitrification, assimilation by plants, adsorption by roots. As well as also the removal of pathogens by natural decay, predation, and excretion of antibiotics by the plants roots (Crites & Tchobanoglous, 2000).

In the literature have been reported several studies focused on the treatment of wastewater by artificial wetland (Castañeda Villanueva and Flores López, 2013). There were obtained removal efficiencies in BOD_5=86%, NT=64%, PT=68%, G and A=60%, using common Reed (*Phragmites australis*), the gladiolus (*Gladiolus spp*) and the Totora (*Typha latifolia*), with retention times of three, five and seven days. In another study (Jiménez López, Solís Silván, López Ocaña, Bautista Margulis, and Castelán Estrada, 2014) employed vegetation *Paspalum paniculatum*, reporting efficiencies for turbidity and colour by 95% and 99%, with a turbidity and color of the 98% and 90% respectively, COD by 94.38% and 95.22%, and with times of hydraulic retention of 5 days with free and surface flow constructed wetlands. Using *Cyperus Papyrus* and *Phragmites Australis* (Torres Guerra, Magno Vargas, Pineda Aguirre, and Cruz Huaranga, 2015) reported effectiveness by BOD_5=84%, Fecal coliforms= 89%, Turbidity=77%, with hydraulic retention time of 3 and 7 days for surface flow wetlands.

> Wetlands based on emerging rooted macrophyte can be of two types, according to the circulation of water used: 1) wetlands of surface flow, if water circulates between the stems of the macrophytes and 2) wetlands of subsurface flow, if water flows below a granular medium (Delgadillo, Camacho, Pérez, y Andrade, 2010).

This study's main objective is to evaluate the efficiency of removal of basic contaminants in subsurface flow constructed wetlands vegetation macrófita de *Pontederia cordata* (Tule) and *Phragmites australis* (Carrizo), belonging to the tropical region of Tabasco. The results of this research may lead to economic, operational and maintenance that help to implement artificial wetlands in rural areas that do not have their wastewater treatment indicators, mitigating pollution before it is discharged to surface water bodies.

Materials and methods

Experimental design. Randomized complete design of a factor (treatment) was used with three levels (HAFS-Tule, HAFS-Carrizo y HAFS-Grava); The experiment was run in quadruplicate. During a period of three months (September, October and November 2015), measurements of the response variables were performed: DBO_5, DQO, NT, PT, SST, Turbidity and color, at the entrance and exit of each artificial wetland. Sampling for turbidity and color measurement was performed daily (Monday to Friday) between 8:00 and 17:00, obtaining a single sample every three hours to form subsequently a composite sample at the end of the day. Measurement DBO_5, DQO, NT, PT and SST It was held one day a week for a period of three months.

According to the sampling campaign, 60 composite samples 720 input and output to measure turbidity and color were obtained. Furthermore, for DBO_5, DQO, NT, PT and SST a total of 720 samples, 144 being individually by parameter were obtained. relative humidity, ambient temperature, pH and water temperature were also measured. The wastewater to be treated in artificial wetlands comes from safflower hub belonging to the

Juarez Autonomous University of Tabasco (UJAT) of the Academic Division of Biological Sciences (DACBiol) whose water has been used in health services and cafes. For the experimental phase 12 units connected artificial wetlands of subsurface flow were built independently.

For pumping wastewater two pumps Truper mark 1 hp, connected to hydraulic pipe 1 in PVC suction strainer coupled to a nipple, union nut with possible tamponade, and to avoid malfunction used. PVC pipe was connected to three tanks that regulate the flow, thus maintaining the same flow rate, inlet velocity and organic load to each of the artificial wetlands.

Each experimental unit was constructed with 10 gauge carbon steel, whose dimensions were 2.5 m long x 1.2 m wide x 1 m high. On the outside of an anticorrosive alkyd enamel (primary 1), and then a white catalyzed epoxy polyamides (SYLPYL®, Mexico) was applied blue. On the inside of a layer of elastomeric waterproofing, which was supplemented with layers of a textile fiber of 0.01 mm (pellon) and a length of 4 meters it was applied. This procedure was replicated five times. Wetlands Control (SFAW-Grava), were designed and constructed with the same materials and dimensions.

Subsequently the hydraulic line within each wetland, along with accessories such as valves, elbows, T's, connectors, leaving space for the entrance of water to a height of 0.45 m was installed, allowing a homogeneous distribution horizontally across the longitudinal section. At the end of this activity, each experimental unit was filled with gravel of 2 cm in diameter to a height of 0.5 m, which acted as support means for the plants.

Finally, we conducted a field sampling in natural wetlands to collect macrophyte vegetation *Pontederia cordata* and *Phragmites australis* belonging to the municipality of Centro. For the distribution of the species planted *Pontederia cordata* 4 wetlands were used, placing 15 plants each. While for the species *Phragmites australis*, 20 rows were seeded at each of the four wetlands, each row with 4 floors. Wetlands Control (4 HAFS-Grava), alone they contained no plant gravel. Plants adapted to the system over a period of 40 days. At the end of this phase we proceeded to perform water sampling in order to evaluate the efficiency of removal of pollutants for different treatments established. The treatment capacity in each wetland was 200 L / d, making hydraulic retention times of 7 days in each treatment.

For data analysis software was used STATGRAPHICS Centurión XVI. Turbidity was measured with a turbidímetro LaMotte® with presicion of 0,01 NTU turbidity (method EPA 180.1, TC-300e, ISO7027, TC-300i). The color was measured with the same equipment with an accuracy of 0,1 C.U-color aparently (estándar method 2120B). The relative humidity and ambient temperature were a team means Hanna®. The pH and water temperature were measured with a multiparameter Hanna^{MR}. Parameters DBO_5, DQO, NT, PT y SST, They were analyzed with methods: NMX-AA-030/1-SCFI-2012, NMX-AA-028-SCFI-2001, NMX-AA-026-SCFI-2001, NMX-AA-029-SCFI-2001 y NMX-AA-034-SCFI-2001.

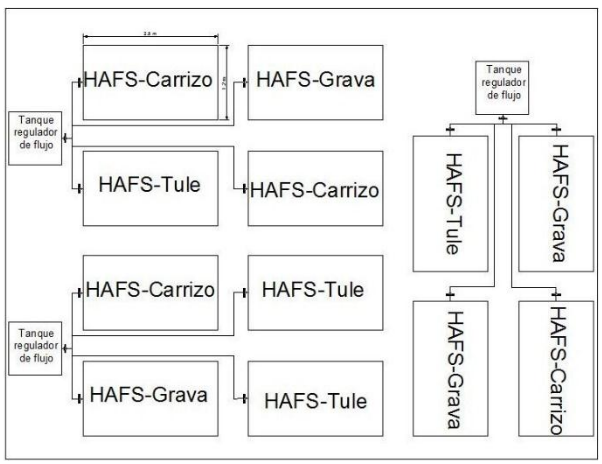

Figure 1. Distribution of artificial wetlands horizontal subsurface flow.

Statistic analysis. To determine statistically significant differences in the treatment of wastewater by wetlands, was contrasted with an analysis of variance classification ranges Kruskal - Wallis, as well as a contrast medium for independent samples U Mann – Whitney, conducting the comparison of the response variables (DBO_5, DQO, NT, SST, Turbiedad y Color). On the other hand, the statistics of total phosphorus (TP) between different treatments wetlands differences were determined using a simple ANOVA, as well as multiple Tukey contrast.

Results and discussion

The results of the various parameters are presented (DBO_5, DQO, NT, PT, SST, Turbiedad y Color) They tested at each treatment and compared with control (HAFS-Grava), thus allowing them to determine which performs most removal efficiency. The results of the parameters measured in the incoming water are on average: DBO_5 408.07 $mg \cdot l^{-1}$, DQO 859.08 $mg \cdot l^{-1}$, NT 80.70 $mg \cdot l^{-1}$, PT 15.08 $mg \cdot l^{-1}$, SST 309.95 $mg \cdot l^{-1}$, Turbiedad 131.36 NTU and Color 946.08 U.C. While the relative humidity was 87.3%, room temperature 32 °C, pH 7.84 and water temperature 27.63 °C.

DBO_5 y DQO

The analysis of variance classification ranges Kruskal - Wallis, for contrast medium in measuring BOD5 and COD of different artificial wetlands (SFAW-Reed, SFAW-Tule and SFAW-Grava) indicates that there are statistical differences highly significant between treatments ($p<0.001$). Independent samples test U Mann - Whitney, he indicated that there are statistically significant differences in both median treatments evaluated ($p<0.05$). The lowest mean value was observed the HAFS-Tule (18.60±1.10), showing greater removal in aerobic decomposition (DBO_5), followed by HAFS-Carrizo (50.85±4.69), so the HAFS-Grava (203.44±9.86) is the least efficient respectively (Figure 2).

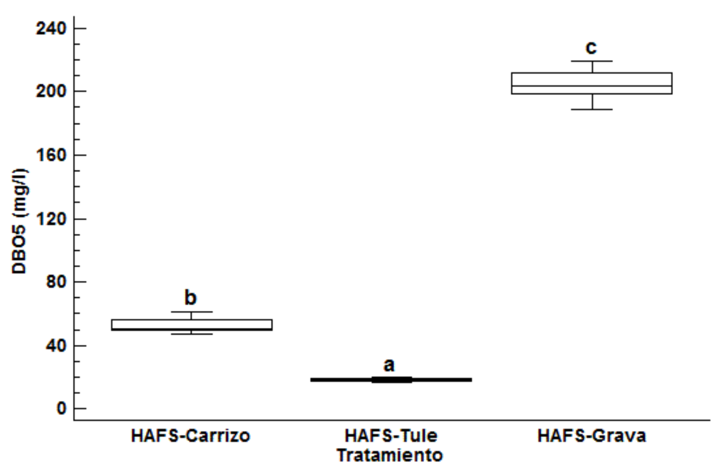

Figure 2. Median values (±EE) in measuring DBO_5 a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments ($p<0.05$), al 95 % confidence level.

As for DQO, the lowest mean value was observed HAFS-Tule (40.23±3.81), followed by HAFS-Carrizo (119.96±13.83), so that HAFS-Grava (362.87±17.84) is the least efficient respectively (Figure 3).

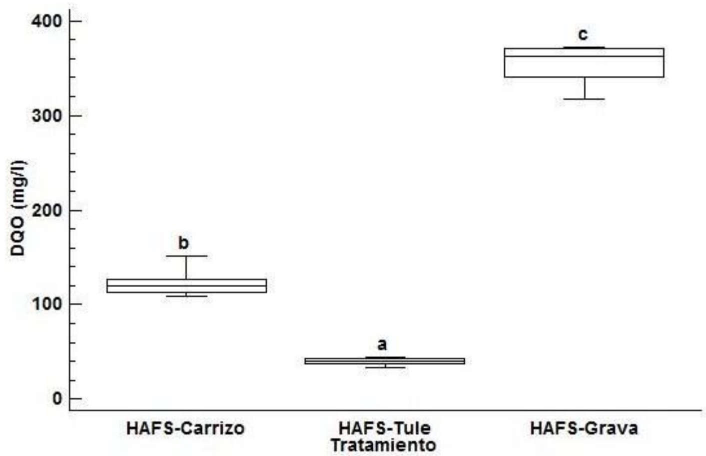

Figure 3. Median values (±EE) in measuring DQO a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments ($p<0.05$), al 95 % confidence level.

According to the above results, the subsurface flow constructed wetland with tule (HAFS-Tule) was the best treatment, because removal efficiencies obtained for DBO_5 (95.44%) and DQO (95.32 %). (Montoya, Ceballos, Casas, y Morato, 2010) They used artificial wetlands of subsurface flow removal efficiencies for: *Canna limbata* DBO_5 (100 % and 99.36 %), DQO (97.31 % and 95.94 %); *Heliconia psittacorum* DBO_5 (99.09 % and 97.49 %), DQO (94.49 % and 93.50 %) and *Phragmites sp* DBO_5 (100 % and 99.45 %), DQO (97.39 % and 97.13 %). These efficiencies are similar to those found in this study, whose differences to different vegetation and synthetic wastewater used in the experiment since the hydraulic retention time and sampling period they were equal attributed.

Output concentration DBO_5 (18.60 $mg{\cdot}L^{-1}$) in the HAFS-Tule This study, fulfilled satisfactorily NOM-003-SEMARNAT-1997 which establishes the maximum permissible limits (LMP) of pollutants for treated wastewater reuse in service to the public, since the LMP for indirect or occasional contact is 30 $mg{\cdot}L^{-1}$. As well as NOM-001-SEMARNAT-1996 which establishes the LMP of pollutants in wastewater discharges into national waters and goods, indicating a daily average of LMP 30 $mg{\cdot}L^{-1}$ and monthly average 60 $mg{\cdot}L^{-1}$ for protection of aquatic life in rivers. While the outlet concentration DQO (40.23 $mg{\cdot}L^{-1}$)

He complied with federal law rights (Applicable Provisions on National Waters), which establishes a LMP 500 mg·L^{-1} for discharges of urban public services (CONAGUA, 2015).

Nitrógeno Total (NT)

For different artificial wetlands (HAFS-Carrizo, HAFS-Tule y HAFS-Grava), analysis of variance classification ranges Kruskal – Wallis He indicated that there were highly significant statistical differences between treatments ($p<0.001$). The test of independent samples, U Mann – Whitney also she indicated that there are statistically significant differences in both median treatments evaluated ($p<0.05$). The lowest mean value was observed HAFS-Tule (4.66±0.62), with the greatest concentration removal in NT, followed by HAFS-Carrizo (12.34±1.34) and HAFS-Grava (40.93±5.19). The latter showed the lowest efficiency (figure 4).

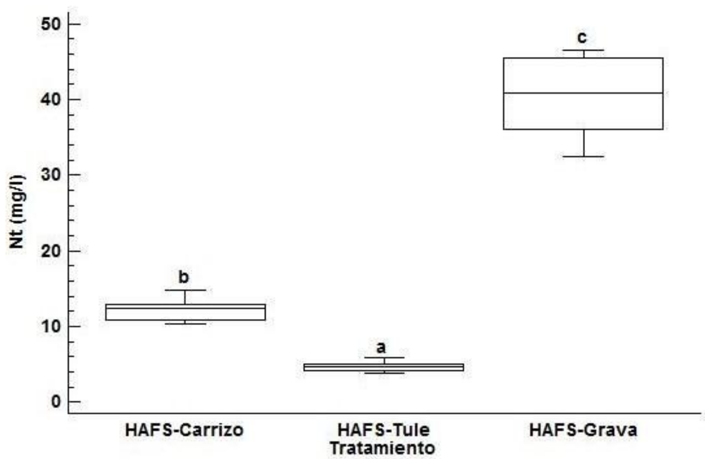

Figure 4. Median values (±EE) in measuring NT a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments ($p<0.05$), al 95 % confidence level.

The removal efficiency obtained for the NT was 94.22 %, proving to be the best treatment for HAFS-Tule (Lara Borrero y Vera Puerto, 2010), with an artificial wetland vegetation subsurface flow reed, achieving average removal efficiency 43 %. To this percentage Lara considered satisfactory, if taken into account the climatic conditions of the area, and especially the wetland was not designed to remove nitrogen. In this research concentration NT (4.66 mg·L^{-1}) at the outlet of the wetland, he fulfilled satisfactorily with the outline of the NOM-001-SEMARNAT-1996, (LMP is indicated daily average 25 mg·L^{-1} and monthly average 15 mg·L^{-1}) for protection of aquatic life in rivers.

Total phosphorus (PT)

he ANOVA for comparison of mean values in variable measurement PT, of different artificial wetlands (HAFS-Carrizo, HAFS-Tule y HAFS-Grava), It indicates that there are highly significant statistical differences between treatments (ANOVA, F2.33=382.67, p<0.001). Test post multiple contrasts Tukey, It indicates presence of statistically significant difference between treatments (p<0.05). The lowest average value was observed HAFS-Tule (3.06±0.63), with the greatest concentration removal in PT, followed by HAFS-Carrizo (6.91±0.42), so the HAFS-Grava (9.79±0.69) is the least efficient respectively (figure 5).

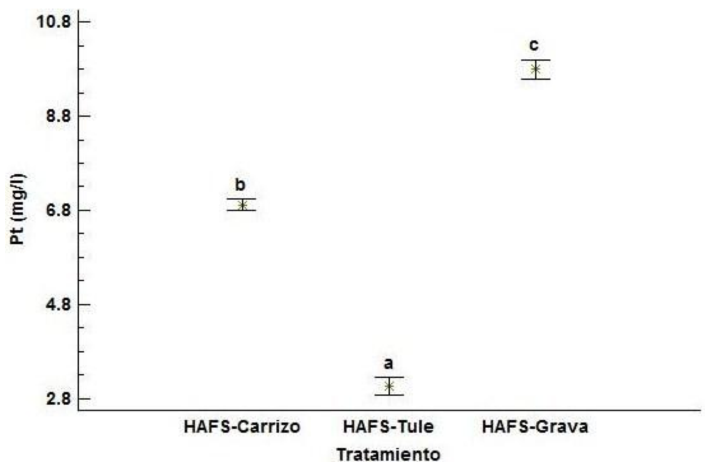

Figure 5. Median values (±EE) in measuring PT a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments (p<0.05), al 95 % confidence level.

For the treatment HAFS-Tule, removal efficiency obtained for the PT was 81.10 %. (J. Olguín, E. González-Portela, Baechler, Mercado, y Sánchez-Galván, 2007). removal efficiencies of 94% for total phosphorus, under the same conditions of vegetation and subsurface flow with a hydraulic retention time of 5 days found. As can be seen, this percentage is higher than the present work, since the entry conditions for which were contrasted 3.17 $mg \cdot L^{-1}$, which facilitates removal by vegetation. While the study of such input are 15.08 $mg \cdot L^{-1}$. Concentration 3.06 $mg \cdot L^{-1}$ corresponding to 81.10 He was evaluated with the LMP NOM-001-SEMARNAT-1996 which does not exceed 5 $mg \cdot L^{-1}$ the monthly average and 10 $mg \cdot L^{-1}$ the average daily, for protection of aquatic life in rivers.

Total Suspended Solids (SST)

The analysis of variance classification ranges Kruskal – Wallis, for contrast medium measurement variable SST, of different artificial wetlands (HAFS-Carrizo, HAFS-Tule and HAFS-Grava), It indicates that there are highly significant statistical differences between treatments ($p<0.001$). The test of independent samples, U Mann – Whitney He indicated that there are statistically significant differences in both median treatments evaluated ($p<0.05$). The lowest mean value was observed HAFS-Tule (18.32±0.59), more removal in concentration SST, followed by HAFS-Carrizo (32.88±3.82), so the HAFS-Grava (156.06±8.86) is the least efficient respectively (figure 6).

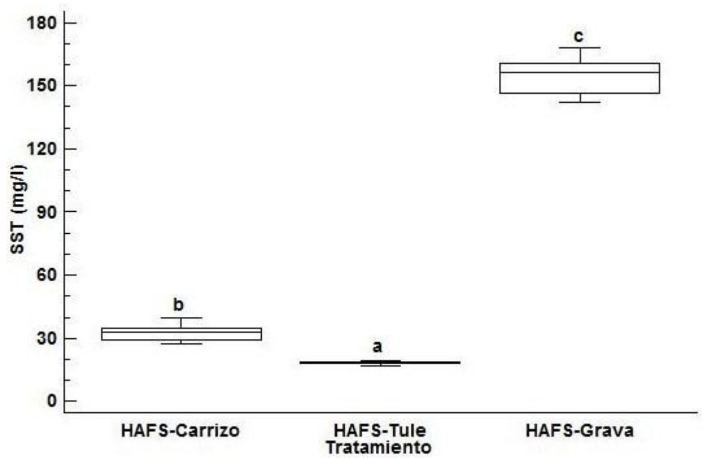

Figure 6. Median values (±EE) in measuring SST a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments ($p<0.05$), al 95 % confidence level.

The efficiency of removal of total suspended solids was 94.09% for the HAFS-Tule. This relationship was highly significant with respect to the applied experiment (Pérez Salazar, Alfaro Chinchilla, Sasa Marín, y Agüero Pérez, 2013), whose removal was 73 % for the SST using *Cyperus papyrus*. According to the results of this work the final concentration was evaluated 18.32 $mg{\cdot}L^{-1}$, with NOM-001-SEMARNAT-1996 which does not exceed 40 $mg{\cdot}L^{-1}$ the monthly average and 60 $mg{\cdot}L^{-1}$ the average daily, for protection of aquatic life in rivers.

Turbidity and color

The analysis of variance classification ranges Kruskal – Wallis, for contrast medium in turbidity measurement and color, in different artificial wetlands (HAFS-Carrizo, HAFS-Tule y HAFS-Grava), It indicates that there are highly significant statistical differences between treatments ($p<0.001$). The test of independent samples U Mann – Whitney, He indicated that there are statistically significant differences in both median treatments evaluated ($p<0.05$). The lowest average turbidity was observed for the HAFS-Tule (10.97±0.64), with greater removal, followed by HAFS-Carrizo (23.34±1.89), so the HAFS-Grava (36.35±3.78) is the least efficient respectively (figure 7).

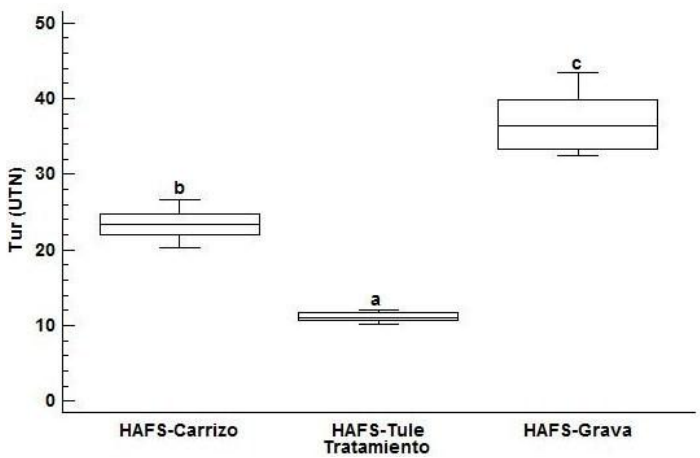

Figure 7. Median values (±EE) in measuring UTN a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments ($p<0.05$), al 95 % confidence level.

While for the color variable, the lowest mean value was observed HAFS-Tule (175.0±3.12), with the highest removal efficiency, followed by HAFS-Carrizo (252.6±12.38), so the HAFS-Grava (308.18±6.25) is the least efficient respectively (figure 8).

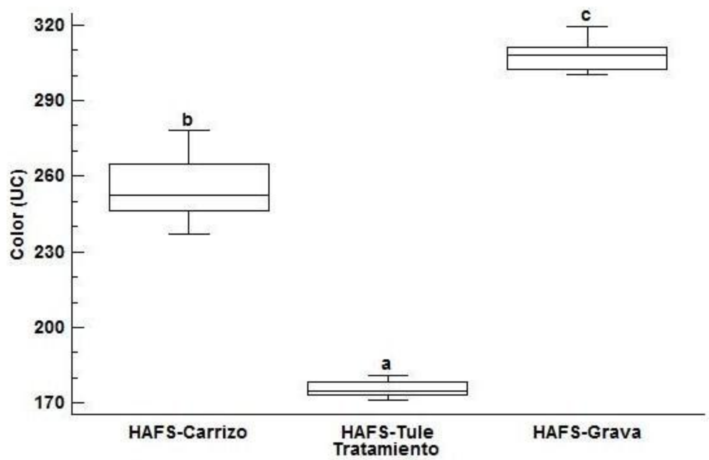

Figure 7. Median values (±EE) in measuring UC a wetlands with different plants. In all cases n=12. Different letters indicate statistically significant differences between treatments (p<0.05), al 95 % confidence level

Best for turbidity removal efficiencies (91.65 %) and color (81.50 %) They were in the HAFS-Tule. These percentages showed similarity to recent research by Solís Silván, López Ocaña, Bautista Margulis, Hernández Barajas, y Romellón Cerino, 2016, where removal efficiencies were found 95.80 % for turbidity and 84.10 % color differences are attributed to the use of vegetation *Paspalum paniculatum*, since they used the same types of artificial wetlands, with dimensions and the same operations in the same region. The concentration Turbidity (10.97 UTN) satisfactorily complied with the Federal Law - Applicable Provisions on National Waters - for protection of aquatic life (CONAGUA, 2015), while for colored (175 U.C) indicates further reduce its concentration, since the LMP is of 15 U.C.

Conclusion

From the results obtained in this study, it is concluded that wastewater treatment by artificial wetlands flow subsuperficial with *Phragmites australis* (Carrizo) It had a significant effect, with good removal efficiencies (89 %) in the response variables. However, the best treatment was obtained by vegetation macrófita de *Pontederia cordata* (Tule), with removal efficiency up 95 %, fulfilling the NOM-001-SEMARNAT-1996. On the other hand, the wetland gravel only (control) has the lowest removal efficiencies (72 %).

Differences removal treatments are attributed to wetland vegetation contribute to the provision of oxygen to the water through the roots, facilitating biochemical oxidation in the wetland; while in control wetlands oxygen supply was by direct diffusion from the atmosphere. In terms of maintenance and operation of wetlands, constructed wetlands proved to be an economically viable and environmentally friendly alternative for the treatment of domestic wastewater.

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