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Evaluación de medios de soporte en humedales artificiales con vegetación Sagittaria latifolia en la remoción de contaminantes básicos

Evaluation of media of support of artificial wetlands with vegetation Sagittaria latifolia in the removal of basics pollutants

Avaliação de meios de suporte em áreas úmidas artificiais com vegetação de Sagittaria latifolia na remoção de poluentes básicos

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Resumen

El objetivo del presente estudio fue evaluar la remoción de parámetros de control y contaminantes básicos de aguas residuales domésticas con humedales artificiales de flujo subsuperficial, para lo cual se emplearon dos medios diferentes de soporte: grava de canto redondo y grava de brecha sedimentaria, con vegetación *Sagittaria latifolia* (cola de golondrina) y con tiempos de retención de 4.8 días y 4.9 días, respectivamente. En concreto, se destinaron tres humedales con vegetación y grava de canto redondo (HACC), tres con vegetación y grava de brecha sedimentaria (HABC), así como tres humedales controles sin vegetación y grava de canto redondo (HACS) y tres sin vegetación y grava de brecha sedimentaria (HABS). Para los medios de soporte se determinaron variables como densidad aparente y real, así como porosidad y conductividad eléctrica (N = 28). Al inicio de la operación de los humedales artificiales, el medio de soporte canto redondo presentó los siguientes valores: densidad aparente de 1390.79 ± 54.36 kg m^{-3} (media ± DE), densidad real de 2626.01 ± 75.43 kg m^{-3}, porosidad 51.87 ± 3.90 % y conductividad eléctrica (CE) 125.46 ± 11.81 dS m^{-1}. El medio de soporte brecha sedimentaria mostró una densidad aparente de 1415.63 ±43.94 kg m^{-3} (media ± DE), densidad real de 2678.16 ± 36.67 kg m^{-3}, porosidad 52.86 ± 1.56 % y CE de 94.13 ± 3.58 dS m^{-1}. Al término de la operación, el medio de soporte de canto redondo demostró ser eficiente con tan solo una pérdida de 5 % de porosidad, mientras que la brecha obtuvo una pérdida de 23 % de esta. En cuanto a la calidad del agua, se analizaron 160 muestras compuestas para los cuatro tratamientos de humedales y 40 simples en el tanque de distribución alimentación (N = 40). Después del primer año de operación, se observa que el HACC es el más eficiente, pues la remoción alcanzada fue de 96.85 % para SST, 95.85 % para DBO_5, 96.78 % para N_T y 96.79 % para P_T. El tratamiento HABC, por su parte, consiguió eficiencias de remoción de 95.52 % para SST, 95.02 % para DBO_5, 95.45 % para N_T y 95.36 % para P_T. Por tal motivo, se considera que existe un alto potencial para que estos medios de soporte se puedan implementar en los HA en el sureste de México, con lo cual se reducirían los costos de construcción y mantenimiento, pues los utilizados actualmente no son nativos de la región, presentan erosión y atrición, y no permiten un adecuado crecimiento de la biopelícula y la vegetación, de ahí que tengan bajas eficiencias.

Palabras clave: agua residual, eficiencia de remoción, humedal artificial de flujo subsuperficial y medio de soporte.

Abstract

In this study the removal of control parameters and basic pollutants of domestic wastewater in artificial wetlands of subsurface flow was evaluated using two different support media, round-ridge gravel and sedimentary-gap gravel, with vegetation *Sagittaria latifolia* (swallow's tail), with retention times of 4.8 days and 4.9 days respectively. Three wetlands with round-ridge vegetation and gravel (HACC), three wetlands with vegetation and sedimentary-gap gravel (HABC); three control wetlands without vegetation and gravel of round ridge (HACS) and three without vegetation and sedimentary gap gravel (HABS). For the support media the variables were determined as apparent density, real, porosity and electrical conductivity (*N=28*). At the beginning of the operation of the artificial wetlands, the round ridge support medium presented an apparent density of 1390.79 ± 54.36 Kg m^{-3} (mean ± SD.), The actual density of 2626.01 ± 75.43 Kg m^{-3}, porosity 51.87 ± 3.90% and an Electrical Conductivity (CE) 125.46 ± 11.81 dS m^{-1}, the sedimentary gap support medium showed an apparent density of 1415.63 ± 43.94 Kg m^{-3} (mean ± SD), actual density of 2678.16 ± 36.67 Kg m^{-3} , porosity 52.86 ± 1.56% and an EC of 94.13 ± 3.58 dS m^{-1}. At the end of the operation the support medium round edge proved to be efficient with only a loss of 5% porosity, while the gap presented a loss of 23% of this. In terms of water quality, 160 composite samples were analyzed for the four wetland treatments and 40 simple samples in the feed distribution tank (*N=40*). After the first year of operation it is seen that he HACC is the most efficient, the removal reached was 96.85% for SST, 95.85% for BOD_5, 96.78% for N_T and 96.79% for P_T. There is a high potential for these support means to be implemented in HAs in southeastern Mexico, reducing construction and maintenance costs, since the means of support currently used are not native to the region, they present erosion and attrition, they do not allow a adequate growth of the biofilm and vegetation and, as a consequence, have low efficiencies.

Keywords: wastewater, removal efficiency, artificial subsurface flow wetland and support medium.

Resumo

O objectivo deste estudo foi avaliar a remoção dos parâmetros de controlo de base e contaminantes das águas residuais domésticas com fluxo alagados construídos subsuperficial, para o qual foram utilizados dois meios de suporte diferentes: borda redonda cascalho e brita lacuna sedimentar vegetação Sagittaria latifolia (cauda de andorinha) e com tempos de retenção de 4,8 dias e 4,9 dias, respectivamente. Especificamente, três vegetação húmida e borda redonda cascalho (HACC), três vegetação e lacuna cascalho sedimentar (HABC) e três controlos zonas húmidas sem vegetação e borda redonda cascalho (HACS) e três sem vegetação e alocados Cascalho de Brechas Sedimentares (HABS). Para o suporte, as variáveis foram determinadas como densidade aparente e real, bem como porosidade e condutividade elétrica (N = 28). No início da operação de zonas húmidas artificiais, os meios de suporte cantando rodada forneceu os seguintes valores: densidade a granel de 1390,79 ± 54,36 kg m-3 (média ± SD), uma densidade efectiva de 2626,01 ± 75,43 kg m-3, porosidade 51,87 ± 3,90% e condutividade elétrica (CE) 125,46 ± 11,81 dS m-1. O apoio médio hiato sedimentar mostrou uma densidade a granel de 1415,63 ± 43,94 kg m-3 (média ± SD), uma densidade efectiva de 2678,16 ± 36,67 kg m-3, porosidade 52,86 ± 1,56% e CE 94,13 ± 3.58 dS m-1 . Ao final da operação, o suporte de borda arredondada mostrou-se eficiente com apenas 5% de perda de porosidade, enquanto o gap obteve uma perda de 23%. Em termos de qualidade da água, 160 amostras compostas foram analisadas para os quatro tratamentos de terras húmidas e 40 amostras simples no tanque de distribuição de alimentos (N = 40). Após o primeiro ano de operação, observou-se que o HACC é o mais eficiente porque a remoção alcançado foi 96,85% de TSS, DBO5 95,85%, 96,78% e 96,79% para o NT para PT. O tratamento com HABC, por outro lado, alcançou eficiências de remoção de 95,52% para SST, 95,02% para DBO5, 95,45% para NT e 95,36% para PT. Portanto, considera-se que existe um grande potencial para estes meios de apoio pode ser implementado em HA no sudeste do México, que os custos de construção e manutenção seria reduzido, como atualmente utilizados não são nativas da região, apresentam erosão e atrito, e não permitem um crescimento adequado do biofilme e da vegetação, portanto, têm baixa eficiência.

Palavras-chave: água residual, eficiência de remoção, alagamento de fluxo artificial subsuperficial e meio de suporte.

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Introduction

Wastewater is a problem that affects many terrestrial and aquatic ecosystems when they are deposited without any prior treatment, which directly affects the self-purification of bodies of water. Therefore, the need to implement technologies that are not aggressive to the environment and that are economically viable (National Water Commission [Conagua], 2016a, Vymazal, 2014) has been raised.

In this regard, artificial wetlands (HA) are an excellent alternative in the treatment of domestic wastewater, as natural technology results in low operating costs and easy maintenance, with minimum personnel requirements (Crites, Middlebrooks and Bastian, 2014) . In these systems, the treatment occurs by a natural process called phytodepuration, which consists of developing a macrophytic plant culture on a support medium within a control volume, where various physical, chemical and biological reactions occur through which the wastewater is progressively purified (Delgadillo, Camacho, Pérez and Andrade, 2010), or also within the wetlands where the removal of contaminants is achieved by sedimentation, absorption and bacterial metabolism (Llagas and Gómez, 2006).

In HA, different plant species have been used, which are the basis of the process, since they are capable of degrading, absorbing and assimilating organic matter and nutrients in their tissues, in addition to the support medium providing an extensive surface where bacterial growth is facilitated, which facilitates the retention of suspended solids, since they also function as a filtering medium (Upadhyay, Bankoti and Rai, 2016).

The artificial subsurface flow wetlands (HAFS) are wastewater treatment systems whose traditional design allows to remove between 40% and 60% of the total phosphorus present. Approximately 90% of the removal is due to adsorption processes that occur in the filter medium, while the remaining 10% happens thanks to the work of the vascular plants and microorganisms. Luna and Ramírez (2004) have tested alternative means of support for the removal of phosphorus in HA, of which CAS and PIECA media removed up to 92%, EVOL 48% and gravel in 42%.

Having explained the above, it can be indicated that in this research the HAFS are used to evaluate the effect of two natural support media in the southeast of Mexico, that is, round ridge and sedimentary gap with vegetation of Sagittaria latifolia (swallow's tail). remove basic pollutants from domestic wastewater.

It is worth noting that in the region there is a problem in selecting and using the means of support, since the installed HAs that have used regional clays have become clogged earlier than planned in their design; this means that if support materials from another region (such as tezontle) were brought in, the construction and operation costs in the wastewater treatment plants via HA would be significantly increased. Therefore, these support materials (round ridge and sedimentary gap) can be efficient and lower the costs of construction and operation of the HA in the region.

Materials and method

Artificial wetlands

The HAFS experimental units were assembled based on the design of López et al. (2014). Likewise, twelve rectangular HAFS 10 gauge carbon steel, with dimensions of 1.2 m wide, 2.50 m long and 1.00 m high, with an individual volumetric capacity of 1.5 m3, with a 0.5 m deep hydraulic tie rod were used. and 0.5 m as free board. The internal pailer and the accessories installed were made of PVC (figure 1). The wastewater that fed the HA was supplied by distribution tanks with a capacity of 200 liters, and they were filled by pumping from the concentrated station of the Academic Division of Biological Sciences of the Universidad Juárez Autónoma de Tabasco (UJAT) (17º 59 '26 "N and 17º 59 '17" W). Each HA was supplied with a flow rate of 160 L / day to treat.

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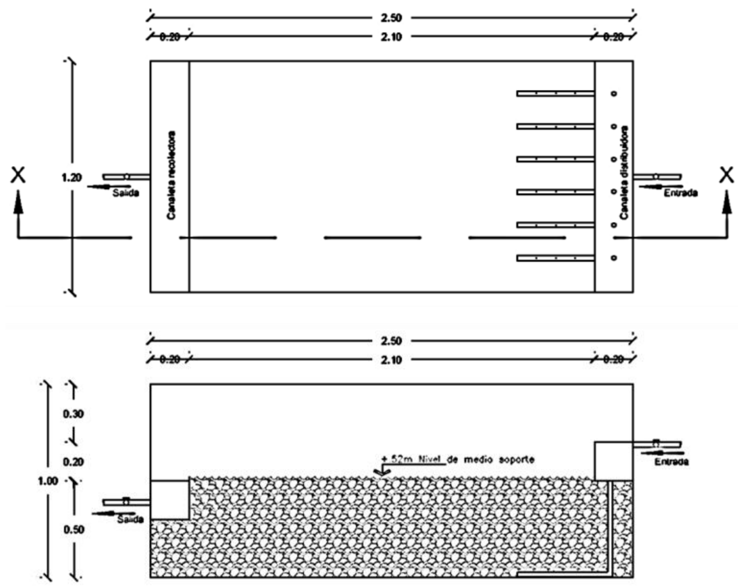
Figura 1. Diseño de humedal artificial de flujo subsuperficial



Fuente: López *et al.* (2014)

Support medium

Two stony materials of different metamorphic origin were chosen (figure 2): round ridge (can) and the sedimentary gap (bre), since they had favorable physical characteristics as a means of support in HA. The stone material was obtained in the municipality of Teapa, Tabasco; the sedimentary gap gravel (limestone type) was obtained in the area surrounding Cerro de Coconá (17 ° 34 '41.61 "N, 92 ° 55' 44.49" W); The second support medium (round ridge) was extracted from a bank of this material in the Teapa River (17 ° 34 '54.30 "N, 92 ° 58' 7.43" W). The granulometry in both media was three quarters of an inch. These stone materials were used as support media in the twelve HAFS, of which six were used for round song and the other six for the sedimentary gap. For each support medium, three reactors planted with vegetation and three as controls without vegetation were used.

Figura 2. Derecha: canto redondo (can); izquierda: brecha sedimentaria (bre)

Fuente: Elaboración propia

Physical parameters evaluated to the support medium

The analysis of the support medium was carried out in two periods: the first was carried out at the beginning of the operation phase, and the second at the end of this (August-December 2017); the sampling points of the medium in the HA were located in the zones of the entrance (surface and bottom), in the center (surface, center and bottom) and in the exit of the HA (surface and bottom), which allowed to collect 7 samples per HA, to analyze a total of 4 HA (28 samples in total), which correspond to sedimentary gap with vegetation (bre-c), sedimentary gap without vegetation (bre-s), round ridge with vegetation (can -c) and round song without vegetation (can-s).

The physical characteristics evaluated were based on the normative methods of real density (AS-04), bulk density (AS-03), electrical conductivity (AS-18) of NOM-021-RECNAT-2000, and porosity, by the method established by Muñoz, Soler, López and Hernández (2015), which consists of its determination based on the values obtained of apparent density and real density, while the calculation of the total porosity of the medium is defined as the volume occupied by the porous space in relation to the total volume of the medium. The porosity is expressed as a percentage and is calculated from the following equation:

$$Porosidad\ (\%) = (1 - \frac{densidad\ aparente}{Densidad\ real}\ X\ 100)$$

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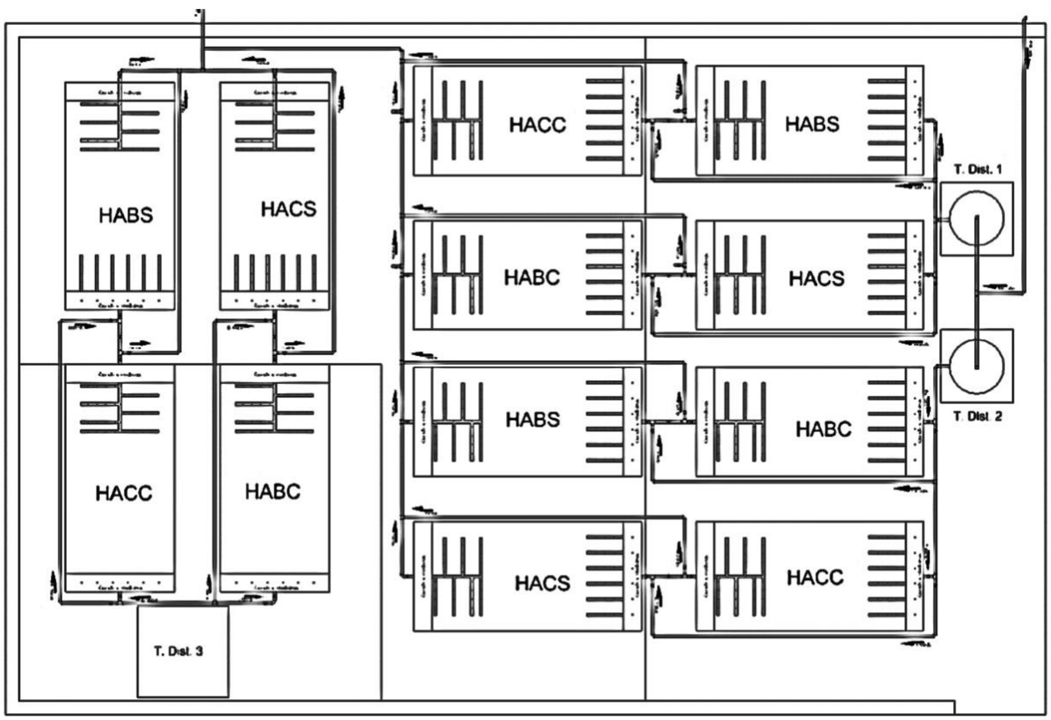
Vegetation sampling and sowing

For each HAFS, 25 specimens of Sagittaria latifolia (swallowtail) collected -as suggested by Novelo (2006)- were requested in natural wetland areas of the municipality of Centro, Tabasco (17 ° 59 '11.91 "N; 92 ° 57' 36.03 "O). Its selection was initially based on the literature of Crites and Tchobanoglous (2000) and Conagua (2016b). The sowing of the vegetation in the HA (November 2016) was planted at a depth of 15 cm in the support medium, with an approximate distance of 15 cm between each plant and a triangular or staggered distribution. Next, Figure 3 shows the arrangement of HAs with vegetation and the type of support medium.

Figura 3. Arreglo de las unidades experimentales de HA



Nomenclatura: HABS es HA con medio de soporte de brecha sedimentaria sin vegetación (control); HABC es HA con medio de soporte de brecha sedimentaria con vegetación (tratamiento); HACS es HA con medio de soporte de canto redondo sin vegetación (control), y HACC es HA con medio de soporte de canto redondo con vegetación (tratamiento).

Fuente: Elaboración propia

Stabilization of vegetation

At the end of the sowing of the Sagittaria latifolia (swallowtail) vegetation in the HA, the period of adaptation of the vegetation to the environmental conditions began and it was submitted to the residual water. This stabilization phase lasted six months (November 2016-April 2017). After this period, a lapse of three months was left, and then the evaluation phase of the treatments was continued, where monitoring began to evaluate the removal of contaminants in the HA with both support media (August-December 2017).).

Parameters of water quality

The control parameters analyzed during the evaluation were temperature, turbidity, color, pH, electrical conductivity (CE), as well as the following basic pollutants: biochemical oxygen demand (BOD5), total phosphorus (PT), total nitrogen (NT) and total suspended solids (SST). These were measured at the entrance and exit in each of the HAFS, taking as sample of input of the HA the obtained in the distribution tanks and as sample of exit the one obtained in the sampling channel present in each HA. The methods used for the measurement of the parameters were temperature (SM 2550), CE (SM 2510B) and pH (SM 9040B), for which the Hanna HI98129 equipment was used; the turbidity was determined by the method EPA 180.1 using the equipment Hanna HI 98703 (USA) with precision of 0.01 UNT. The color was determined using the standard 2120B method, with the Lamotte equipment whose accuracy is 0.1 UC. The parameters DBO5, PT, NT and SST were determined by the methods NMX-AA-028-SCFI-2001, NMX-AA-026-SCFI-2001, NMX-AA-029-SCFI-2001 and NMX-AA-034- SCFI-2001, respectively.

The behavior of the HA was obtained by measuring the control parameters and basic pollutants between August and December of 2017. Throughout each month, eight samples were taken (twice a week) taking simple samples from the distribution tank and samples composed of the effluent of each of the four HA treatments evaluated. Samples were taken at 12:00 every day. According to the sampling campaign, 480 total samples were obtained for HA (treatment and two replicates), analyzing 160 composite samples for the four HA treatments and 40 simple samples in the distribution tank (200 analyzes).

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Removal efficiency

The removal efficiencies were calculated with the following equation:

$$ER\ (\%) = \left(\frac{CE - CS}{CE}\right) X\ 100$$

Where ER is the removal efficiency percentage, CE is the input concentration, CS is the concertation obtained at the output of the HA, it is applied to each pollutant or parameter (Chung, Wu, Tam and Wong, 2008).

Experimental design

For this research, a random design of a factor was required to analyze the treatment systems (support medium with vegetation) and their controls (support medium without vegetation). For each of these was run in triplicate during the four-month period (August-December 2017).

Statistic analysis

In the support media, the variables of apparent density and real density followed a normal and homocedastic behavior, for which an ANOVA was determined. Regarding the porosity and electrical conductivity, by not presenting the attributes of normality, we proceeded to determine its nonparametric analysis by performing the Kruskal-Wallis test and the contrast of Mann-Whitney medians.

Likewise, and because for water variables the only parameter that fulfills the postulates of normality and homoscedasticity is temperature, a one-way ANOVA was performed, while the variables of quantitative responses of BOD5, PT, NT, SST, color, turbidity, EC and pH in the different types of treatments present in HA did not follow the normal distribution, so they were applied the non-parametric statistical analysis, the Kruskal-Wallis test and the contrast of Mann-Whitney medians , for which the statistical package was used Statghapics 16^{MR}.

Results

Characteristics of the support media

The initial characteristics of the support media rounded edge and sedimentary gap - before being subjected to wastewater, vegetation and microorganisms - are presented in table 1.

Tabla 1. Valores promedio y desviación estándar de los parámetros físicos evaluados en los medios de soporte (N = 28)

Parámetro	**Canto redondo (can)**		**Brecha sedimentaria (bre)**	
	M	**DE**	**M**	**DE**
Densidad real (kg m^{-3})	2626.01	75.43	2678.16	36.67
Densidad aparente (kg m^{-3})	1390.79	54.36	1415.63	43.94
Porosidad (ɳ) (%)	51.87	3.90	52.86	1.56
Conductividad E. (dS m^{-1})	125.46	11.81	94.13	3.58

Fuente: Elaboración propia

Real and apparent density

The results for the analysis of the apparent density and the statistical test of ANOVA analysis of variance do not indicate statistically significant differences (p <0.05) between the average values of the two gravels used as support medium in the different HA. Specifically, the lowest average value was presented by the sedimentary gap without vegetation 1142.17 ± 71.23 kg m-3 (mean ± SD) and the highest the round-ridge gravel without vegetation 1221.14 ± 77.54 kg m-3, which did not differ statistically significant by LSD analysis (figure 4). The LCD test performed on the real density data shows statistically significant differences along with the rest of the treatments (p> 0.05) (figure 5), the sedimentary gap gravel with vegetation reached the highest real density 2826.54 ± 87.01 kg m- 3 (mean ± SD), while the sample of round ridge with vegetation presented 2643.76 ± 94.57. kg m^{-3}.

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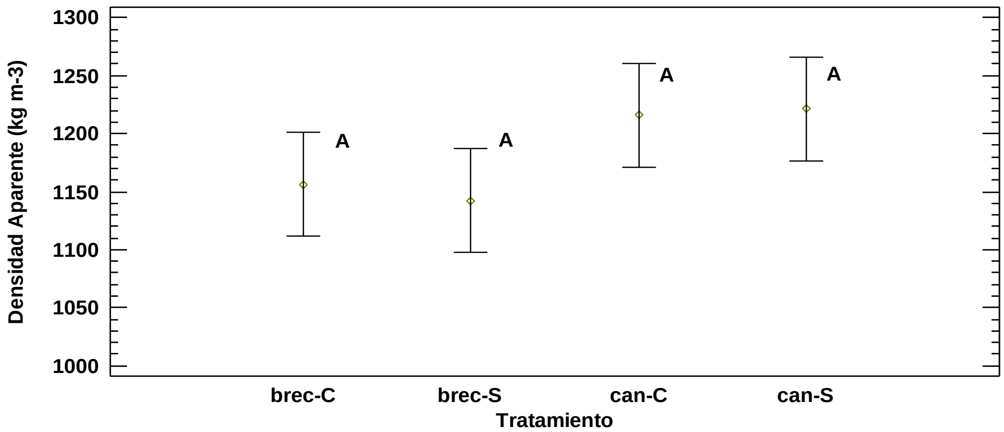
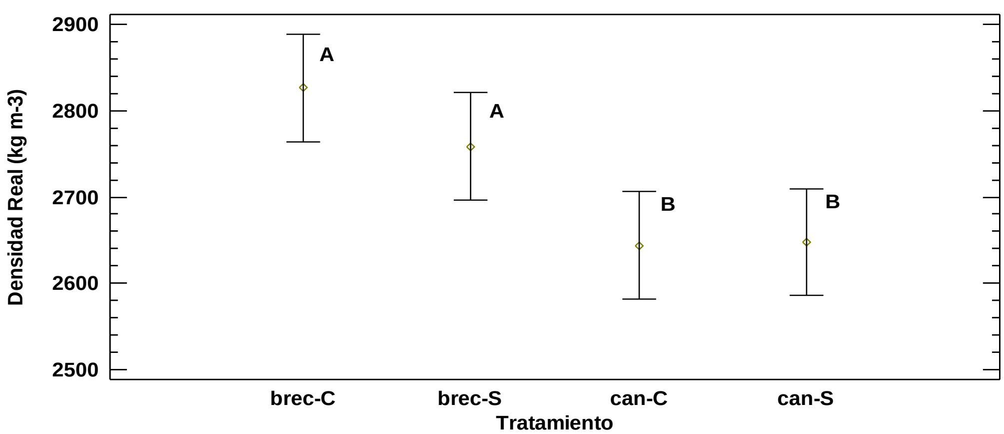
Figura 4. Valores promedio (± DE) de la densidad aparente de los medios de soporte en cada tratamiento



Nota: El tamaño de muestras compuesta es *N* = *28* para cada tipo de medio. Letras desiguales indican diferencias estadísticamente significativas.

Fuente: Elaboración propia

Figura 5. Valores promedio (± DE) de la densidad real de los medios de soporte en cada tratamiento



Nota: El tamaño de muestras compuesta es *N* = *28* para cada tipo de medio. Letras desiguales indican diferencias estadísticamente significativas.

Fuente: Elaboración propia

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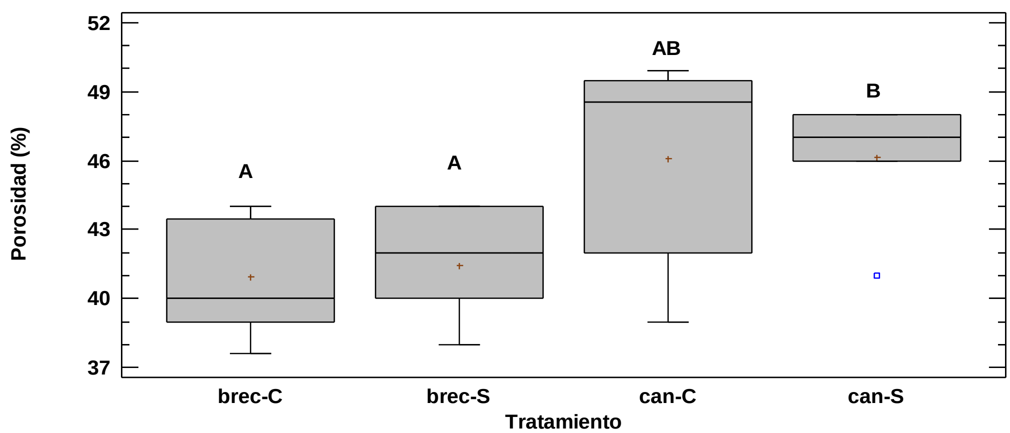
Porosity

As the data did not comply with the postulates established by the parametric statistics, we chose to analyze them using non-parametric statistics using the Kruskall-Wallis test, with which differences were found between treatments (p <0.05) with a level of confidence of 95% (figure 6). The analysis of porosity in the two different support media allowed to identify that the gravel of round ridge with vegetation presented 48.52 ± 4.26% (median ± SD), while the vegetation gap obtained 40.02 ± 2.40% (median ± DE).

Figura 6. Contraste de medianas de la porosidad de los medios en cada tratamiento (mediana ± DE)



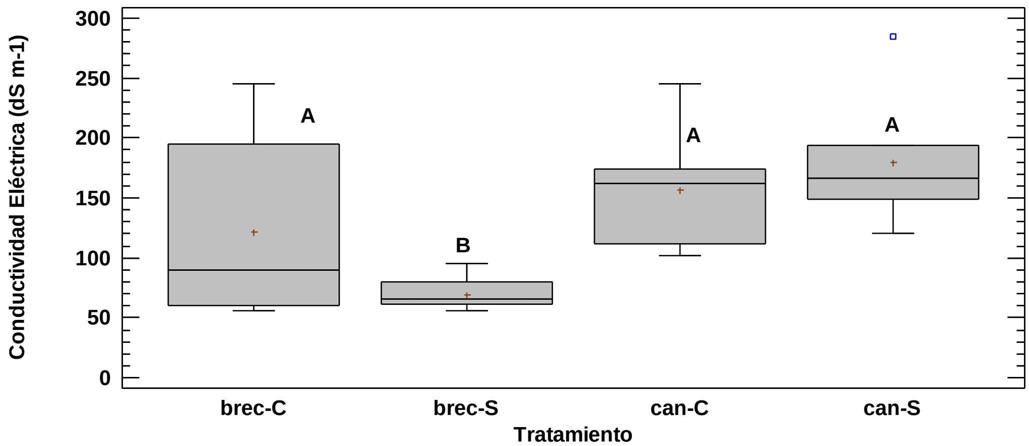
Nota: El tamaño de muestras compuesta es *N = 28* para cada tipo de medio. Letras desiguales indican diferencias estadísticamente significativas.

Fuente: Elaboración propia

Electric conductivity

The Kruskal-Wallis test evaluates the hypothesis that the electrical conductivity medians (dS m-1) within each of the four treatment levels are equal, since the p-value is greater than or equal to 0.05, so that there is a statistically significant difference between medians with a 95% confidence level. The gravel with median of greater electrical conductivity was the round ridge without vegetation (can-S) 166.00 ± 52.25 dS m-1, while the sedimentary gap without vegetation (bre-s) was the lowest 66.0 ± 13.47 dS m-1 (figure 7).

Figura 7. Contraste de medianas de la CE de los medios en cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es *N = 28* para cada tipo de medio. Letras desiguales indican diferencias estadísticamente significativas.

Fuente: Elaboración propia

Evaluation of control parameters and basic pollutants

The basic pollutants and the control parameters of the water entering the HA are presented in Table 2.

Tabla 2. Promedio y desviación estándar de los parámetros de control y contaminantes básicos del agua residual de entrada a los humedales artificiales (N = 40)

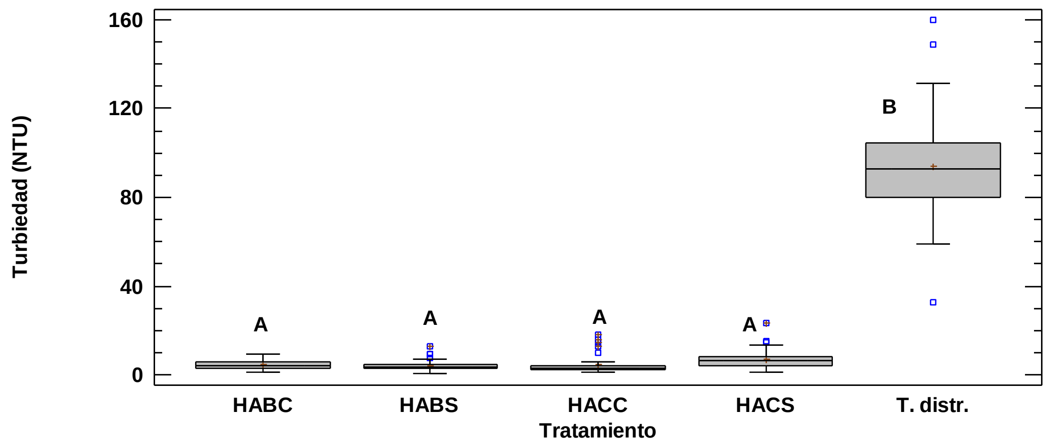
Parámetro	M	DE
Turbiedad (NTU)	93.98	22.89
Color (UC)	1282.39	254.09
pH	8.35	0.18
CE (μ S cm^{-1})	1381.11	140.19
Temperatura (°C)	26.84	1.08
SST (mg L^{-1})	250.10	59.91
DBO_5 (mg L^{-1})	289.91	65.51
NT (mg L^{-1})	146.6	23.50
PT (mg L^{-1})	5.79	1.31

Fuente: Elaboración propia

Turbiedad

The Kruskal-Wallis test evaluates the hypothesis that turbidity medians (NTU) are equal within each of the five treatment levels. Since the p-value is less than 0.05, there is a statistically significant difference between the medians with a 95% confidence level (Figure 8). Among the wetlands, the treatment with the lowest median ± SD was HACC with 2.89 ± 2.46 NTU, followed by HABS with 3.42 ± 4.07 UTN, and HABC with 4.09 ± 2.23 NTU. The wetland with the highest average value was the HACS with 6.67 ± 4.29 NTU and with regard to the water entering the distribution tank, it had a mean value of 93.0 ± 22.89 NTU (Figure 8).

Figura 8. Contraste de medianas de la turbiedad en cada tratamiento (mediana ± DE)



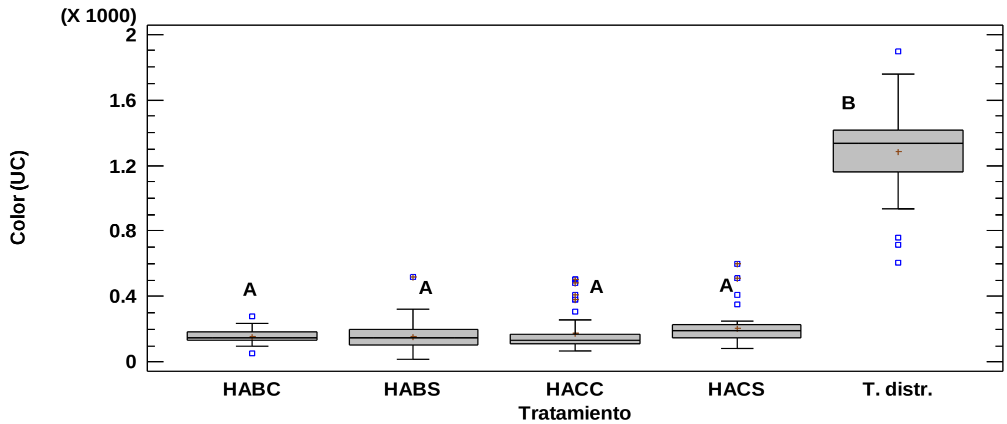
Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Color

The Kruskal-Wallis test for the color variable (UC) shows that the p-value is less than 0.05, so there is a statistically significant difference between the medians with a confidence level of 95%. The treatment with the lowest value of median ± SD was HACC with 132.0 ± 123.49 UC, followed by HABC with 149.5 ± 43.04 UC and HABS with 149.5 ± 92.78 UC. The wetland with the highest median value was the HACS with 187.5 ± 104.03 UC. Regarding the water entering the distribution tank, a median value of 1333.25 ± 466.59 UC was presented (Figure 9).

Figura 9. Contraste de medianas del color (UC) en cada tratamiento (mediana ± DE)



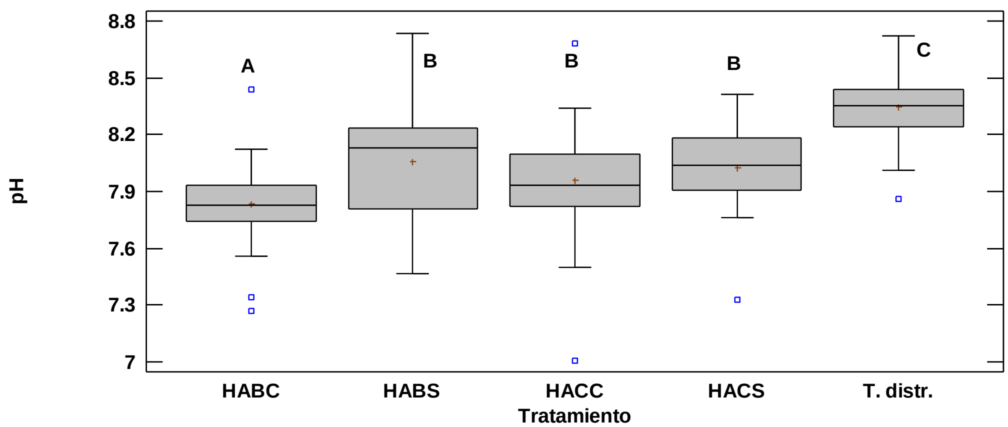
Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

pH

The Kruskal-Wallis test shows that the p-value is less than 0.05, so there is a statistically significant difference between the medians with a confidence level of 95% (Figure 10). The behavior of the tributary during the monitoring period was slightly alkaline (8.34 ± 0.02). The HA that exhibited the most stable values of neutral pH were the HABC and the HACC (7.83 ± 0.02 and 7.93 ± 0.02) during the whole operation phase; nevertheless, the HACC presented an atypical behavior, since it reached a maximum value in September of 8.68, although it subsequently stabilized until October, where it had a minimum value of 7.01. For HA control (HABS and HACS) the average behavior during the operation phase was slightly alkaline trend (8.05 ± 0.02 y 8.00 ± 0.02).

Figura 10. Contraste de medianas del pH en cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Electric conductivity

The Kruskal-Wallis test shows that the p-value is less than 0.05, so there is a statistically significant difference between the medians with a confidence level of 95%. The median values of ± SD were lowest in the HABS treatment (915.0 ± 204.47 µ S cm-1), followed by HACS (925.5 ± 169.65 µ S cm-1), HACC (1014.0 ± 201.66 µ S cm-1) , HABC (1055.0 ± 153.92 µ S cm-1) and the highest average value was the distribution tank with 1371.0 ± 140.19 µS cm-1 (figure 11).

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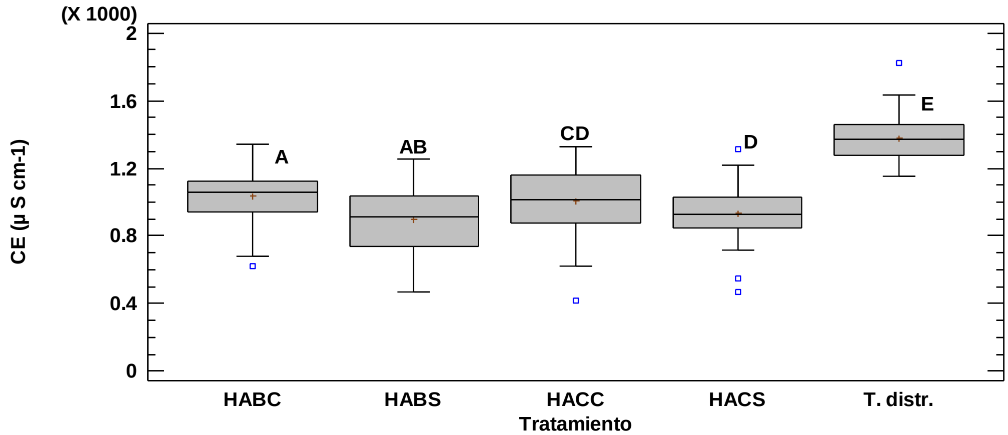
Figura 11. Contraste de medianas de la CE en cada tratamiento (mediana ± DE)



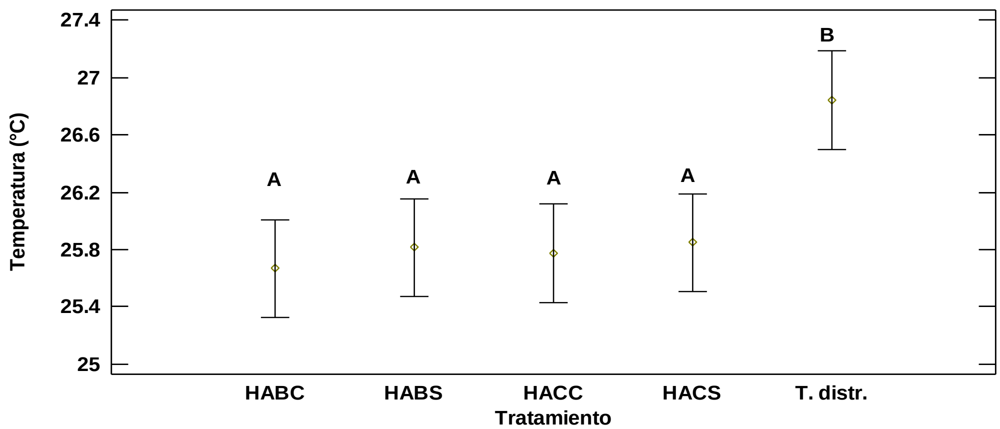
Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Temperature

The ANOVA analysis shows that there is a statistically significant difference (p> 0.05) in the average values of the temperature variables (° C) between the different treatments evaluated in the artificial wetlands. The wetlands that presented the lowest average value at the temperature were the HABC (25.66 ± 1.66 ° C), followed by the HACC (25.77 ± 1.62 ° C). The highest average was presented in the distribution tank with 26.84 ± 1,008 ° C (Figure 12).

Figura 8. Valores promedio (± DE) en medición de temperatura en humedales con diferentes plantas



Nota: En todos los casos N = 40. Letras distintas indican diferencias estadísticamente significativas entre tratamiento ($p < 0.05$) con 95 % de nivel de confianza.

Fuente: Elaboración propia

Total suspended solids

The Kruskal-Wallis one-way analysis shows the existence of statistically significant differences ($p < 0.05$) in the medians of the variables of total suspended solids (TSS) between the different treatments evaluated in the HA of the values, with 95% of reliability. The wetlands that presented in the SST parameter the lowest mean ± SD value were the HACC (7.81 ± 12.64 mg L-1), followed by the HABS (9.23 ± 10.12 mg L-1) and the HABC (11.04 ± 6.03 mg). L-1). The record of the highest median in SST was presented in the HACS (18.01 ± 11.65 mg L-1) (figure 13). The distribution tank that is raw water presented a median of 246.44 ± 98.63 mg L^{-1}.

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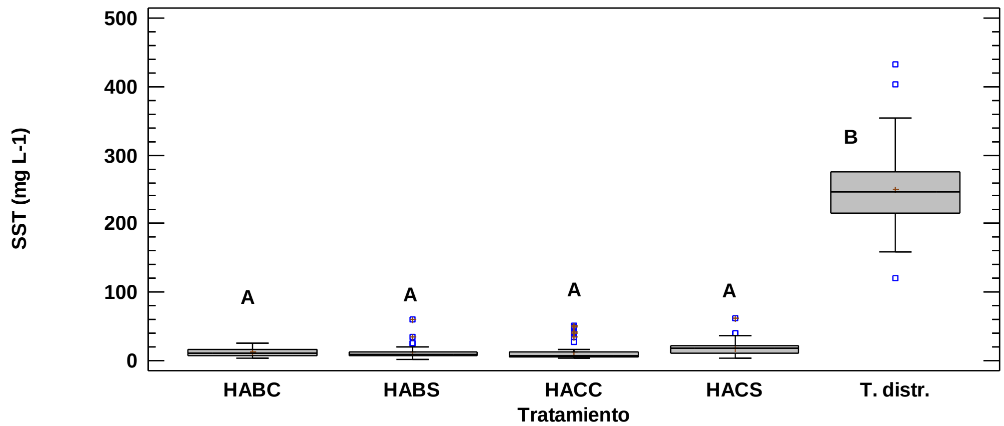
Figura 9. Contraste de medianas de la SST en cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Biochemical Oxygen Demand

The one-way Kruskal-Wallis analysis shows the existence of a statistically significant difference ($p < 0.05$) between the medians of the BOD5 variable of the treatments evaluated, with 95% reliability. The wetlands that presented the BOD5 parameter with the lowest median value were the HACC (8.91 ± 12.60 mg L-1), followed by the HABS (12.23 ± 7.51 mg L-1), the HABC (12.59 ± 10.62 mg L-1).) and HACS (20.53 ± 13.51 mg L-1). The record of the highest median in BOD5 was presented in the distribution tank (280.94 ± 65.51 mg L-1) (figure 14).

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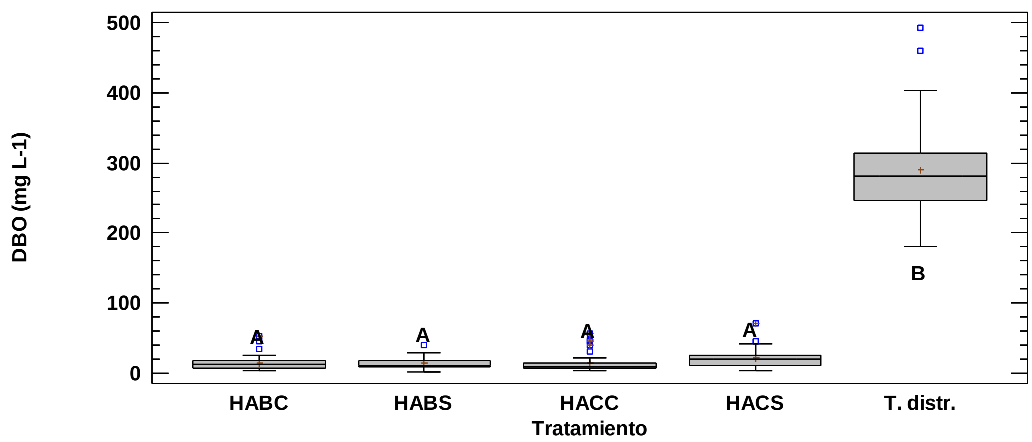
Figura 10. Contraste de medianas de la DBO_5 en cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Total nitrogen

The one-way Kruskal-Wallis analysis shows the existence of a statistically significant difference ($p < 0.05$) between the medians of the NT variable of the treatments evaluated in artificial wetlands with 95% reliability. The wetlands that presented the NT parameter with a value of median ± SD lower were the HACC (4.74 ± 11.24 mg L-1), followed by the HABS (5.6 ± 10.24 mg L-1) and the HABC (6.7 ± 3.65 mg L -one). The record of the highest median in NT was presented in the feed tank or raw water (147.47 ± 23.50 mg L-1) and later in the HACS (10.92 ± 7.18 mg L-1) (figure 15). The wetland that had the support media sedimentary gap with vegetation was the most efficient with 96.14% removal efficiency, followed by the wetland with support medium with sedimentary gap without vegetation and round ridge with vegetation, with 95.59% and 95.42%, respectively.

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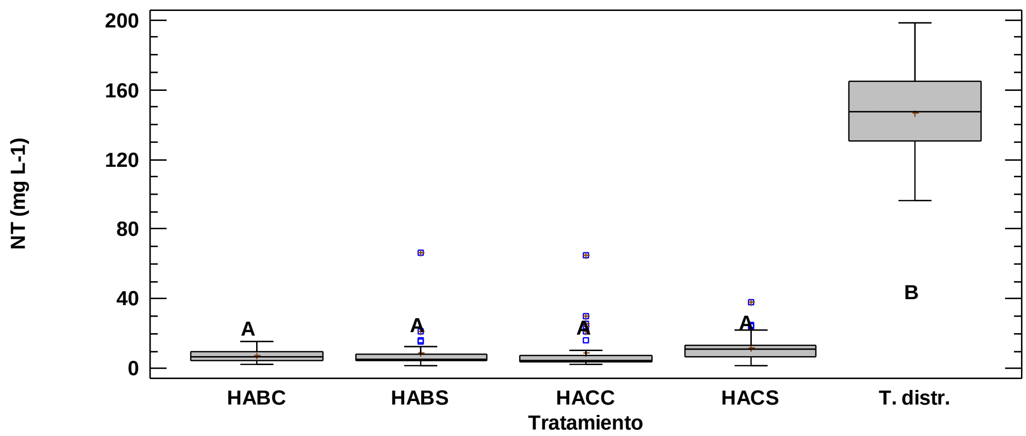
Figura 11. Contraste de medianas de N_T cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Total phosphorus

The one-way Kruskal-Wallis analysis shows the existence of statistically significant differences ($p < 0.05$) in the medians of the PT variables between the treatments evaluated in the HA, with 95% reliability. The wetlands that presented in the PT parameter the lowest median value were the HACC (0.18 ± 0.42 mg L-1), followed by the HABS (0.21 ± 0.24 mg L-1) and the HABC (0.26 ± 0.19 mg L-). one). The record of the highest median phosphorus in HA was presented in the HACS (0.41 ± 0.27 mg L-1) (Figure 16); however, the highest PT value was present in the incoming water with a median of 5.61 ± 1.31 mg L-1. The wetland that had the sedimentary gap support medium without vegetation was the most efficient with 95.94% removal efficiency, followed by the wetland with support medium, sediment gap with vegetation and round with vegetation, with 95.59% and 95.42%, respectively.

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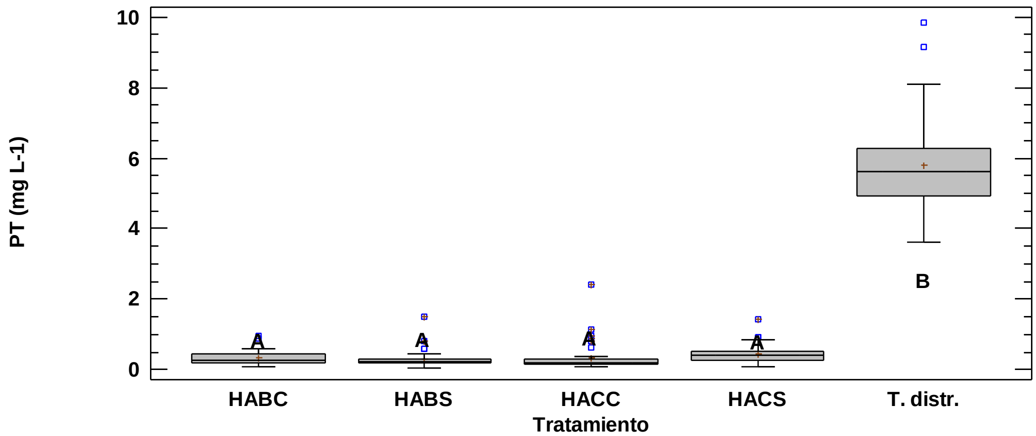
Figura 12. Contraste de medianas de la P_T en cada tratamiento (mediana ± DE)



Nota: El tamaño de muestras compuesta es N = 40 para cada tipo de medio. Letras distintas representan diferencias estadísticamente significativas.

Fuente: Elaboración propia

Discussion

Color and turbidity

During the operation phase, HA with vegetation presented lower values of color and turbidity of up to 54 UC and 1.32 NTU, while the maximum value was 505 UC and 18.40 NTU. With this, a removal efficiency for the HABC of 88.91% of color and 96.38% of turbidity was reached, while the HACC reached 87.32% of color and 95.71% of turbidity. The control HAs achieved an efficiency of removal with the media support gap sedimentary (HABS) of 88.93% UC and 95.87% NTU, and with the round-ridge HA (HACS) the efficiency was 85.45% CU and 94.40% NTU.

According to García and Corzo (2008), color and turbidity are related to the presence of solids in suspension in the wastewater in the HA. In this sense, the support means fulfills a filtering function of these solids, retaining them by adhesion, while the same flow due to its low velocity allows sedimentation, which favors the HAFS to have a yield of more than 90% in effectiveness. the removal of suspended matter (Conagua, 2016b).

Electrical conductivity and pH

Regarding the EC, during the monitoring (August-September 2017) the inlet water presented values higher than the HA, because the highest median value was 1824 µS cm-1, while the lowest was 1150 µS cm -one. This behavior is probably related to the increase in water temperature that promoted the dissolution of ammonium nitrate in water (Mietto, Politeo, Breschigliaro and Borin, 2015). During the first month of monitoring, the HAs with round support medium showed EC higher than the HA with sedimentary gap, since they were located above 1000 µS cm-1, although afterwards a stabilization was achieved in both media, which showed the same tendencies. As of October, the HAs had the same behavior until the end of the evaluation, which could have happened due to the formation of the biofilm in the support, since in their interaction soluble salt can be released from the water support media (Stefanakis and Tsihrintzis, 2012). Another factor may have been the increase in evapotranspiration and the growth of the plants, as reported by Hench et al. (2003).

The pH in the HA promotes the development of the processes of degradation of pollutants such as BOD5, nitrification and denitrification, which can be affected if it is not maintained in a range of 6.5 to 8.5, discharge criteria established by NOM-001 - SEMARNAT-1996 and satisfactorily fulfilled in the HA effluents of this study (HABC of 7.9 and HACC of 8.0); this parameter must be taken care of, given that a change in pH higher than the established one can cause an impact on the entire HA biota (Winanti, Rahmadyanti and Fajarwati, 2018). The results in this study for pH, although they comply with our regulations, are slightly alkaline in comparison with those reported by Bedoya, Ardila and Reyes (2014), where residual water from a university campus was treated, whose incoming water presented a pH of 8.7. In this work, after being treated by an HA with T. latifolia, the effluent had a pH of 7.09 and the second treatment by an HA with C. papyrus reached an average value of 6.98, a change that could have occurred due to the liberated ions. by the medium of support used.

Temperature

The variation that showed the temperature of the incoming wastewater was from 25 ° C to 29 ° C. The temperature in the HA presented a change from 25.5 ° C to 25.8 ° C, efficient values to eliminate organic matter and nitrogen (Fan, Zhang, Ngo, Guo and Yin, 2016) because temperature is a factor that positively influences the microbial activity, because it favors the growth of mesophilic organisms, which have an adequate metabolic development at that temperature. Likewise, the temperature parameter was regulated in its discharge to receiving bodies with the NOM-001-SEMARNAT-1996, which establishes for certain receiving bodies a maximum permissible limit of 40 ° C, a threshold that was not reached in the whole process of evaluation.

Total suspended solids

The HABC achieved 95.52% removal efficiency of SST and the HACC 96.85%. These figures were very similar because this parameter is influenced particularly by the hydraulic retention time (HRT), which for the HA with gravel of round edge was 4.86 days, while the HA with sedimentary gap was 4.95 days, qualities that serve to achieve efficiencies of solid removal greater than 90% (Conagua, 2016b, Crites and Tchobanoglous, 2000). With these efficiencies, the criteria for the protection of aquatic life are met, which allows the discharge of 40 mg L-1 (NOM-001-SEMARNAT-1996). Comparing our study with that of Bedoya et al., (2014), the concentration of SST input in their HA was 67 mg L-1, while the outflow concentration of HA with T. latifolia was 3 mg L- 1, and in HA with C. papyrus was 3 mg L-1. These results were obtained in HA that were fed with 15 L / day-1, with a HRT of 9 days. This difference in input load and TRH increases the removal efficiency of SST.

Biochemical Oxygen Demand

The wetland with support of round ridge with vegetation was the most efficient, with 95.85% efficiency of removal of BOD5, followed by wetland with support medium of sedimentary breccia without vegetation with 95.02%. This efficiency is similar to that achieved by Abou-Elela, Golinielli, Abou-Taleb and Hellal (2013), who evaluated two wetlands at pilot scale: one artificial horizontal flow (HAFH) and one vertical flow (HAFV).

The HAFH was filled with gravel between 40 mm and 80 mm (1.57 "and 3.14"), while the HAFV with gravel between 10 mm and 20 mm (0.03 "and 0.06"). Both were planted with three different types of vegetation: Canna edulis, Phragmites australis and Cyperus papiro. These wetlands achieved a BOD5 removal of 92.8% for HAFH, and 93.6% in HAFV, findings similar to those obtained in this study. Such removal efficiency may have been due to the presence of a variety of species.

Likewise, other authors (Rai et al., 2013) obtained efficiencies of 63.22%, which represents 57 mg L-1 where they used vegetation Typha latifolia, Phragmitis Australia, Colocasia esculenta. The percentage of the highest removal efficiency obtained in the present work represents the concentration of 14.18 mg L-1 of BOD5, which meets the requirements of NOM-001-SEMARNAT-1996, which establishes an LMP value of 30 mg L-1 for the protection of aquatic life in rivers. Likewise, it complies with NOM-003-SEMARNAT-1997, which establishes a value of 20 mg / l for service water that is in indirect or occasional contact with the public.

Total nitrogen

The results of the effluents of the HA for the variable NT were presented with a variation of 7.5 mg L-1 to 11.6 mg L-1, reaching a removal of 94% to 96%. These findings are comparable with those presented by Bai et al. (2017), who in their study of artificial multilayer wetlands treating wastewater from a university campus in Guilin, China, reported NT removal efficiencies of 74% with respect to the quality of wastewater that fed their HA. These researchers consider that the effect of nitrification is a limiting factor for NT elimination. These efficiencies are probably linked to the effect of temperature because it influences microbial activity, which is inhibited at low temperatures, while at warm temperatures it increases due to the aerobic, anoxic and aerobic conditions of these systems (Fan et al. al., 2016). This is represented by the study by Wu, Ma, Kong and Liu (2018), who using HA in a climate of 0 ° C to 10 ° C obtained removal efficiencies of 59.92%. In this study, the researchers used a combination of coarse gravel and sand as a support medium with a vegetation of *Phragmites australis.*

It is worth noting that in the last two works referred to, combinations of substrates of different sizes were used as support media, which differs from what was reported in the present study, where the support medium, the temperature of the water and the temperature were taken into account. pH for the establishment of microorganisms that favor the removal of this parameter, which complies with the maximum permissible value for aquatic life of 15 mg L-1, as established in NOM-001-SEMANRNAT-1996.

Total phosphorus

The removal efficiencies of PT were presented from 94% to 95.9%, and can be compared with those obtained by Wang, Dong, Liu, Liu and Zhu (2013), who achieved a maximum removal efficiency of 95.88% with a medium of oyster shell support, and whose feeding affluent had a PT load of 83.64 mg L-1. In this sense, Yin, Yan and Gu (2017) have also reported that calcium-rich and thermally modified attapulgite can achieve a removal efficiency of 94.3% with an HRT of 8 hours. The differences of these two investigations in relation to the present one are in the dimensioning of the units (given that the scale presented in this study is larger) and in the absorption by the vegetation Sagittaria latifolia (swallow's tail). This parameter is discharged into the effluents of the HA within the limits established by NOM-001-SEMARNAT-1996 for the protection of aquatic life.

Conclusion

According to the results of the present investigation, it can be concluded that HAFS on a pilot scale with Sagittaria latifolia (swallowtail) vegetation with round ridge support means and sedimentary gap are useful for removing basic pollutants and control parameters from domestic wastewater. In fact, it can be affirmed that during the first year of evaluation, the round-topped HA with vegetation is more efficient for that purpose because it achieved the following removal percentages: 96.85% for SST, 95.85% for BOD5, 96.78% for NT and 96.79% for PT, while in the experiments with sediment gap the removal efficiencies reached were 95.52% for SST, 95.02% for BOD5, 95.45% for NT and 95.36% for PT.

This means that there is a high potential for these support media to be able to be implemented in artificial wetlands in the southeast Mexican region, which would reduce the costs of construction, operation and maintenance, since the means of support currently employed are not native to the region, they present erosion and attrition, and they do not allow an adequate growth of the biofilm and vegetation, hence they have low efficiencies.

Finally, the implementation of the round-bottom support medium for HA in tropical zones can be recommended, since its multifactor interaction as biofilm, vegetation and temperature not only significantly improve the efficiency of the removal, but also conform to the environmental standard Mexican discharge to receiving bodies.

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