Correlational Analysis of Ibuprofen Behavior in Constructed Wetlands Planted with Ornamental Plants

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Abstracts

The presence of ibuprofen in wastewater is a topic of global interest, and the mechanisms and behavior of its correlation with its elimination in ecological systems, such as constructed wetlands, is a little known topic. The objective of this study was to perform a correlational analysis of the behavior of the emerging contaminant ibuprofen in a horizontally constructed wetland in a tropical climate planted with the ornamental plant Spathiphyllum blandum. 10 experimental units were used at the mesocosm level of 20 L, 5 planted with Spathiphyllum B., and 5 without plants. The elimination of ibuprofen was measured and the correlation was analyzed using computational methods and neural networks. Spathiphyllum blandum was used in this study. The removal of ibuprofen in HC was significantly improved by up to 23% compared with that in non-planted systems. Based on the prediction obtained from ibuprofen in the effluent, it can be concluded that it has an exponential decay behavior tending to zero, and the model obtained explains in an acceptable way the relationship between the height of the plant and the concentration of ibuprofen in the effluent, reaffirming that this relationship is inverse. Further studies should be conducted to understand the behavior of these compounds in relation to different species of tropical plants.

Keywords: Ornamental Plants, Ibuprofen, Wastewater, Spathiphyllum Blandum.

Introduction

Constructed wetlands or eco-technologies are technologies developed by humans to emulate a symbiosis of physical, chemical, and biological processes, and the interactions between macrophytes and liquid and solid states in a short time of contact and/or residence, present in water with a high content of contamination, without the use of electric energy, and without the application of chemical products. On the other hand, several authors have agreed that constructed wetlands or eco technologies are conceived as an appropriate technology for the ostensible reduction of contaminants present in wastewater, where the complementary elements of engineering are explicit and converge (WBM, 2003; Day Water, 2005; Asuman, 2004; Rodriguez, 2010; Vymazal, 2008; Sandoval, 2019; Wallace, 2019).

According to the quality of the treated or reused wastewater, they can be classified into artificial and/or constructed wetlands of free or surface flow and artificial and/or constructed wetlands of subsurface flow, although some authors also mention lagoons or ponds with microalgae as a type of wetland (Crites, 2000; Murillo, 2012; Tanaka, 2011; Vymazal, 2008). These eco-technologies present significant advantages compared to other technologies for the treatment of wastewater, among which we can mention: the elimination of a fraction of pathogens, emerging contaminants, metals and pseudo metals, volatile organic compounds, nutrients and micronutrients, organic matter, among others (Murillo, 2012; Rodriguez, 2010; Sandoval, 2019; Turgut, 2020). On the other hand, artificial intelligence computational techniques can be established as the ability of a machine to perform cognitive functions that we associate with human minds, such as perceiving, reasoning, learning, interacting with the environment, solving problems and even exercising creativity, these techniques have been created to make decisions, make predictions and estimates of phenomena, in sectors such as health, production processes, human resources, financial, judicial and lately with topics in environmental sciences and especially work in wastewater, hydrology, solid waste, basins among others, that is, it takes as information the use of open data (Sanchez, 2020).

According to the above, the use of Artificial Neural Networks computationally emulates a biological neural network, which are distributed, adaptive, generally non-linear learning machines, built from many processing elements (EP) that are called neurons and are organized in layers, an input layer, an output layer, and hidden layers. Each neuron receives connections from other neurons or from itself, and interconnectivity defines the topology. The signals that flow in the connections are scaled by adjustable parameters called weights Wij. The neurons add all of these contributions and produce an output that is a nonlinear (static) function of the sum. The outputs of the neurons become outputs of the system or are sent to the same or other neuron (Garcia, 2018; Sánchez, 2018).

An Artificial Neural Network is an information processing paradigm inspired by the manner and structure of the brain, which processes information through a parallel computational model composed of adaptive processing units with a high interconnection between them. The main uses of this network are to solve optimization problems (nonlinear individuals), information classification, and associative memory (Cano, 2014; Cárdenas, 2012). The advantages of this technique are that it is trained through examples, allowing rapid identification, analysis of situations, and real-time diagnosis, among others (Borges, 2013). Evolutionary Algorithms are stochastic methods that have been applied to search, optimize, and learn problems and partially imitate the mechanisms of biological evolution and natural selection (Armendáriz, 2014).

Pharmaceutical products are compounds used all over the planet to alleviate different kinds of diseases; these products evolve day by day to be more efficient, displacing others that are less effective. Thus, they have brought well-being to human beings in the world. The existence and development of different drugs have attracted the attention of epidemiological outbreaks that put the lives of humans and animals at risk (Branchet et al. 2019; Foureaux et al. 2019); however, their use in large quantities has led to them being found in surface waters (rivers, lakes, seas, wetlands) and underground waters and even in drinking water (Quesada-Peñate et al. 2009; Boleda et al. 2011; Veras et al. 2019). The presence of these compounds in water can be attributed to several reasons. One is their presence in excretions and urine because the body cannot metabolize them completely when they are ingested to cure and prevent diseases (Vyas et al. 2014; Fonseca et al. 2017); another is from the inadequate final disposal of waste from the manufacture of these products by industries (Quesada-Peñate et al. 2009); another form of contamination of water bodies by drugs is the final disposal of medications that expire by people, pharmacies and urban and rural hospitals (Ayele & Mamu, 2018).

According to Roloff (1998), at least 30 to 60 pharmaceutical compounds can be found in any type of water. Furthermore, in Europe, the presence of pharmaceutical compounds has been recorded in all bodies of water, both surface and underground (Fedorka-Cray et al. 2002). In the last decade, the interest in removing pharmaceutical compounds present in wastewater has gained great interest; mainly, non-steroidal anti-inflammatory drugs (Kasprzyk-Hordern et al. 2009; Santos et al. 2010), because of their capacity to negatively affect aquatic ecosystems. In parallel with the growing concern for their removal, their use to treat health problems in humans is increasing exponentially, as they are prescribed to more than 700 million people per year (Williams et al. 2013; Ghauch et al., 2012).

The use of these drugs is beneficial to human health; however, their fate in the environment is a latent concern, mainly because consumer wastewater reaches urban and inter-urban drains and wastewater treatment plants (Ayele & Mamu, 2018; Ternes et al. 2004). Ibuprofen is one of the most commonly prescribed non-steroidal anti-inflammatory drugs (Ghauch et al. 2012) and is found in wastewater treatment plant effluents at concentrations ranging from 10 ngL^{-1} to 169 μgL^{-1} (Ghauch et al. 2012; Miège et al. 2009) and is the third most manufactured drug worldwide, with production exceeding 15,000 tons per year (Audino et al. 2019; Ghauch et al. 2012). Ibuprofen has been found to be removed at very low concentrations by conventional wastewater treatment systems (Clara et al. 2005; Li et al. 2014). However, the high costs generated by the construction and implementation of other types of advanced technologies have proven to be efficient in removing these types of compounds (oxidation, UV radiation, and membrane biofilm reactors) (Zhang et al. 2017; Li et al. 2014; Molinos-Senante et al. 2013), makes them technologies that are not very accessible to solve the problem of specific pollutants, such as ibuprofen. Constructed wetlands (CW) have been evaluated as an economic and sustainable alternative to treat contaminated water from domestic and industrial sources (Sandoval-Herazo et al. 2018; Sandoval et al. 2019; Wu, 2019), proving to be efficient in removing compounds, such as organic matter (70-95%), nitrogen (40 – 80%), and phosphorus (20-65%) (Marín-Muñiz, 2017).

Other recent studies on wastewater treatment from different origins using HC have evaluated the elimination of different pharmaceutical compounds, such as carbamazepine (Tejada et al. 2015; Tejada et al. 2017; Dordio et al. 2009; Zhang et al. 2013; Anderson et al. 2013), Gemfibrozil, Sulfamethoxazole, Sulfapyridine (Anderson et al. 2013), Acetaminophen, Diclofenac, Ibuprofen (Unk Vila et al. 2013), Enrofloxacin and Tetracycline (Carvalho et al. 2013); however, the removal of non-steroidal anti-inflammatory drugs such as ibuprofen in HC requires a complete understanding regarding the removal mechanisms, the influence of designs, vegetation, substrates, environmental factors and toxicity (Li et al. 2014) required for better removal efficiency. Therefore, more attention is needed to decrease the possible negative effects that these compounds may cause in the future (Fernández-Rubio et al. 2019; Sandoval, 2020).

The objective of this study was to conduct a correlational analysis of the behavior of the emerging pollutant ibuprofen in a horizontal flow constructed wetland in a tropical climate planted with the ornamental plant Spathiphyllum blandum.

Materials and Methods

2.1 Description of the area where the study was carried out

This study was conducted in the city of Xalapa, Veracruz, Mexico (19º30´10"N and 96º52´51"W). This city is located at an average altitude of 1560 meters above sea level, the climate of the area is classified as humid subtropical with an average temperature of 20.4 °C, average annual rainfall of 1,436 mm (INEGI, 2014).

2.2 Method used

The established ordered procedure to analyze the facts and the behavior of the phenomenon of the variables in the constructed wetland, considers an inductive method (from the particular to the general) and analytical, based on the empirical (reality), abstract study (nature), causes, effects, and real observation of the particular phenomenon. According to the analysis and scope of the results, it can be mentioned that it is descriptive (describes some characteristics of the homogeneous phenomenon), explanatory (determines origins and causes in the whole phenomenon) and experimental (conditions of rigorous control establishes cause-effect relationships) (Hurtado, 2000; Vergel, 2010; Hernández, 2010; Balestrini, 2001). In the Neural Network model, a block of inputs is estimated in the first layer, with an admissible result of two layers, which can be used in the second stage of network design. This corresponds to a standard design of the artificial neural network known as feedforward, which usually has one or more hidden layers with the respective training method, followed by a linear output layer (Zhou et al., 2008; Zhu & Hao, 2009; Cano et al., 2012; Gill, Murray, & Wright, 1981; Sánchez, 2018).

2.3 Description of the experimental units

The experimental units studied at the mesocosm scale consisted of 10 cylindrical plastic units conditioned as 20 L subsurface wetlands, which were recycled buckets to reduce the construction costs of the systems. These units were established outdoors, and each unit was filled with tezontle (1 to 1.8 cm in diameter), of which five units were planted with a S. blandum plant and five without vegetation as a control (see Figure 1).

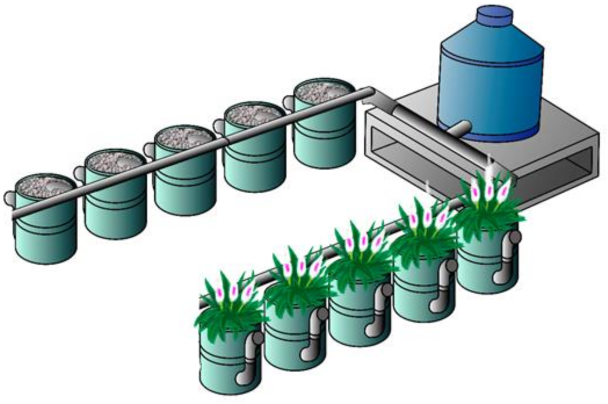

Figure 1. Macrocosms of wetlands built on tezontle substrate (TZN)

A 1,000 L settling tank was used to store the effluent that supplied the subsurface wetlands. The capacity of the tank was selected to require weekly refilling. After construction, the units were initially supplied with tap water for 30 d. Subsequently, a vegetation adaptation process was implemented involving a mixture of 50% contaminated water from the Sordo River and 50% tap water. Following this, the systems were supplied exclusively with Sordo River water for eight months, supplemented with liquid ibuprofen to achieve a concentration of 50 μgL^{-1}. The ibuprofen (Motrin® for children) was obtained from a local pharmacy. All units were operated with a 3-day hydraulic retention time.

The substrate, tezontle, had a porosity of 0.79 (Sandoval-Herazo et al., 2018) and was sourced from a material bank near Xalapa. Tezontle, a porous rock with an extensive contact surface area, is considered to be an excellent substrate candidate for subsurface wetlands.

2.4. Monitoring parameters in the system

Monitoring was conducted between March 1 and October 26, 2018. During this period, the water quality parameters were monitored. Water analyses of the mesocosm effluent and influent were conducted biweekly using standard methods (APHA-AWWA-WEF, 2005).

Ibuprofen was obtained from a local pharmacy (Motrin® for children with an ibuprofen concentration of 2 g/100 ml), and the concentration of ibuprofen in the commercial product was analyzed before the experiment, and was dosed for each 100 L, 2.5 bottles of 100 ml of Motrin® for children were used, equivalent to 5 gL^{-1}, equivalent to 5,000 ugL^{-1}, to achieve the concentration of 50 ugL^{-1} required to feed the mesocosms, which was stored in a 1000 L tank, which was filled every 8 days, to feed the 10 experimental units.

The ibuprofen quantification process began 30 days after the water supply in the surface wetland systems, thus providing a stabilization period during which the plants adapted to the systems and the internal physicochemical processes were stabilized. It was measured in both the influent and effluent every 30 days for a period of eight months from March 1 to October 26, 2018. The procedure used was based on Gracia-Lor et al. (2012) and Cervantes et al. (2017), which was modified for improvement. An ultra-performance liquid chromatograph (UPLC) coupled to a Xevo TQD (triple quadrupole) mass spectrophotometer equipped with an electrospray ionization (ESI) source was used (Cervantes et al., 2017).

In addition, certified vials and septa for LC/MS, centrifuge, volumetric equipment for dilutions, such as 100, 500, and 200 mL volumetric flasks, and automatic pipettes (Transferpette, 1000, 100, and 10 µL) were used. For dilutions and the mobile phase, deionized water type 1, LC/MS grade methanol brand Merck, and 98% formic acid were used (Aristizabal-Ciro, 2014). The standards used were as follows:

- Standard solutions of ibuprofen at 100 μgL^{-1} and 1000 μgL^{-1} in water.
- Standard solution of deuterated ibuprofen 2000 μgL^{-1}.

UPLC chromatographic analysis was performed on an Acquity UPLC H-Class system equipped with an ACQUITY UPLC BEH C18 column, 2.1×50 mm, 1.7 µm particle size) at a flow rate of 0.3 mL min^{-1}. The column temperature was set at 440 °C and the sample handling system was maintained at 5 °C. Mobile phase C: 0.01% formic acid in water and mobile phase D: 0.01% formic acid in methanol were used (Otero-Hermida et al., 2014). The limit of quantification (LC) of the method was 1 μgL^{-1} (Otero-Hermida et al., 2014). Each sample was centrifuged in a 25 mL Falcon tube at 5000 rpm for 10 min, and then 1 mL of the supernatant was placed in a 2 mL amber glass vial (certified for LCMS). In cases where necessary, dilution with ultrapure water was performed so that the reading was within the working range of 1-300 μgL^{-1}. Then, 50 µL of a 2 mgL^{-1} solution of deuterated ibuprofen was added as an internal standard before injecting the sample into the UPLC to take the reading. In accordance with the quality management system implemented by the soil and plant water laboratory of the National Technological Institute of Mexico, for each batch of 20 samples, a reagent blank (UP water), replica, enriched sample, and control in ultrapure water were prepared, providing reliability to the results obtained.

Results and discussions

3.1. Environmental conditions

The wetlands constructed at the mesocosm level were operated within the facilities of the Xalapa headquarters of the National Institute of Technology of Mexico. The climatic conditions during the study period between March 2018 and October 2018 were an average temperature of 21°C and humidity of 82%. These conditions positively influenced vegetation development. On the other hand, the light intensity, which is an indicator that favors the development of vegetation, averaged 805.81 lux (see Figure 2). In tropical areas, light intensity ranges from 500 to 2,100 lx, which is the range where vegetation can grow the most (Dong et al., 2001).

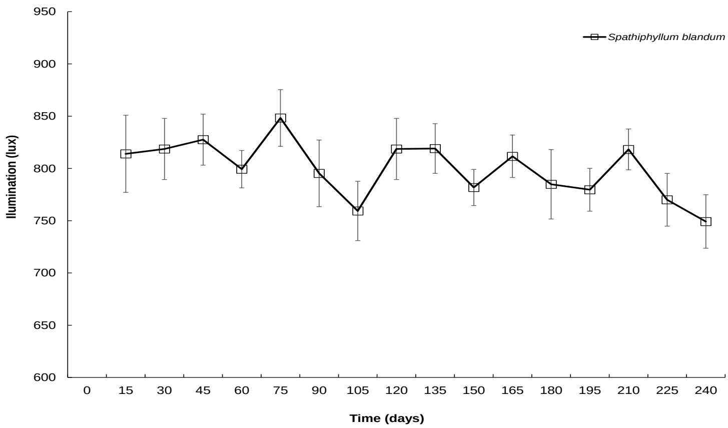

Figure 2. Light intensity during the study period

3.2 Plant Development

Spathiphyllum blandum is a perennial plant with large leaves 12-65 cm long and 3.25 cm wide. The flowers are produced on a spadix surrounded by a spathe 10-30 cm long, white, yellow, or greenish spathe. The results are shown in Figure 3, where it can be observed that the plant showed development similar to that recorded by this type of vegetation (average of 1 m) in its natural environment over a period of 12 months (Chízmar-Fernández, 2009). Therefore, through this 8-month study, it was observed that the growth of vegetation fed with wastewater contaminated with ibuprofen not only did not affect the growth of the species, but also favored its development, achieving growth in a shorter time compared to its natural habitat, probably because of the presence of nutrients in the wastewater. S. blandum showed a higher growth rate than that of its natural state (6.7% in the natural state to 8.8% in HC systems).

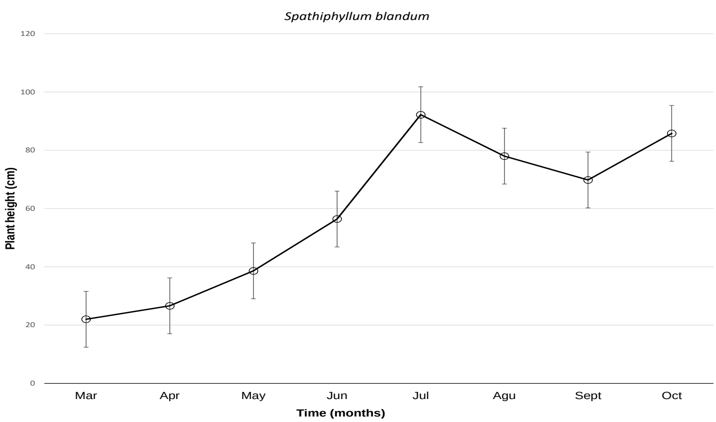

Figure 3. Plant growth

On the other hand, the pH of the water was found at 7.2 ± 0.3; these values are within adequate ranges for the development of vegetation 7.0 to 8.5 (Zurita et al. 2008). This characteristic of water could favor the adequate development of vegetation, along with the ambient temperature, relative humidity, and light intensity found in this study, as they are within adequate ranges for the development of tropical plants (Sandoval-Herazo et al. 2018) and those reported for the development of Spathiphyllum blandum by Chízmar-Fernández (2009) under natural conditions. The average number of flowers per plant was 3 ± 1. It is worth mentioning that there is no information regarding the use of this species in constructed wetlands. Therefore, this study is one of the first in relation to the subject; however, its flowering period is known, which is on average two flowers per plant over a period of 12 months (Iremonger et al. 1995), and the greater production of flowers in mesocosms fed with water contaminated with ibuprofen could induce greater flowering in this plant species. It is important to evaluate the effects of other pharmaceutical compounds on this vegetation in terms of its development, as well as the study of bioaccumulation in tissues, to better understand the role played by plants in the removal of this type of substance.

3.3 Ibuprofen in constructed wetland mesocosms

Figure 4 shows the concentration of ibuprofen used in the study. As mentioned, 50 ugL^{-1} of ibuprofen was used throughout the study period, but an increase of around 11 ugL^{-1} was found in the effluent due to the presence of the drug in untreated domestic wastewater, which explains the variations of the compound in the effluents. This information is consistent with that reported by Ghauch et al. (2012), who indicated that ibuprofen was present in wastewater effluents at concentrations of 10 ngL^{-1} - 169 μgL^{-1}.

Regarding removal, significant differences ($P<0.05$) were found between systems with and without vegetation. In the systems with S. blandum, greater removal of pharmaceutical compounds was found (71% with vegetation and 52% in HC without vegetation). Although this study did not consider the elimination mechanisms of ibuprofen, and it is a little-known topic, according to Bhatia & Goyal (2014) and Cervante et al. (2017), the rhizosphere of plants acts as a microcosm, where recalcitrant chemical compounds such as ibuprofen are degraded, which may have an influence on the removal of ibuprofen in HC. However, biodegradation and biotransformation in wetlands occur mostly in the rhizomes; likewise, the exudates released in the radical zones of the plants intensify microbial activity and can improve the bioavailability of pharmaceutical products in these systems. Regarding the significant differences found between systems with S. blandum and without vegetation, this coincides with what is reported in the literature since in HC with less presence of oxygen, the removal of ibuprofen is lower, assuming that aerobic microorganisms favor the removal of this compound (Verlicchi et al., 2012).

In this study, the DO concentrations in the systems were low, mainly in systems without vegetation, where oxygen was not released in the root zones, which could have allowed the development of aerobic microorganisms in the root zone. This may explain the greater removal of the compound in HC with vegetation, which has been reported to help in the elimination of this compound with high efficiencies of >90% (Verlicchi et al., 2012).

In general, it has been shown that the presence of HC vegetation improves the elimination of drugs (Truu et al., 2015), as has been demonstrated in this study. The observed drug removal efficiencies were lower than those documented in previous studies. Research by Chen et al. (2016) demonstrated removal rates ranging from 74% to 99% in saturated HC with higher plant density, whereas Zhang et al. (2011, 2012, 2016) reported efficiencies between 68 and 83% in HC in tropical climates. However, it is worth noting that these studies utilized lower input concentrations of ibuprofen (11.5 μgL^{-1} to 48.5 μgL^{-1}) than the current study, which may account for the discrepancy in removal rates.

The elimination of ibuprofen appears to be influenced by both the plant species and microorganisms present, as evidenced by the significantly increased removal in vegetated systems compared to that in unvegetated systems. Nevertheless, there remains a lack of understanding of ibuprofen removal at high concentrations and the specific role of microbial communities in this process. Consequently, further research is necessary to gain a better understanding of the elimination dynamics of this compound in wastewater systems globally (Březinova et al., 2018).

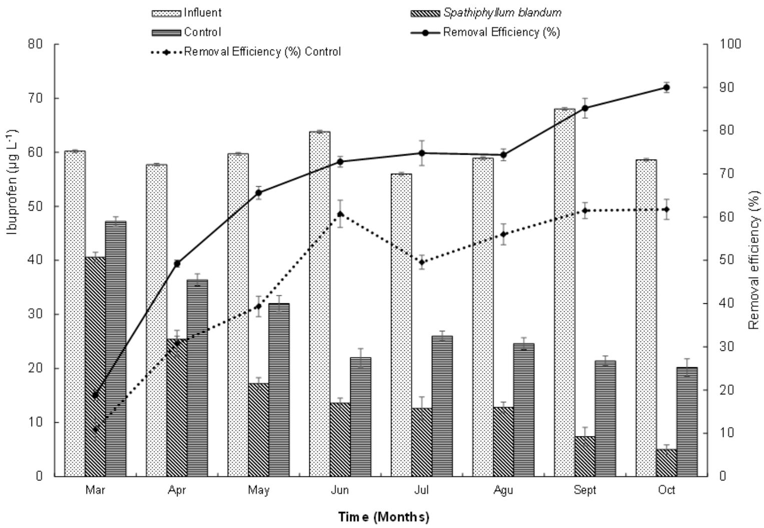

Figure 4. Concentrations and removals of ibuprofen in mesocosm during the study. Source: Sandoval et al. (2020)

3.4 Analysis of experimental data

The study of the Constructed Wetland and the measurement of ibuprofen concentration revealed that the correlated variables, including plant height and ibuprofen levels in both the influent and effluent, demonstrated moderate data variability, weighted recurring frequency, and limited influent and effluent data in the correlational analysis. To address this, missing data points were filled using the average of the preceding and subsequent values for each period, lacking representative information. Furthermore, a linear regression was conducted using the 'units' variable and the available data (including imputed values). Subsequently, the concentration value under a specific temporal condition of the analysis was predicted.

Thus, a dataset with no empty values was obtained for all time periods. The variables “Plant height”, “Ambient temperature”, “Humidity”, “Lighting”, “Ibuprofen influent,” and “ibuprofen effluent” were extracted for further study. According to the above, the following results were obtained, which are acceptable in the context of the experiment (see Table 1).

Table 1. Results of the analysis of variables in the Constructed Wetland

	Ambient Temperature	Humidity	Plant Height	Lighting	Ibuprofen Influent	Ibuprofen Effluent
Count	16.0000	16.0000	16.0000	16.0000	16.00	16.000
Mean	20.4443	81.0000	61.4540	799.6937	50.00	15.685
STD	3.0216	9.6678	25.9706	27.0068	0.00	9.871
Min.	14.3000	54.0000	22.0000	749.2000	50.00	6.461
25%	19.6000	76.2500	37.1000	781.2500	50.00	10.750
50%	20.7500	85.0000	71.8500	805.4500	50.00	12.250
75%	21.4750	86.0000	79.7750	818.6000	50.00	15.125
Max.	26.6000	92.0000	98.3647	848.3000	50.00	43.000

As shown in Table 2, the variables exhibiting the highest standard deviations were plant height and lighting data. The data traffic analysis revealed that ambient temperature is the sole variable approximating a normal distribution, while the other variables display some form of bias, predominantly skewed to the left.

Table 2. Analysis of variables in the Constructed Wetland

	Ambient Temperature	Humidity	Plant Height	Lighting	Ibuprofen Influent	Ibuprofen Effluent
Ambient Temperature	1.0000	-0.4330	-0.1289	0.3367	NaN	-0.2886
Humidity	-0.4330	1.000	0.2128	-0.0823	NaN	-0.1045
Plant Height	-0.1289	0.2128	1.000	-0.4844	NaN	-0.8055
Lighting	0.3367	-0.0823	-0.4844	1.000	NaN	0.3849
Ibuprofen Influent	NaN	NaN	NaN	NaN	NaN	NaN
Ibuprofen Effluent	-0.2886	-0.1045	-0.8055	0.3849	NaN	1.000

It can be observed that ibuprofen in the effluent has a tendency with low variability to be constant, which establishes that the standard deviation is close to zero, which means that it is not possible for this variable to have a direct influence on the other variables. Therefore, the correlation with other variables is always undefined. According to the above analysis, there is a significant correlation between the low frequency of ibuprofen in the effluent and the height of the plant.

3.5. Regression applied to data in experimentation .

By applying simple linear regression with the variables described above, it is established in Table 3 that it is not possible to reject the null hypothesis, which states that there is no relationship between the model constant, humidity, and lighting, and the variable to be described.

Table 3. Result of the linear regression with the set of variables in the Constructed Wetland

Dep . Variable:	Ibuprofen Effluent	R- squared :	0.839
Model :	OLS	Adj. R- squared :	0.780
Method :	Least Squares	F- statistic :	14.31
Date:	Sunday, 13 Dec. 2020	Prob (F- statistic):	0.000246
Time:	17:37:45	Log- Likedlihood :	-44.222
No. Observations :	16	AIC:	98.44
Df Residuals :	11	BIC:	102.3
Df Model :	4		
Covariance Type:	nonrobust		

	coefficient	std err	t	P>|t|	[0.025	0.975]
Const	27.1551	43.021	0.631	0.541	-67.534	121,84
Temp Amb.	-1.6725	0.471	-3.554	0.005	-2.708	-0.637
Humidity	-0.1545	0.142	-1.091	0.299	-0.466	0.157
Lightning	0.0660	0.054	1.218	0.249	-0.053	0.185
Plant Height	-0.2858	0.054	-5.269	0.000	-0.405	-0.166

Bus :	0.784	Durbin-Watson:	1.814
Prob (Omnibus):	0.676	Jarque- Bera (JB):	0.255
Skew :	-0.308	Prob (JB):	0.880
Kurtosis :	2.952	Cond. No.	3.00e+04

Additionally, the opposite can be said for temperature and plant height, and because the latter variable has a high correlation with the target variable, a linear regression was performed including only this variable. Table 4 presents the results of the analysis.

Table 4. Result of the linear regression with plant height and temperature in the Constructed Wetland.

Dep . Variable:	Ibuprofen Effluent	R- squared :	0.649
Model :	OLS	Adj. R- squared :	0.624
Method :	Least Squares	F- statistic :	25.88
Date:	Sunday, 13 Dec. 2020	Prob (F- statistic):	0.000166
Time:	17:47:28	Log- Likedlihood :	-50.447
No. Observations :	16	AIC:	104.9
Df Residuals :	14	BIC:	106.4
Df Model :	1		
Covariance Type:	nonrobust		

	coefficient	std err	t	P>|t|	[0.025	0.975]
const	34.5015	3.997	8.632	0.000	25.929	43.074
Plant Height	-0.3062	0.060	-5.087	0.000	-0.435	-0.177

Bus :	5.629	Durbin-Watson:	0.505
Prob (Omnibus):	0.060	Jarque- Bera (JB):	2.807
Skew :	0.850	Prob (JB):	0.246
Kurtosis :	4.149	Cond. No.	175.0

Complementing the above, Figure 5 shows the regression obtained, data, and predictions made with the variables of plant height and ibuprofen concentration. When comparing the adjusted R-square of the univariate model with the adjusted R square of the multivariate model, a notable deterioration in the model fit was evident. However, when observing the results in detail, an approximately logarithmic behavior is evident (see Figure 6). Therefore, this transformation is performed on both variables involved, and the following results are obtained when performing a linear regression on the behavior within the constructed wetland. When performing a visual inspection of the obtained model, a better fit is evident with respect to the simple linear model, and an R value close to 1.

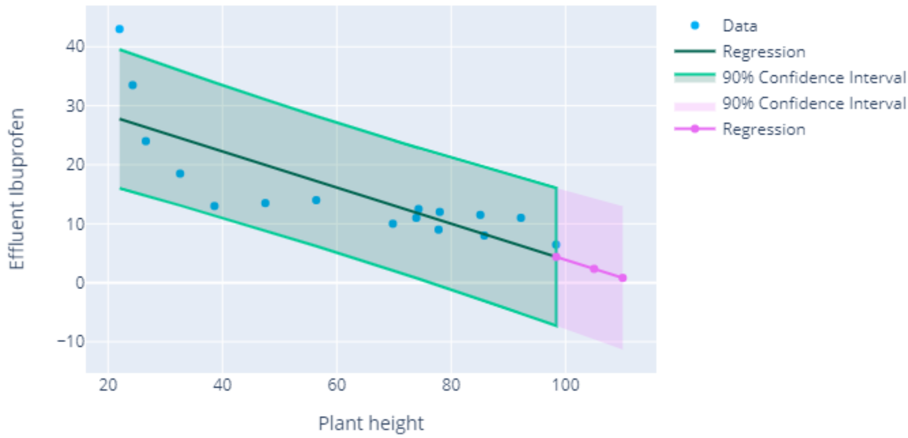

Figure 5. Preliminary linear regression in the Constructed Wetland

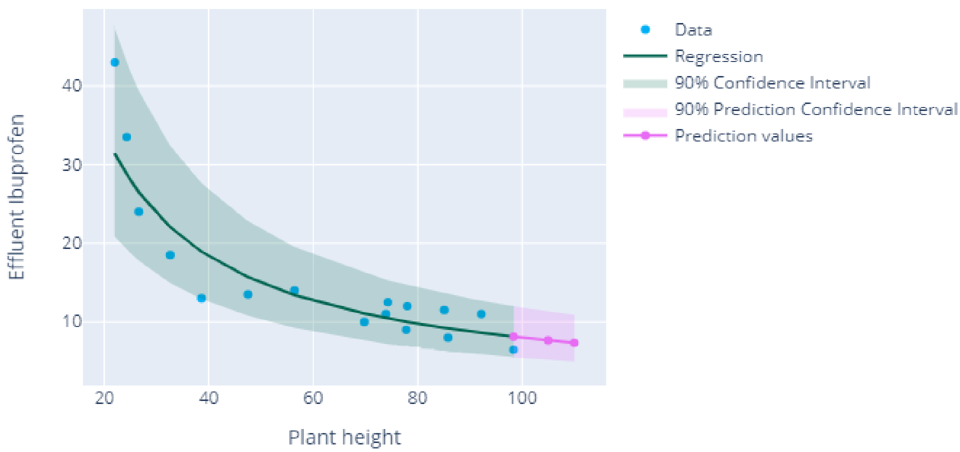

Figure 6. Preliminary log. regression in the Constructed Wetland

The data traffic analyzed for the ibuprofen contaminant in the constructed wetland, as shown in Figure 7, generated a high test determination coefficient (R = 0.99738), which expresses an adequate representation of the degree of reliability or certainty in the goodness of fit of the analyzed model in the temporal context of the data structure. The above is significant in the few points of dispersion in the data volume, especially in the analysis period of the experiment; therefore, the validation of the reliability of the prediction through the computational technique of neural networks, which was evaluated through a comparison of linear regression (R=0.99738 and R=0.97931) and a test for the prediction of the contaminant in question.

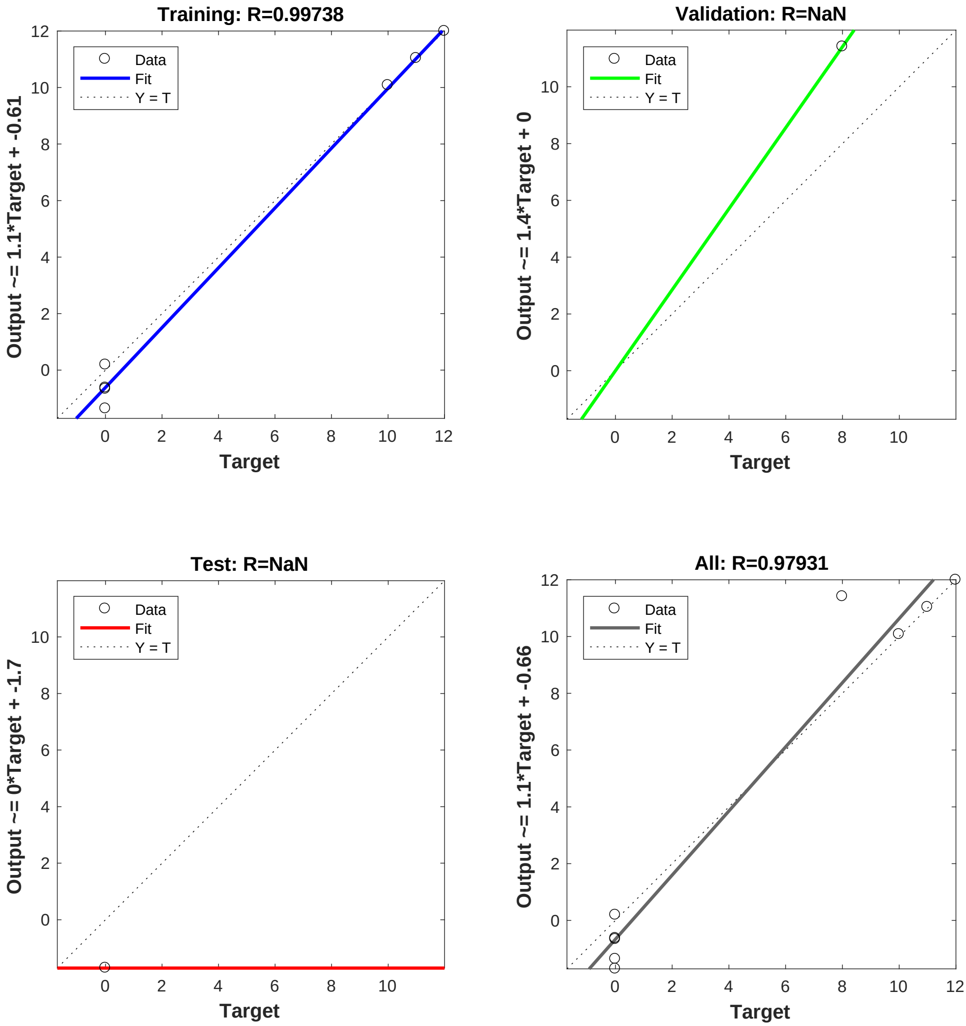

Figure 7. Linear regression for the behavior of Ibuprofen in the Constructed Wetland

In Figure 8, the line entities of the emerging contaminant ibuprofen can be observed through a simple harmonic behavior of the concentration of ibuprofen inside the Constructed Wetland, which presents a volatile fluctuation with low recurrent frequency and low variability in its quantification in the constructed wetland. When analyzing the estimated concentration after the time of operation of the constructed wetland, a considerable reduction with an asymptotic tendency of the concentration of ibuprofen was observed, which can be a favorable indicator to avoid environmental effects in the receiving water body and, of course, undesirable effects on public health and aquatic ecosystems. Additionally, when comparing the mean square error calculations (reference value < 0.030), relative and absolute errors, with the references for the Artificial Neural Network computational technique with the Levenberg Marquardt algorithm, results of < 0.028, 1.2932%, and 0.0210, respectively, are obtained, which are substantially lower than those reported in the specialized literature.

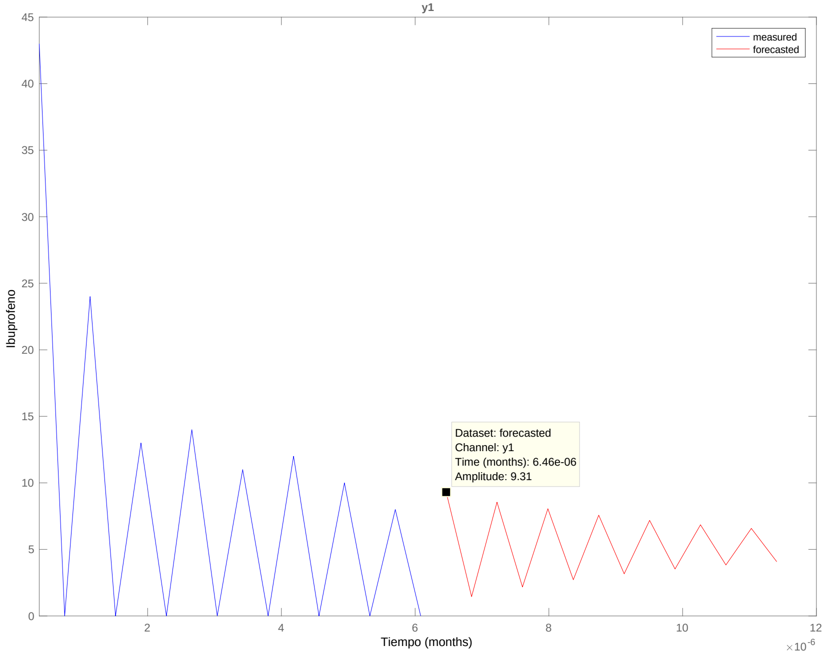

Figure 8. Behavior of Ibuprofen in the Constructed Wetland

Conclusions

The use of Spathiphyllum blandum significantly improved the removal of ibuprofen in HC relative to non-planted systems by up to 23%. HC proved to be an efficient system for the removal of ibuprofen, and its presence in the water appears to favor the healthy development of the vegetation used in this case, in the case of S. blandum. Although there is no certainty about this, the good development of vegetation could be due to the presence of nutrients in the treated wastewater. Saturation conditions were favorable for the removal of ibuprofen, contrary to other studies reported in the literature, but not for other specific contaminants present. Studies evaluating the removal of these drugs under partially saturated conditions are required to assess whether these conditions favor the removal of both conventional contaminants and drugs, as the removal of ibuprofen is favored by high temperatures and conditions of greater presence of oxygen, which can be incorporated artificially. Given the small amount of data to be analyzed in the ibuprofen experiment in the Constructed Wetland, it is difficult to achieve a prediction with line entities that have low variability and low volatile fluctuation; that is, they have a high reliability according to the appropriate ranges, in terms of the mean square error. Based on the prediction obtained for ibuprofen in the effluent, it can be concluded that it has a behavior with exponential decay tending toward zero, and the model obtained explains in an acceptable way the relationship between the height of the plant and the concentration of ibuprofen in the effluent, reaffirming that the relationship is inverse (as the size of the plant increases, the concentration tends to decrease and vice versa). Therefore, there is no correlation between external variables, such as temperature and humidity.

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