



## CASE STUDY

## Sub-surface flow constructed wetland for the treatment of sewage generated in a municipal park

A.M. Vazquez<sup>1</sup>, A. Samudio-Oggero<sup>2,\*</sup>, H.D. Nakayama<sup>2</sup>, I. Cantero-García<sup>2</sup><sup>1</sup> Faculty of Chemical Sciences, National University of Asunción, FCQ/UNA, Asunción, Paraguay<sup>2</sup> Laboratory of Biotechnology, Multidisciplinary Technological Research Center, National University of Asunción, CEMIT/UNA, Asunción, Paraguay

## ARTICLE INFO

**Article History:**

Received 10 September 2020

Revised 27 November 2022

Accepted 01 January 2023

**Keywords:**

Bioremediation

Black water

Constructed wetlands

Typha domingensis

## ABSTRACT

**BACKGROUND AND OBJECTIVES:** The Municipal Park of Areguáis is located in the Central Department of Paraguay. Part of this Park is within the area of influence of Ypakarai Lake, which is widely recognized by vacationers for its natural spaces. Despite being one of the most representative ecological reserves in the country, annual water quality reports indicate the presence of a high content of pollutants; mainly nitrogen, phosphorus, and fecal coliforms, among others. These conditions promote the proliferation of cyanobacteria which consume the available oxygen and compromise the reserve's flora and fauna. Following several laboratory tests, the present work has the objective of evaluating the impact of the park's recently constructed wetland on the treatment of residual waters. There are several parameters evaluated in this study of final wastewater discharge disposal treatment through a constructed wetland of horizontal flow with *Typha domingensis*. The objective is to develop an adequate system for the treatment of residual waters that can be replicated in places with similar conditions.

**METHODS:** The evaluation consisted of analyzing the residual water and finding the removal percentage for each of the following parameters such as chemical oxygen demand; biochemical oxygen demand; total phosphorus; total nitrogen; fecal coliforms; hydrogen potential; and temperature. The quality of the treated water was determined by comparing it with the limits established in Article 7 of Resolution Number 222/02 of the Environment Secretary for effluents. The results demonstrate that this system is a viable option for the removal of fecal coliforms and nutrients such as phosphorus and nitrogen.

**FINDINGS:** In terms of the quality of the treated water, the parameters studied are within the limits established by Resolution Number 222/02 of the Environment Secretary for Class 2 waters, for water to be discharged into the receiving body. The results obtained were: 88.9 percent fecal coliform removal; 84.9 percent total nitrogen; 73.3 percent chemical oxygen demand; 61.4 percent biochemical oxygen demand; and 14.2 percent Total Phosphorus. Considering Resolution 222/02, the biochemical oxygen demand, Total Nitrogen, and Total Phosphorus were outside the admissible limits.

**CONCLUSION:** It is very feasible for wastewater generated in public parks to be treated through the construction of sub-surface flow wetlands. This study confirms that the treated wastewater is within the established limits for all the parameters: temperature, hydrogen potential, biochemical oxygen demand, chemical oxygen demand, total nitrogen, total phosphorus, and fecal coliforms. This model of water treatment can be easily adopted.

DOI: [10.22035/gjesm.2023.03.\\*12](https://doi.org/10.22035/gjesm.2023.03.*12)

NUMBER OF REFERENCES

32



NUMBER OF FIGURES

9



NUMBER OF TABLES

2

\*Corresponding Author:

Email: [asamudio@rec.una.py](mailto:asamudio@rec.una.py)

Phone: +595984395136

ORCID: [0000-0003-1374-7974](https://orcid.org/0000-0003-1374-7974)

Note: Discussion period for this manuscript open until October 1, 2023 on GJESM website at the "Show Article".

## INTRODUCTION

Biodiversity and the exuberance of nature are good tourism products. In Paraguay, the valorization of springs, streams and rivers is achieved through rural tourism. The protection of these, along with forests, is therefore prioritized in order for tourists to enjoy this rich natural heritage in a healthy way (López Moreira et al., 2018). Ypacaraí Lake is considered to be one of the most beautiful landscapes in Paraguay, surrounded by flora and fauna. It is located between the Central and Cordillera departments, covering an area of 90 square kilometers (km<sup>2</sup>). It is 24 kilometers (km) long and 6 km wide, with an average depth of 3 meters (m) (SENASA and JICA, 2001). However, many of Paraguay's water resources are critically endangered due to significant discharges of contaminated water without prior treatment. Residual water is the liquid that was used by a population or industry that contains dissolved or suspended organic and inorganic material (Englande et al., 2015), while wastewater refers to water that needs treatment before arriving at its final destination in a receiving body because its initial characteristics have been changed (OEFA, 2014; Rahman et al., 2022). The wastewater discharged into Ypacaraí, as well as other bodies of water, is loaded with different contaminants, including: dyes, solid particles, heavy metals, nutrients, bacteria, and others. This has prompted the prioritisation of applying treatment technologies to clean up the polluted water (Zaboon et al., 2022). Over time, different treatment methods have been developed to treat water, each designed according to the characteristics of the wastewater and its desired quality. Many studies have found constructed wetlands with different species of plants to perform well (Zhang et al., 2014). Several studies (Saeed et al., 2016) have reported on the potential application of groundflow wetlands to improve water quality. When designing these processes, the aim is to accelerate these mechanisms (Piédrola, 2008). Phytoremediation is a set of technologies that reduce the concentration of different compounds from biochemical processes carried out by plants and microorganisms associated with them (Leto et al., 2013). An artificial or constructed wetland is a water purification system that uses natural processes for domestic wastewater treatment in shallow water entrusted aquatic species (Swarnakar, 2022). Aquatic

plants known as macrophytes can live in permanently flooded land or in water logged conditions for long periods. In recent years, phytoremediation using aquatic plants with high productivities and nutrient removal capabilities has received increasing public attention (Moore et al., 2016). *Typhas* sp, commonly known as "Totora", is an emergent aquatic macrophyte that grows in temperate and tropical climate regions and is generally implemented in artificial wetlands to improve water quality in treatment systems (Mufarrege, 2012). It is emergent because it has aerial reproductive organs, and its roots are sunk into the soil at the bottom of the wetland (García, 2010). However, even with all the aforementioned advantages, compared to other existing technologies, it is still necessary to evaluate its efficiency according to the specific place and type of effluent to be treated. Within the Paraguayan context, research on wastewater treatment through constructed wetlands present a significant gap in the literature. A few isolated studies have been undertaken on a laboratory scale. Therefore, field studies are required to establish wetland technology as a sustainable approach to wastewater treatment. There has been very limited research on natural and sustainable wastewater treatment methods in Paraguay. Thus, the present study was conducted to evaluate the treatment of wastewater through constructed wetlands in order to find ways to produce treated wastewater in a way that is less harmful to the environment. Therefore, goal of this study was to evaluate the efficiency of the artificial sub-surface flow wetland for the treatment of wastewater generated in the Aregua Municipal Park, Central Department, Paraguay, developed between 2019 and 2020.

## MATERIALS AND METHODS

### Research location

This study was conducted between September and December 2019, in the Municipal Park of the city of Areguá, located in the Central Department of Paraguay, 20 km away from the Capital city of Asunción (Fig. 1). The project was located within the area covered by the Reserve of Managed Resources of Ypacaraí Lake, coordinates: Latitude 25°18'8.83" S. and Longitude 57°22' 28.19" W. During this study, there was an average rainfall of 120 mm and temperatures (T) ranged between 13.5 to 38 degrees Celsius (°C).

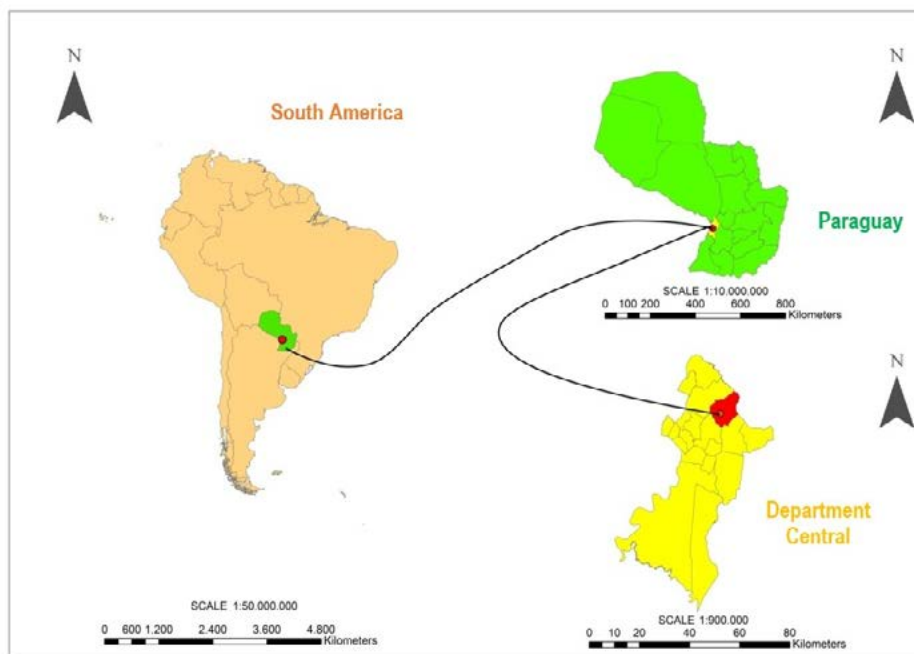


Fig. 1: Geographic location of the study area in Ypacaraí Lake, Municipal Park of Aregua, Central Department, Paraguay

#### Used species

*T. domingensis*, commonly known as “Totora”, is a monocot that belongs to the *typhaceae* family. It is a perennial, herbaceous, rhizomatous, and emergent plant, 1 to 2.5 m tall (Peralta et al., 2022). It has leaves with linear blades that equal or exceed the height of the spikes, they are tapered, 40 to 120 cm long by 0.5 to 2 cm wide, with a flat upper side and a slightly convex lower side. Its flowers are unisexual, very small, and arranged in dense spikes. The staminate flowers are in the upper region of the spike, while the pistillate flowers are found in the basal part. The fruit is fusiform, 1 to 1.5 millimeters (mm) long and it blooms in spring. It lives in low-lying areas such as, ditches, lagoons, floodplains, and the edges of estuaries and watercourses. This species is widely studied, both in natural and constructed wetlands, for the treatment of effluents due to its high tolerance to contaminants (Mufarrege, 2012; Mukhtar and Abdullahi, 2017; Hazra et al., 2015).

#### Wetland construction

Fig. 2 shows the dimensions of the system designed by Tecno-ambiental S.A. The calculations were made according to a database of effluents

generated with a hydraulic retention of 1.62,  $d = 39$  hours (Delgadillo, 2010). A high density polyethylene (HDPE) geomembrane was used to waterproof the system and prevent infiltrations, and it was built with a 2% slope to favor effluent runoff. Ten *T. domingensis* plants were transplanted per square meter ( $m^2$ ), (300 plants in total) obtained by multiplying seeds from the Multidisciplinary Center for Technological Research’s (CEMIT) Biotechnology Laboratory greenhouse. The system was monitored for 90 days to evaluate its development. During this period, the plants reached an average height of 2m while new shoots generated approximately 750 additional plants.

#### Sampling methodology

To evaluate the efficiency of the wetland, samples were taken at the entry point (M x P1) and the exit point (M x P2), where MX represents the Sample number (5 samples in total). The sampling was carried out consecutively, with 15 day intervals. The samples were transferred to the CEMIT Water Quality Laboratory for analysis.

#### Parameters analyzed

For in situ determinations of parameters such as

### Sub-surface flow constructed wetland

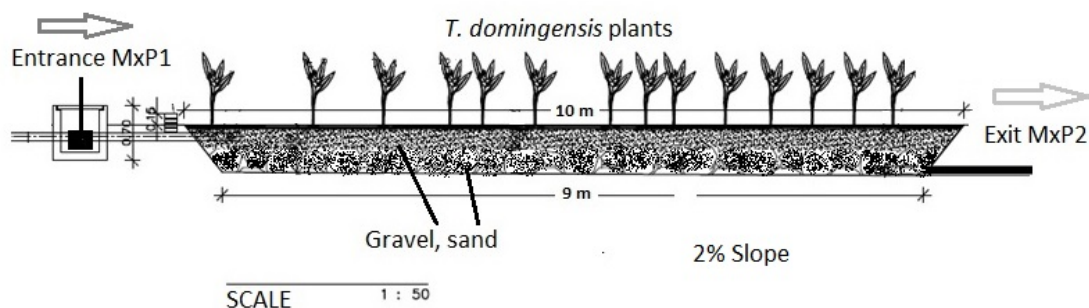


Fig. 2: Cross section of the constructed wetland's design

temperature, conductivity, oxygen, and pH, containers and beakers were used along with multiparametric field equipment.

#### Methods used for each study parameter

a) Potential of hydrogen (pH): pH measurements were made using a pH meter, as described by [Peralta et al. \(2022\)](#).

b) Temperature: T was determined using a portable thermometer. As outlined in [Peralta et al. \(2022\)](#), measurements were made directly at the analyzed points.

c) Chemical oxygen demand (COD): COD was established using a closed reflux, colorimetric method. A calibration curve was prepared with five potassium hydrogen phthalate solution standards; 2 mL of the sample was measured and added to tubes filled with 3 mL of digest solution (potassium dichromate, sulfuric acid, mercury fate); it was brought to 150 °C for 2 hours. Then it was allowed to cool and the absorbance was read at a wavelength of 600 nanometers (nm). It was calculated using the formula  $\text{mg O}_2/\text{L} = (\text{Absorbance (Abs.) of the sample} - \text{Abs. of the blank}) \times \text{factor} \times \text{dilution}$  ([Peralta et al., 2022](#)).

d) Biochemical oxygen demand (BOD): BOD after five days ( $\text{BOD}_5$ ) was found by first bubbling the dilution water (phosphate buffer, magnesium sulfate, calcium chloride, ferric chloride) for 25 minutes. Three dilutions of the samples were made, filling the hermetic flasks with dilution water to the point of overflowing. Then, the dissolved oxygen was measured with the oximeter. The flasks were incubated at 20 °C for 5 days. On the fifth day dissolved oxygen was measured again. It was calculated using the formula:  $\text{mgO}_2/\text{L} = (\text{initial dissolved oxygen} - \text{final dissolved}$

oxygen)  $\times$  300  $\times$  dilution ([Peralta et al., 2022](#)).

e) Total nitrogen (TN): TN was measured using a macro Kjeldahl method. 250 mL of the sample, 0.5 mL of magnesium sulfate and 10 mL of the digest mix were added into a Kjeldahl flask. This was mixed and digested over a heating device until the mix became clear. Then, it was refilled with 250 mL of distilled water, and homogenized. A 25 mL sample was taken and transferred to an Erlenmeyer flask with lid before adding 25 mL of distilled water, 1 drop of ethylenediaminetetraacetic acid (EDTA) and 1 mL of citrate buffer and homogenizing again. This was later neutralized with 30% sodium hydroxide to a pH of 10. After this, 2 mL of reagent A (dried reagent containing phenol and sodium nitroferrocyanide) and 2 mL of reagent B (concentrated reagent of sodium hypochlorite and sodium hydroxide) were added. The mix was homogenized and after 1 hour the calculation was made using the formula:  $\text{mg/L N} = (\text{Abs. of the sample} - \text{Abs. of the blank}) \times \text{factor} \times \text{dilution}$  ([Peralta et al., 2022](#)).

f) Total phosphorus (TP): TP was studied using an automated ascorbic acid reduction method. 25 mL of the sample previously digested by the Kjeldahl method (same digestion that was used in the determination of TN). Then, 2 drops of phenol phthalein were added and neutralized with 30% sodium hydroxide until a permanent pink color was obtained. Later a 5 normal (N) sulfuric acid was added by drops, until the mix became clear. Afterwards, 8 mL of mixed reagent (potassium and ammonium double tartrate, ammonium molybdate, ascorbic acid, sulfuric acid) were added and brought to 50 mL. After 10 minutes, the reading was made at a wavelength of 880 nm. The calculation was made using Eq. 1 ([Peralta et al., 2022](#)).

Phosphorus (mg/L) = (Abs. of the sample – Abs. of the blank) × factor × dilution (1)

g) Fecal coliforms (FC): MPN procedure was followed for for FC. In the presumptive phase, five tubes with lauryl tryptose liquid medium were used with 10 mL of sample inoculated in each tube. The samples to be studied were mixed with the medium by gentle agitation. The inoculated tubes were incubated at 35°C. After 24 hours each tube was shaken gently and gas production was observed. Gas formation constitutes a presumed positive reaction. In the confirmatory phase, the primary tubes in which gas was formed were taken. The fermentation tubes containing brilliant green lactose bile were inoculated with a sterile loop (3 mm diameter) and incubated at 35°C for 48 hours. The production of any amount of gas at 48 hours constitutes a positive result. The presumptive tubes that showed some amount of gas during the 48 hours of incubation in the confirmation test were studied (Peralta *et al.*, 2022).

#### Contaminant removal determination

According to the parameters that were analyzed at the entrance and exit of the system, a calculation of the percentage of removal of the values obtained was made. It was calculated using Eq. 2 (Peralta *et al.*, 2022).

$$\%R = \frac{CE - CS}{CE} \times 100 \quad (2)$$

Where;

R: Removal

CE: Entrance concentration

CS: Exit concentration

## RESULTS AND DISCUSSION

### Physicochemical and microbiological characteristics of the effluent entrance and exit

Table 1 shows the values recorded for each evaluated parameter (hydrogen potential (pH), temperature (T), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorus (TP), total nitrogen (TN), and fecal coliforms (FC)) from the entry (P<sub>1</sub>) and exit (P<sub>2</sub>) points of the effluent from each different sampling, with the first collected on 09/12/2019 and the last on 11/04/2019.

#### pH

In Fig. 3 the pH values at the entrance (P<sub>1</sub>) and exit (P<sub>2</sub>) of the wetland are shown. In each instance a decrease in pH (ranging between 8.8 and 7.3) was observed in the samples after passing through the wetland. These results are similar to those found by Peralta *et al.* (2009) who found the pH of the treated wastewater in the wetland to stay close to the pH value of 7, which is considered neutral. The results reported by Samudio *et al.*, (2022) controlled test evaluation of another species (*Cyperus giganteus*) also indicate a pH of around 6 and 5.5 between the control and treated effluent. On the other hand, Delgado *et al.* (2010) comment that *T. domingensis*

Table 1: Values obtained in the physicochemical and microbiological analyses

Parameters	Date: 09/12/2019 Hour: 10:26		Date: 09/23/2019 Hour: 10:29		Date: 10/07/2019 Hour: 10:30		Date: 10/21/2019 Hour: 10:40		Date: 11/04/2019 Hour: 10:00	
	1 <sup>st</sup> SAMPLING		2 <sup>nd</sup> SAMPLING		3 <sup>rd</sup> SAMPLING		4 <sup>th</sup> SAMPLING		5 <sup>th</sup> SAMPLING	
	P <sub>1</sub>	P <sub>2</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>1</sub>	P <sub>2</sub>	P <sub>1</sub>	P <sub>2</sub>
pH	8,8	7,76	8,5	7,79	8,39	7,54	8,07	7,37	8,0	7,48
T (°C)	21,0	21,0	24,6	26,0	25,5	25,5	23,0	23,7	28,0	30,0
COD (mgO <sub>2</sub> /L)	188,6	97,2	154,71	134,39	49,2	141,25	25,78	52,77	11,43	35,78
BOD <sub>5</sub> (mgO <sub>2</sub> /L)	115,5	81,2	81,9	74,1	16,9	26,2	19,9	38,7	9,41	20,25
TP (mg/L)	3,34	1,51	3,27	1,64	4,22	5,69	3,04	1,57	5,41	2,84
TN (mg/L)	56,2	49,3	37,6	25,2	35,1	27,4	21,64	27,98	14,0	5,91
FC (MPN/100mL)	110.000	750	110.000	11.000	110.000	24.000	4.300	230	240	23

Constructed wetland performance for each parameter

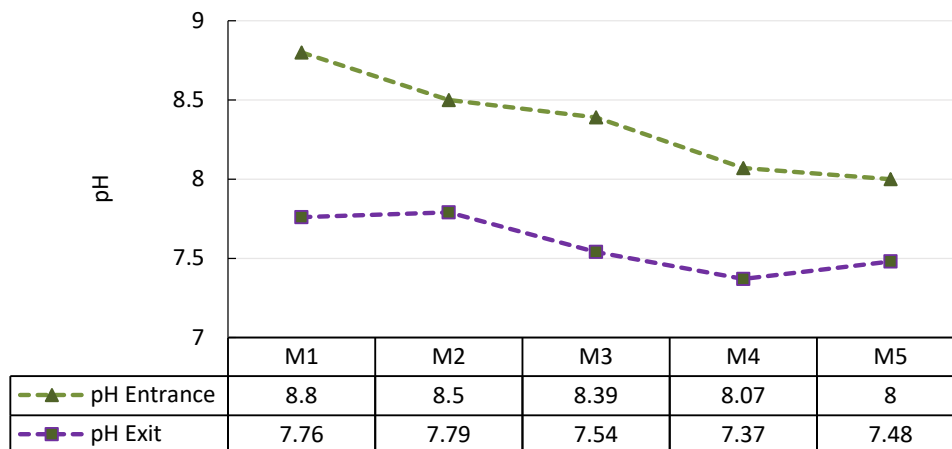


Fig. 3: Temperature of the treated and untreated effluents in the 5 sampling

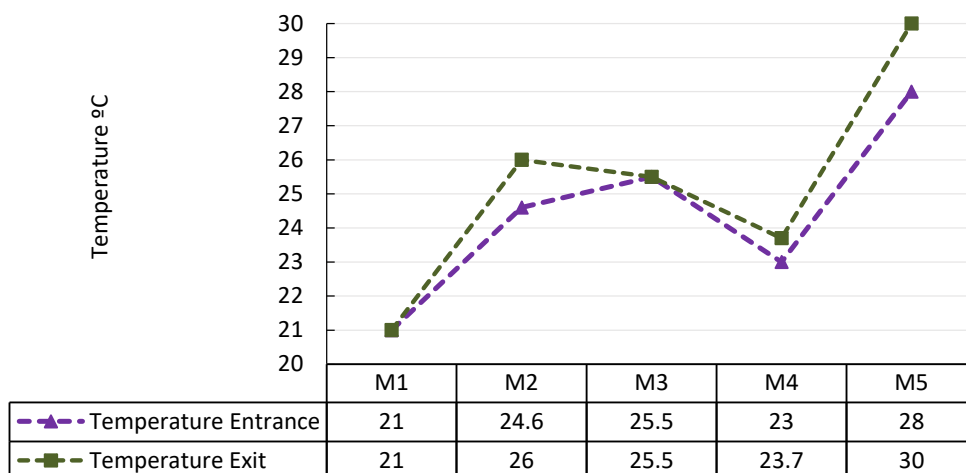


Fig. 4: Temperature of the treated and untreated effluents in the 5 samplings

tolerates a wide range of pH (4-9). Therefore, in this system, the development of the plants was not affected by the pH of the wastewater from the toilets.

#### Temperature

The temperature's tendency to increase is normal, and an increase of 2°C is estimated between the months of September and December. However, between this period (September to December) of 2019, a historical average of 26°C was recorded. This is an increase of 2.9 °C compared to the 1971-2010 average (Grassi,2020).The temperature values did not show large variations between the entrance ( $P_1$ ) and exit ( $P_2$ ), as can be seen in

Fig. 4. The recorded temperature range remained between 21°C and 30°C. The optimal temperature for the development of bacterial activity is between 25 and 35 °C. During the study the temperatures recorded were close to these values resulting in a good development of bacterial activity. However, according to Espigares (2009) high temperatures present in wastewater have a detrimental effect on the receiving waters and can potentially modify their flora and fauna, giving rise to the undesirable growth of algae, fungi, etc. Additionally, as the solubility of oxygen decreases with temperature, increasing temperatures can also contribute to the depletion of dissolved oxygen.

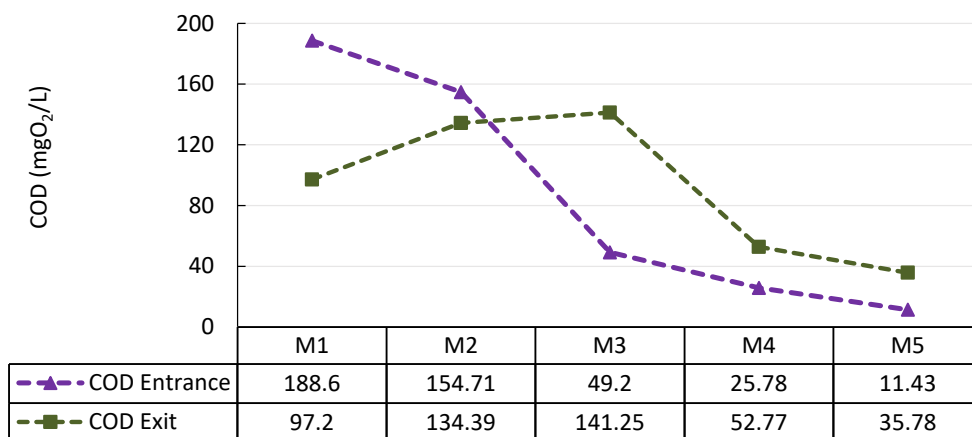


Fig. 5: Biological oxygen demand of the treated and untreated effluents in the 5 sampling

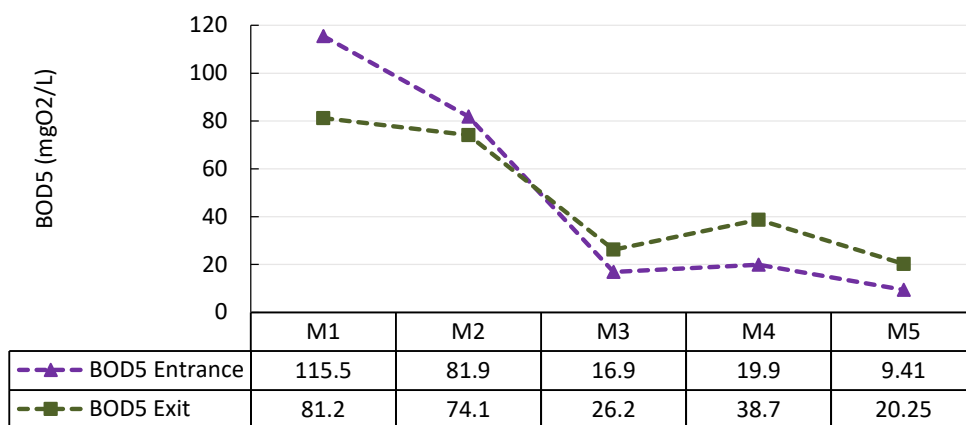


Fig. 6: Biochemical oxygen demand of the treated and untreated effluents in the 5 samplings

**COD**

The COD values obtained during the study can be observed in Fig. 5, which presents a high degree of variability. The wetland’s desired performance was only reflected in samplings 1 and 2, where COD decreased after the residual water had passed through the wetland. Sampling 1 decreased from 188.6 milligram of oxygen per liter (mgO<sub>2</sub>/L) to 97.2 mgO<sub>2</sub>/L and sampling 2 from 154.71 mgO<sub>2</sub>/L to 134.39 mgO<sub>2</sub>/L. However, in samplings 3, 4 and 5, higher COD concentrations were recorded at the exit (P<sub>2</sub>) of the wetland when compared to the entrance (P<sub>1</sub>). As has already been mentioned, this could be due to the residual water from toilets being unable to fully reach the entrance of the wetland (P<sub>1</sub>) due to leaks, resulting in a decreased amount of water at

the exit (P<sub>2</sub>). Therefore, some sediment was collected along with the sample at the time of collection, which could interfere with the analysis. In addition, when considering the high temperatures recorded during this study, the cause of the lower efficiency COD reduction may be the eutrophication that takes place in water exposed to high temperatures and consistent solar rays (Samudio et al., 2022).

**BOD<sub>5</sub>**

The BOD<sub>5</sub> values evidenced in Fig. 6 followed the same behavior as the COD. This is to be expected as they are theoretically related processes. According to successive samplings, the wetland’s efficiency decreased over time. In sampling 1 the BOD<sub>5</sub> value decreased from 115.5 mgO<sub>2</sub>/L to 81.2 mgO<sub>2</sub>/L,

while in sampling 2 it decreased from 81.9 mgO<sub>2</sub>/L to 74.1 mgO<sub>2</sub>/L. In contrast, in subsequent samplings, higher concentrations of BOD<sub>5</sub> were recorded at the exit (P<sub>2</sub>) of the wetland compared to the entrance (P<sub>1</sub>). It was considered that the explanation could be the same as for the decrease in COD reduction efficiency. Notwithstanding the above, Osnaya (2012) mentions that in relatively warm climates, although the BOD removal observed during the first days is very fast, subsequent removal can be very limited due to the influence of residual BOD production from the decomposition of plant residue.

**Phosphorus**

Phosphate is one of the most salient parameters present in domestic wastewater as detergent is widely used in all domestic activities, especially for washing (Harittash and Bahel, 2015). In this sense, the fluctuations registered may be due to the use of soaps and detergents, which increase and decrease the levels at the effluent entrance (P<sub>1</sub>). As can be seen in Fig. 7, in samplings 1, 2, and 4, the recorded phosphorus values behaved in a similar way: phosphorus decreased after the residual water passed through the system. In sampling 5, a value of 5.41 milligram per Liter (mg/L) was recorded at the entrance (P<sub>1</sub>) to the wetland with a notable decrease in concentration at the exit (P<sub>2</sub>) of 2.84 mg/L. Following

the work of Delgadillo et al. (2010), these results were expected. The authors reported that the purification potential of wetlands varies seasonally, and that the capacity to treat various factors, including the removal of phosphorus, phosphates and nitrogen, are affected by high summer temperatures and increased plant activity. In the third sampling, a higher concentration of phosphorus was recorded at the exit (P<sub>2</sub>) of the wetland (5.69 mg/L) when compared to the entrance (P<sub>1</sub>) (4.22 mg/L). This result could be due to several reasons. Firstly, elements such as phosphorus have been reported to be essential for various biochemical and physiological functions in biological systems (Tchounwou et al., 2012). Furthermore, aquatic plants have been reported to accumulate both macro and microelement ions through their roots and other organs in concentrations higher than those detected in the water, regardless of whether or not they are necessary for their lives (Tatar et al., 2019). Osnaya (2012) offers another explanation, arguing that in wetland systems the removal of phosphorus is not very effective due to the limited contact between the residual water and the soil. Adsorption is one of the main mechanisms through which phosphorus is removed, and considering the limited absorption capacities of soil which are subject to saturation, after these sites are occupied no new phosphorus absorption can occur.

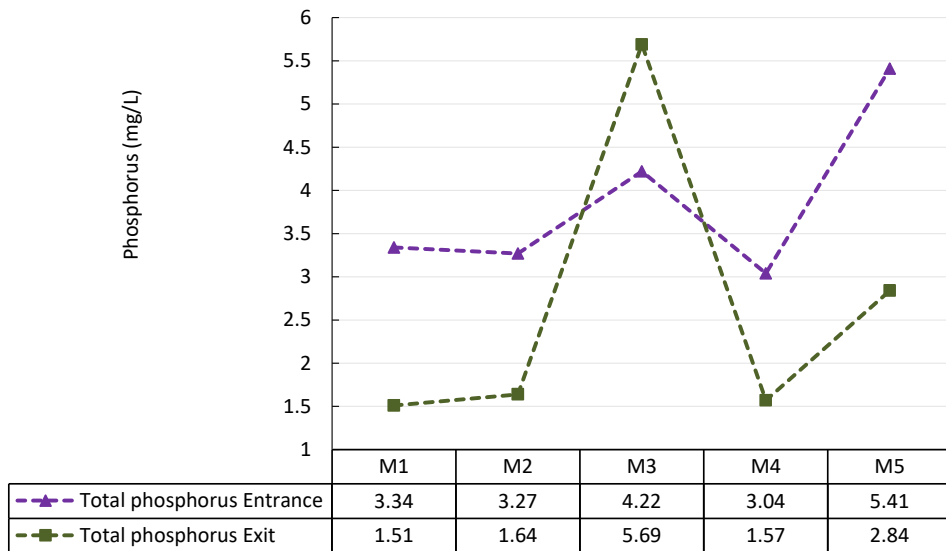


Fig. 7: Phosphorus content of the treated and untreated effluents and the 5 samplings.



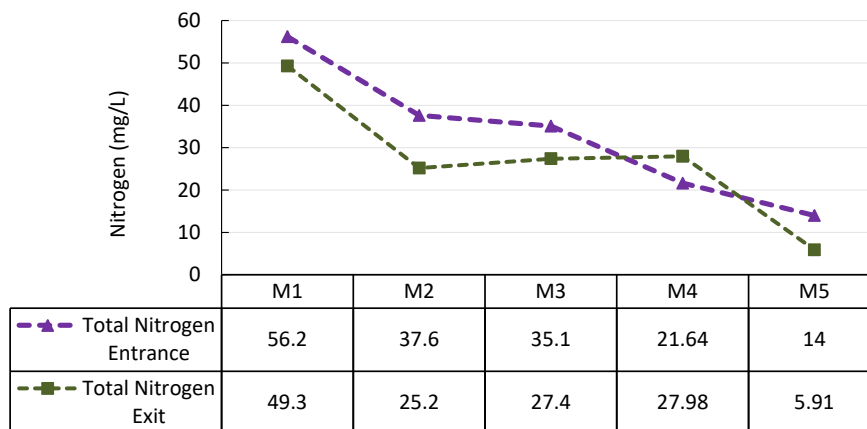


Fig. 8: Nitrogen content of the treated and untreated effluents of the 5 sampling

### Total Nitrogen

The behavior of total nitrogen is detailed in Fig. 8. The highest concentration of nitrogen (56.2 mg/L) was recorded at the entrance ( $P_1$ ) to the wetland in sampling 1. This later decreased to 49.3 mg/L at the exit ( $P_2$ ). In subsequent samplings, the nitrogen concentration values at  $P_1$  decreased consecutively in each sampling. These reached a value of 14 mg/L in the fifth sampling, which then decreased to 5.91 mg/L at  $P_2$ . In sampling 4, a higher concentration of nitrogen was recorded at  $P_2$  (27.98 mg/L) when compared to  $P_1$  (21.64 mg/L). Consideration should be given to the rainfall during the month in which the sampling was carried out. October is one of the rainiest months for the country. Storms are very frequent and some bring strong winds and even hailstorms (DINAC, 2019). These results are similar to those reported by Romero *et al.* (2009), where in some cases the system did not remove nitrogen, but rather nitrification led to the formation of nitrites. This was probably because anaerobic conditions predominated in some areas of the system. In addition the results in rainy seasons show a similar trend: increase of nitrites in water as it passes through the wetlands. Considering the work of Delgadillo *et al.* (2010), the influent nitrogen in the artificial wetland is found as organic or ammonia nitrogen, with low amounts of nitrates. The decomposition and mineralization processes carried out by microorganisms transform this nitrogen into nitrites or nitrates (nitrification), resulting in  $N_2$  (denitrification). The rates of these processes are highly dependent on the oxygen concentration in

the system. Gizinska-Górnaet *al.* (2020) evaluated several species, including Salix (*Salix viminalis* L.) and water cabbage (*Phragmites australis*) in several different seasons. They found that the efficiency of TN removal was 41%, reaching level shigherth an those established for control organisms. It is crucial to remember that typhas plants can reach 3 m in height, and develop vegetative growth quickly. The high requirement of elements such as nitrogen, when compared to other species, is there for advantageous.

### Fecal coliforms

The values for fecal coliforms obtained during the study can be seen in Fig. 9. In all cases a decrease in fecal coliforms was observed after passing through the wetland system. In samplings 1, 2, and 3, consistent entrance values were obtained: 110,000 most probable number per 100 milliliters (MPN/100 mL), decreasing to 750, 11,000 and 24,000 MPN/100mL, respectively. This evidences a significant removal of fecal coliforms. In the subsequent samplings (4 and 5), the entrance concentrations of fecal coliforms decreased consecutively. This could be because the residual water generated by toilets did not reach the wetland in its entirety due to leaks, as already mentioned. Regardless, the fecal coliform concentration in residual water decreased after passing through the wetland in both samplings. Among all the evaluation parameters, the highest removal efficiency was found in the reduction of fecal coliforms. These results support the findings of Peralta *et al.* (2022), who stated that concentrations of

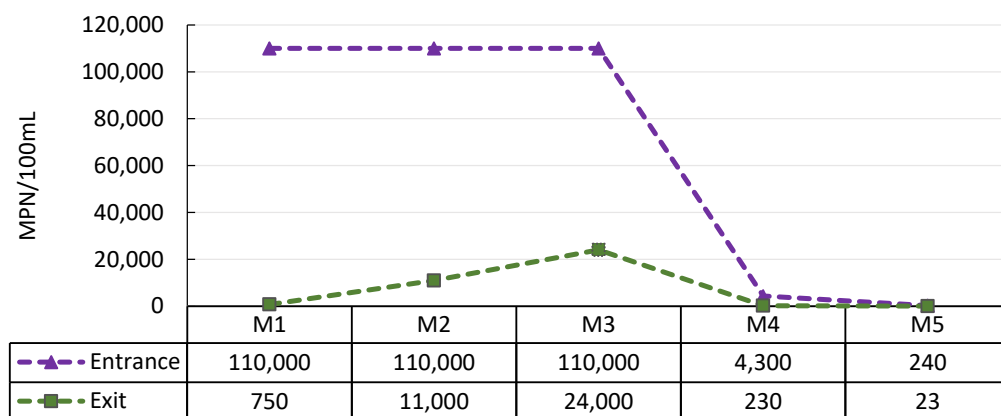


Fig. 9: Content of treated and untreated fecal coliforms in the 5 samplings

fecal coliforms present in wastewater were efficiently reduced in the first sampling. In addition, these results confirm [Samudio et al.'s \(2022\)](#) evaluation of *Cyperus giganteus* plants, and the work of [Osnaya \(2012\)](#), who argue that in general, wetlands are able to reduce fecal coliforms by one or two logarithmic orders.

#### Percentage of removal of studied parameters

This study took place during the period between spring and summer. [Osnaya \(2012\)](#) argues that the purification potential of wetlands varies seasonally, and that increased plant activity in summer results in a greater removal of fecal indicators and bacteria than in winter. Following this, it was observed that the evaluated parameter with the greatest degree of removal was the fecal coliforms. As shown in [Fig. 9](#), the reduction of these ranged between 78% and 99%. This indicates that the use of the flow wetland system subsurface with *T. domingensis* during the summer season is effective in the elimination of fecal contamination. This efficiency confirms the findings of [Delgadillo et al. \(2010\)](#), who suggested that the treatment capacity of wetlands with *T. domingensis* can reach a reduction of 99.9% of coliforms and bacteria. Total phosphorus is the second parameter with the highest removal efficiency in this study. As evidenced by [Fig. 7](#), it was only possible to reach a 50% removal of this nutrient in sampling 1. In the case of sampling 3, a negative value was obtained. This is because an increase in phosphorus was recorded at the entrance compared to the exit. The rate of phosphorus removal in samples 1, 2, 4, and 5 ranged

between 47.5 and 54%. These values were higher than expected because there are many reports that phosphorus removal is very low in wetland systems. For example, [Osnaya \(2012\)](#) states that phosphorus reduction generally varies between 10% to 20%. In general, the values for the remaining parameters were lower than expected, especially because the design of the wetland system studied was based on nitrogen yield calculations. As shown in [Fig. 5](#), positive COD removal values were only obtained in samples 1 (48.8%) and 2 (13%). The value for sample 1 is the only one that demonstrates a desired wetland performance, comparable to the work of [Arroyave \(2010\)](#), who found a 45.8% removal of COD in subsurface wetlands with horizontal flow. Samples 3, 4, and 5 all yielded negative removal values: -187%, -103%, and -213%, respectively. The same occurred for BOD<sub>5</sub>, as shown in [Fig. 6](#). positive values were only given for samples 1 (29.7%) and 2 (9.52%), which are considered extremely low. Subsequent results yielded negative values: for samples 3, 4, and 5, the values were -55%, -94% and -115%, respectively. According to [Leto et al. \(2019\)](#), who evaluated identical systems with two different species *Cyperus alternifolius* L. and *Typha latifolia* L., a higher level of BOD<sub>5</sub> removal (72.4%) was obtained for the reed *T. latifolia* L. The authors mentioned that the chosen plant species capacity for vegetative development in the system plays an important role in overall removal efficiency. [Table 2](#) summarises the efficiency of all the parameters evaluated in this study. The results vary according to different criteria. It is therefore important to consider that the evaluation of the constructed

Table 2: Percentage of removal of physicochemical and microbiological parameters

Sampling	COD	BOD <sub>5</sub>	TP	TN	FC
M1	48,4 %	29,7 %	54,7 %	12,3 %	99,3 %
M2	13 %	9,52 %	49,8 %	32,9 %	90 %
M3	-187 %	-55 %	-34 %	22 %	78,2 %
M4	-103 %	-94 %	48,3 %	-29,3 %	94,7%
M5	-213%	-115%	47,5%	57,8%	90,41%

wetland was carried out between September and November. This is a period of time during which climatic conditions such as temperature, solar radiation, rainfall, and others, vary. It has been found that the absorption rate of plants varies according to climatic conditions, therefore, it is argued that the absorption of nutrients and elements also depends on these environmental conditions. [Sayadi et al. \(2012\)](#) reported high removal efficiencies for all contaminants in their study of wetland treatment systems, but highlighted that efficiencies depend on system properties and the operating conditions of treatment systems. In their study, [Limoli et al. \(2016\)](#) noted that some parameters were subject to pH and wastewater temperature. According to [Singh et al. \(2022\)](#) bibliographical work, the literature indicates that the degree of removal of organic compounds (COD and BOD<sub>5</sub>) and total phosphorus is not likely to be affected by temperature, but the removal total nitrogen appears to decrease at low temperatures.

## CONCLUSION

The treatment of wastewater for subsequent discharge into watercourses in urban and peri-urban environments presents a contemporary challenge. The United Nations' 2021 Report on the development of water resources, "The Value of Water", argues that there is a need for better management of water resources given their current state. In addition, the value of water must be recognized, measured, and expressed, and incorporated into decision making. This is essential for achieving the sustainable and equitable management of water resources, and to achieve the United Nations' Sustainable Development Goals (SDGs) stipulated in the 2030 Agenda for Sustainable Development. It is therefore crucial to look for alternatives for wastewater treatment

that are adapted to the needs of each region or country, considering their economy and culture. In this context, constructed wetland systems may be a viable option when deciding on a suitable method. This study found that a reduction of the values was achieved in most of the parameters studied. In some cases, such as phosphorus, the results were inconsistent. This could be due to climatic variation, such as rainfall, and the concentration of phosphates in wastewater. Article 7 of the SEAM's Resolution Number 222/02 establishes that "Effluents from any polluting source may only be discharged, directly or indirectly, into bodies of water, if they obey the conditions and criteria established in the classification of the receiving body". When evaluating the values of the treated water according to the limits established in Article 7, the treated wastewater is considered to be within the limits for all the parameters studied. The reduction of the following parameters was considered to be highly efficient: TN (57.8%), TP (54.7%) and FC (99.3%). Although the utility of the system should continue to be evaluated, this study offers a significant contribution to the search for more suitable systems for wastewater treatment in public spaces.

## AUTHOR CONTRIBUTIONS

A. Vázquez carried out the data collection, experimental design, survey campaigns, effluent analysis, and prepared the text of the manuscript. A. Samudio-Oggero carried out the experimental design, organized the literature review methodology, interpreted the data and results, and edited the manuscript. H. Nakayama organized the methodology, analyzed and interpreted the data and results. I. Cantero organized the methodology and edited the manuscript.

## ACKNOWLEDGMENTS

Acknowledgments to the Company Tecnambiental for allowing the evaluation of the wetland built for the recovery of contaminated water, and to the Multidisciplinary Center for Technological Research (CEMIT) for the parameters and laboratory equipment used.

## CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely witnessed by the authors.

## OPEN ACCESS

©2023 The author(s). This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third-party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit: <http://creativecommons.org/licenses/by/4.0/>

## PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

## ABBREVIATIONS

%	Percent
°	Degree
'	Minute
"	Second
°C	Degrees Celsius
=	Same

-	Subtract
x	multiply
Abs.	Absorbance
BOD	Biochemical oxygen demand
CE	Entrance concentration
CEMIT	Multidisciplinary Center for Technological Research
cm	Centimeter
COD	Chemical oxygen demand
CS	Exit concentration
d	Days
EDTA	Ethylene diamine tetraacetic acid
Eq	Equation
FC	Fecal coliforms
HDPE	High density polyethylene
h	Hour
Km	kilometers
km <sup>2</sup>	Square kilometers
m	Meter
m <sup>2</sup>	Square meter
mgO <sub>2</sub> /L	Milligram of Oxygen per liter
mg/L	Milligram per Liter
mm	Millimeter
mL	Milliliter
MPN/100mL	Most probable number per 100 milliliters
MxP <sub>1</sub>	Sample of point 1
MxP <sub>2</sub>	Sample of point 2
N <sub>2</sub>	Nitrogen
nm	nanometer
pH	Hydrogen potential
P <sub>1</sub>	Point 1
P <sub>2</sub>	Point 2
R	Removal
Res.	Resolution
S	South
S.A.	Anonymous society
SEAM	Environment Secretariat (Paraguay)
T	Temperature
TN	Total nitrogeno
TP	Total Phosphorus
W	West

## REFERENCES

- Arias, S.; Bentancur, F.; Gomez, G.; Salazar, J.; Hernandez, M., (2010). Fitorremediación con humedales artificiales para el tratamiento de aguas residuales porcinas. *Informador Técnico*, 74:12–22 (11 pages).
- Arroyave, A., (2010). Efectos del tipo de vegetación y de las variaciones de profundidad en la eficiencia de patógenos en humedales construidos de flujo subsuperficial. [Tesis de Grado]: Universidad Tecnológica de Pereira. (127 pages).
- Delgadillo, A.; González, C.; Prieto, F.; Villagómez, J.; Acevedo, O., (2001). Fitorremediación: una alternativa para eliminar la contaminación. *Trop. Subtrop. Agroecosystems*. 14: 597-612 (16 pages).
- Delgadillo, O.; Camacho, A.; Andrade, M., (2010). Depuración de aguas residuales por medio de humedales artificiales. Durán N, editor. Cochabamba(115 pages).
- Englande, A.J.; Krenkel, P.; Shamas, J., (2015). Wastewater Treatment & Water Reclamation. *Earth Syst. Environ.Sci.*,1-32(32pages).
- Espigares, M.; Pérez, J., (2009). Aspectos sanitarios del estudio de las aguas residuales. *Granada. Hig. Sanid. Ambient.*, 2: 19-25(7pages).
- Grassi, B., (2020). State of the climate Paraguay 2019 “Climate change, scientific evidence and impacts” Technical Report. 1-33 (33 pages).
- Gratao, P.L.; Prasad, M.N.; Cardozo, P.F.; Lea, P.J.; Azevedo, R.A., (2005). Phytoremediation: green technology for the cleanup of toxic metals in the environment. *Braz. J. Plant Physiol.*, 17(1):53-64 (12 pages).
- Gizinska- Górna, M.; Józwiakowski, K.; Marzec, M., (2020). Reliability and Efficiency of Pollutant Removal in Four-Stage Constructed Wetland of SSVF-SSHF-SSHF-SSVF Type. *Water*. 12: 3153 (25 pages).
- Haritash, A. K.; Sharma, A.; Bahel, A.,(2015). The Potential of *Canna lily* for Wastewater Treatment Under Indian Condition. *Int. J. Phytoremediation* 17(10): 999-1004 (6 pages).
- Hazra, M.; Avishek, K.; Pathak, G., (2015). Phytoremediation Potential of *Typhalatifolia*, *Eichorniacrassipes* and *Monochoriahastata* found in Contaminated Water Bodies across Ranchi City (India). *Int. J. Phytoremed.*, 12(9): 835-840 (6 pages).
- Leto, C.; Tuttolomondo, T.; La Bella, S.; Leone, R.; Licata, A., (2013). Effects of plant species in a horizontal subsurface flow constructed wetland phytoremediation of treated urban wastewater with *Cyperus alternifolius* L. and *Typha latifolia* L. in the West of Sicily (Italy). *Ecol. Eng.*, 6(A) 282-291 (10 pages).
- Limoli, A.; Langone, M.; Andreottola, G., (2016). Ammonia removal from raw manure digestate by means of a turbulent mixing stripping process. *J. Environ. Manage.*, 176: 1-10 (10 pages).
- López Moreira, M.; Hinegk, L.; Salvadore, A.; Zolezzi, G.; Hölker, F.; Monte Domecq S.; Bocci, M.; Carrer, S.; De Nat, L.; Escribá, J.; Escribá, C.; Benítez, G.A.; Ávalos, C.R.; Peralta, I.; Insaurralde, M.; Mereles, F.; Sekatcheff, J.M.; Wehrle, A.; Facetti-Masulli, J.F.; Facetti, J.F.; Toffolon, M., (2018). Eutrophication, Research and Management History of the Shallow Ypacaraí Lake [Paraguay]. *Sustainability*. 10: 2426 (32 pages).
- Mereles, F.; Degen, R.; Lopez de Kochalca, N., (1992). Humedales del Paraguay: Breve reseña de su vegetación. *Amazoniana*. 12(2): 305-316 (9 pages).
- Moore, M.T.; Locke, M.A.; Kröger, R., (2016). Using aquatic vegetation to remediate nitrate, ammonium, and soluble reactive phosphorus in simulated runoff. *Chemosphere*.160:149–154 (6 pages).
- Mufarrege, M., (2012). Tolerancia y eficiencia de *Typhadomingensis* Pers. en la retención de metales y nutrientes de efluentes industriales. Universidad Nacional del Litoral.(177 pages).
- Mukhtar, A.A.; Abdullahi, I.L., (2017). Heavy metals phytoremediation using *Typhadomingensis* flourishing in an industrial effluent drainage in kano, Nigeria. *Bayero J. Pure Appl. Sci.*, 10(1):277-280 (4 pages).
- OEFA,(2014). Regulation of the registry of good environmental practices of the agency for environmental evaluation and control resolution No. 034 (80 pages).
- Peralta, I.; Cardozo, C.; Nakayama, H.; Ávalos, C.; Benítez, G.; Elkhallij, R.; Ayala, J.; Arenas, R.; Samudio-Oggero, A., (2022). Evaluation of a wetland constructed with *Typhadomingensis Pers.*, for the recovery of contaminated water from hospital effluents. *J. Ecol. Eng.*, 23(9): 136-145 (10 pages).
- Piédrola, G., (2008). Medicina preventiva y salud comunitaria, 11th ed. Elsevier, Editor (2607 pages).
- Rahman, D.A.; Priambodo, E.W.; Caturputranto, FebriEkoWahyudianto, F.E., (2022). Kinetics of pollutants removal in wetlands influenced by retention time and number of plants using *Cyperusalternifolius*. *J. Ecol. Eng.*, 23(12): 37-43 (7 pages).
- Romero, M.; Colín, A.; Sánchez, E.; Ortíz, M., (2009). Tratamiento de aguas residuales por un sistema piloto de humedales artificiales: evaluación de la remoción de la carga orgánica. *Rev.Int.Contam. Ambient.* 25(3):157-167(11pages).
- Saeed, T.; Paul, B.; Afrin R.; Al-Muyeedb, A.; Sun G., (2016). Floating constructed wetland for the treatment of polluted river water: A pilot scale study on seasonal variation and shock load. *Chem. Eng. J.*, 287: 62-73 (12 pages).
- Samudio-Oggero, A.; Villalba, N.; Lucas, V.; Nakayama, H. D.; Benitez, J. V.; Cantero-García, I.; Ayala, J. F., (2022). Evaluation of a wetland species: *Cyperusgiganteus*Vahl (Poales – Cyperaceae), propagation and efficiency in effluents bioremediation. *Egypt. J. Aquat. Biol. Fish.*, 26(3): 787 – 799 (13 pages).
- Sayadi, M.H.; Kargar, R.; Doosti, M.R.; Salehi, H., (2012). Hybrid constructed wetlands for wastewater treatment: a worldwide review. *Proc. int. Acad. Ecol. Environ. Sci.*, 2(4): 204-222 (20 pages).
- SENASA and JICA, (2001). Water Improvement Plan for Lake Ypacaraí and Its Basin. National Environmental Sanitation Service of Paraguay. Japan International Cooperation Agency. Asunción, Paraguay. (13 pages).
- Singh, A.; Katoch, S.S.; Bajpai, M.; Rawat, A., (2022). Constructed Wetlands: A sustainable way of Treating Wastewater in Cold Climate - A review. *Pollution*. 8(2): 373-396 (24 pages).
- Swarnakar, A.K.; Bajpa, S.; Ahmad I., (2022). Various Types of Constructed Wetland for Wastewater Treatment- A Review. *IOP Conf. Ser.: Earth Environ. Sci. IOP Conference Series*. 1032 (2022) 012026 (14 pages).
- Tatar, Ş.; Öbek, E.; Arslan, Topal, E.I.; Topal, M., (2019). Uptake of Some Elements with Aquatic Plants Exposed to the Effluent of Wastewater Treatment Plant. *Pollution*.5(2): 377-386 (7 pages).
- Turker, O.; Bocuk H.; Yakar, A., (2013). The phytoremediation ability of a polyculture constructed wetland to treat boron from mine effluent. *J. Hazard. Mater.*, 253: 132-141 (10 pages).
- Zhang, D.Q.; Jinadasa, K.; Gersberg, R. M.; Liu, Y.; Ng, W. J.; Tan, S.K., (2014). Application of constructed wetlands for wastewater treatment in developing countries: A review of recent developments (2000-2013). *J. Environ. Manage.*, 141: 116-131 (16 pages).

#### AUTHOR (S) BIOSKETCHES

**Vazquez, A.M.**, B.Sc., Instructor, Faculty of Chemical Sciences, National University of Asunción, Asunción, Paraguay.

- Email: [ale-vqz@hotmail.com](mailto:ale-vqz@hotmail.com)
- ORCID: [0000-0002-1034-4099](https://orcid.org/0000-0002-1034-4099)
- Web of Science ResearcherID: **NA**
- Scopus Author ID: **NA**
- Homepage: <https://qui.una.py/>

**Samudio-Oggero, A.**, Ph.D. Candidate, Department of Biotechnology, National University of Asunción, Asunción, Paraguay.

- Email: [asamudio@rec.una.py](mailto:asamudio@rec.una.py)
- ORCID: [0000-0003-1374-7974](https://orcid.org/0000-0003-1374-7974)
- Web of Science ResearcherID: **NA**
- Scopus Author ID: 57792874200
- Homepage: <https://cemit.una.py/asamudio/>

**Nakayama, H.D.**, Ph.D. Candidate, Department of Biotechnology, National University of Asunción, Asunción, Paraguay.

- Email: [hnakayama@rec.una.py](mailto:hnakayama@rec.una.py)
- ORCID: [0000-0002-7445-502X](https://orcid.org/0000-0002-7445-502X)
- Web of Science ResearcherID: **NA**
- Scopus Author ID: **NA**
- Homepage: <https://cemit.una.py/hnakayama/>

**Cantero-García, I.**, M.Sc. Student, Department of Biotechnology, National University of Asunción, Asunción, Paraguay.

- Email: [isauracangar@gmail.com](mailto:isauracangar@gmail.com)
- ORCID: [0000-0002-7445-502X](https://orcid.org/0000-0002-7445-502X)
- Web of Science ResearcherID: **NA**
- Scopus Author ID: **NA**
- Homepage: <https://cemit.una.py/>

#### HOW TO CITE THIS ARTICLE

Vazquez, A.M.; Samudio-Oggero, A.; Nakayama, H.D.; Cantero, I., (2023). Sub-surface flow constructed wetland for the treatment of sewage generated in a municipal park. *Global J. Environ. Sci. Manage.*, 9(3): 545-558.

DOI: [10.22035/gjesm.2023.03.12](https://doi.org/10.22035/gjesm.2023.03.12)

URL: [https://www.gjesm.net/article\\_700915.html](https://www.gjesm.net/article_700915.html)

