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CASE STUDY

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

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ABSTRACT

BACKGROUND AND OBJECTIVES: The Municipal Park of Areguais 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 vacationersfor its natural spaces. Despite being one of the most representative ecological reserves in the country, annual waterquality reports indicate the presence of a high content of pollutants; mainly nitrogen, phosphorus, andfecalcolifoirs, among others. These conditions promote the proliferation of cyanobacteria which consume the available oxygenand compromise the reserve's flora and fauna. Following several laboratory tests, the present work has the objective of evaluating the impact of thepark's recently constructed wetland'son the treatment of residual waters.There are several parameters evaluated in thisstudy of final wastewater discharge disposal treatmentthrough a constructed wetland of horizontal flow with Typhadomingensis. 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 aviableoption 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 222/02of the Environment Secretary for Class 2 waters, for water to be discharged into the receiving body. The results obtainedwere: 88.9 percent fecal coliform removal; 84.9 percent total nitrogen; 73.3 percentchemical 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 flowwetlands. This study confirms that the treated wastewater is within the establishedlimitsfor 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.

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INTRODUCTION

Biodiversity and the exhuberance of nature are good tourism products. In Paraguay, thevalorization of springs, streams and rivers is achievedthrough rural tourism. The protection of these, along with forests, is therefore prioritized in order fortourists 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(km²). 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 endangereddue to significant discharges of contaminated water without prior treatment.Residual wateris the liquid that was used by a population or industrythatcontains 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; Rahnman *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). *Typha*s 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 stillnecessary 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. here has been very limited research on natural and sustainable wastewater treatment methods in Paraguay. Thus, the present study was conducted toevaluate the treatment of wastewater through constructed wetlands in order to find ways to produce treated wastewaterin 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 wetlandfor 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).

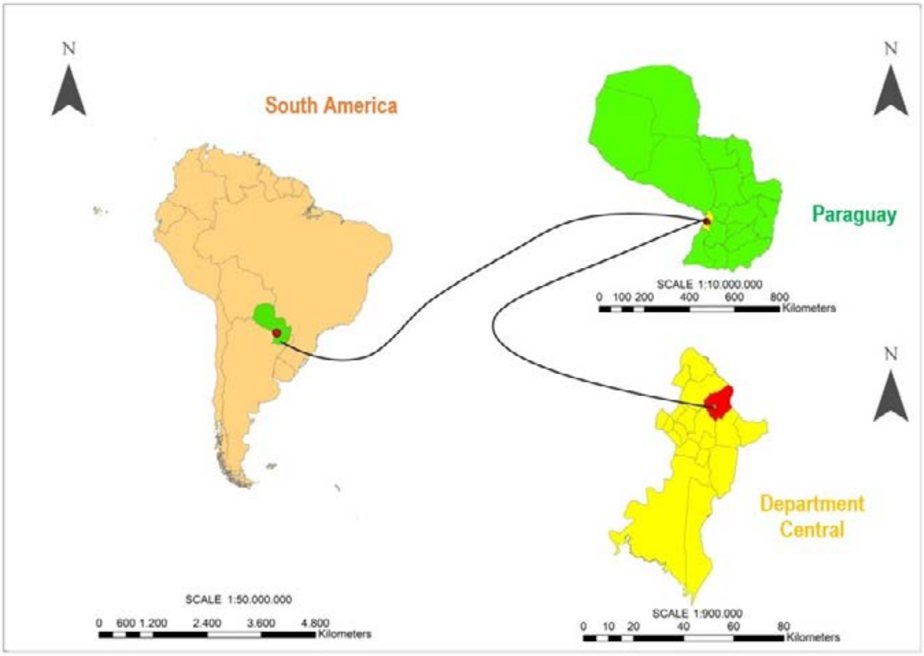


Fig. 1: Geographic location of the study area inYpacaraí Lake, Municipal Park of Aregua, Central Department, Paraguay

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 effluentsdue 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 (MxP2), 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 determinationsof parameters such as

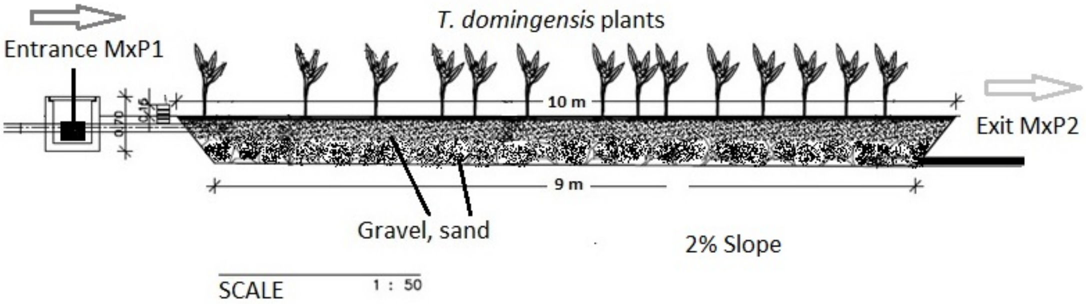


Fig. 2: Cross section of the constructed wetland's design

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 mg O_2/L = (Absorvance (Abs.) of the sample – Abs. of the blank) × factor × dilution (Peralta *et al.*, 2022).

d) Biochemical oxygen demand (BOD): BOD after five days (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: mgO_2/L = (initial dissolved oxygen – final dissolved oxygen) x 300 x 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 alid 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 nitroferricyanide) 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: mg/L N = (Abs. of the sample – Abs. of the blank) × factor × dilution (Peraltaet *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 tryp tose 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_1) and exit (P_2) points of the effluent from each different sampling, with the first collected on 09/12/2019 and the last on 11/04/2019.

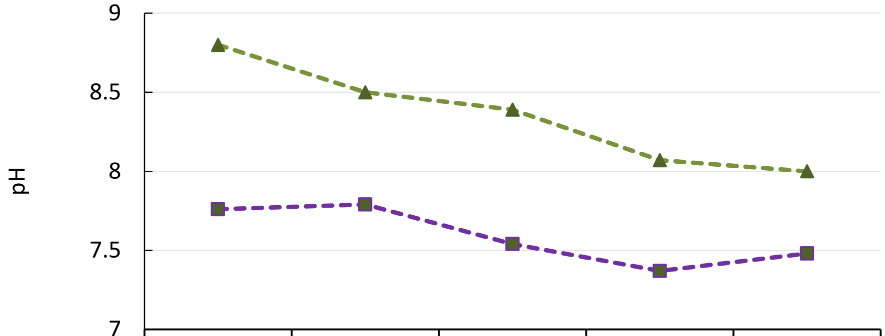
pH

In Fig. 3 the pH values at the entrance (P_1) andexit (P_2)of the wetland are shown. In each instance a decrease in pH (ranging between 8.8 and 7.3) was observedin 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 (*Cyperusgiganteus)* also indicate a pH of around 6 and 5.5 between the control and treated effluent. On the other hand, Delgadillo *et al*. (2010) comment that *T. domingensis*

Table 1: Values obtained in the physicochemical and microbiological analyses

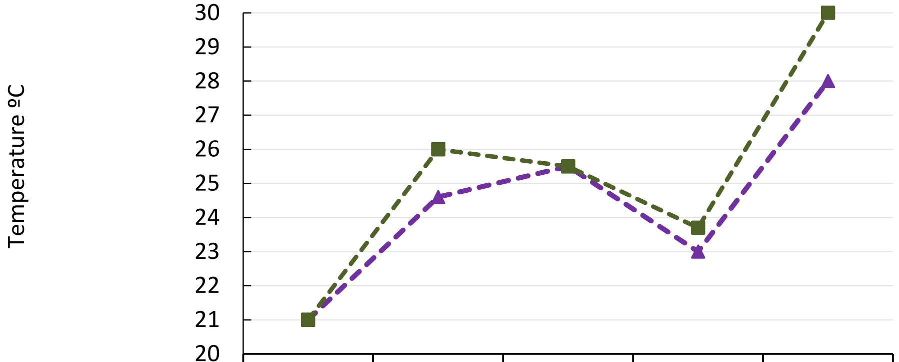
Parameters	Date: 09/12/2019 Hour: 10:26		Date: 09/23/2019 Hour: 10:29		Date: 10/07/2019 Hour: 10:30		Date: 10/21/2019 Hour: 10:40		Date: 11/04/2019 Hour: 10:00	
	1st SAMPLING		2nd SAMPLING		3rd SAMPLING		4th SAMPLING		5th SAMPLING	
	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2	P_1	P_2
pH	8,8	7,76	8,5	7,79	8,39	7,54	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_2/L)	188,6	97,2	154,71	134,39	49,2	141,25	25,78	52,77	11,43	35,78
BOD_5 (mgO_2/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



	M1	M2	M3	M4	M5
▲ pH Entrance	8.8	8.5	8.39	8.07	8
■ pH Exit	7.76	7.79	7.54	7.37	7.48

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



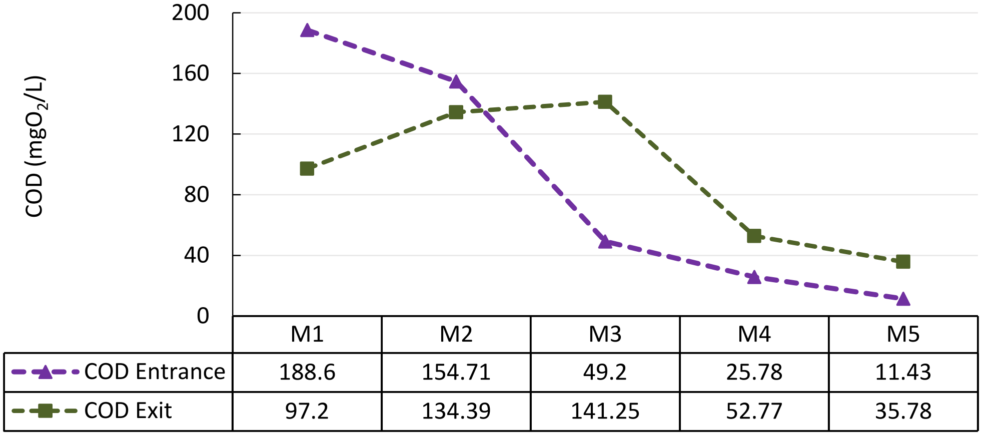
	M1	M2	M3	M4	M5
▲ Temperature Entrance	21	24.6	25.5	23	28
■ Temperature Exit	21	26	25.5	23.7	30

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.

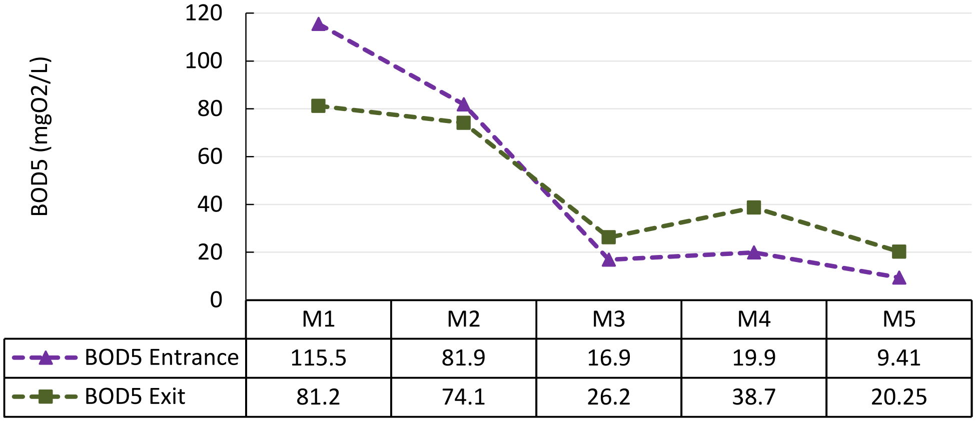
Temperature

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) andexit (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 thereceiving 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 alsocontribute to the depletion of dissolved oxygen.



	M1	M2	M3	M4	M5
COD Entrance	188.6	154.71	49.2	25.78	11.43
COD Exit	97.2	134.39	141.25	52.77	35.78

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



	M1	M2	M3	M4	M5
BOD5 Entrance	115.5	81.9	16.9	19.9	9.41
BOD5 Exit	81.2	74.1	26.2	38.7	20.25

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

COD

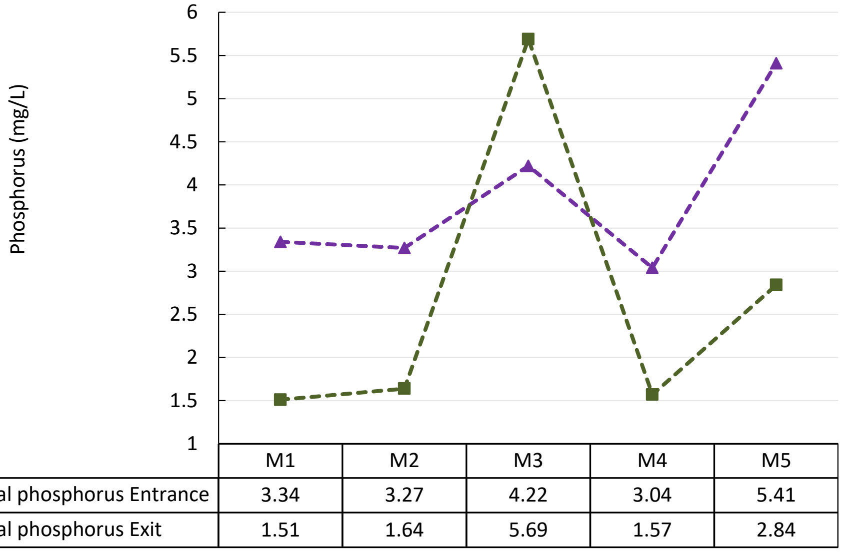
The COD values obtained during the study can be observed in Fig. 5, which presents a high degree of variability. The wetland's desired performance was onlyreflected in samplings 1 and 2, where COD decreasedafter the residual water had passed through the wetland. Sampling1 decreased from 188.6 milligram of oxygen per liter (mgO$_2$/L) to 97.2 mgO$_2$/L and sampling 2 from 154.71 mgO$_2$/L to 134.39 mgO$_2$/L. However, in samplings 3, 4 and 5, higher COD concentrations were recorded at the exit (P$_2$) of the wetland when compared to the entrance (P$_1$). As has already been mentioned, this could be due to the residual water from toilets beingunable to fully reach the entrance of the wetland (P$_1$) due to leaks, resulting in a decreasedamount of water at the exit (P$_2$). The refore, some sediment was collected along with the sample at the time of collection, which could interfere withthe analysis. In addition, whenconsidering the hightemperatures recorded during this study, the cause of the lower efficiency COD reduction may be the eutrophication that takes placein water exposed tohigh temperatures and consistent solar rays (Samudio *et al*., 2022).

BOD$_5$

The BOD$_5$ values evidenced in Fig. 6 followed the same behavior as the COD. This is to be expected as theyare theoretically related processes. According to successive samplings, the wetland's efficiency decreased over time. In sampling 1 the BOD$_5$ valuedecrease from 115.5 mgO$_2$/L to 81.2 mgO$_2$/L, whilein sampling 2 it decreased from 81.9 mgO_2/L to 74.1 $mgO_2/$ L. In contrast, in subsequent samplings, higher concentrations of BOD_5 were recorded at the exit (P_2)of the wetland compared to the entrance (P_1). It was considered that the explanation could be the same as for the decrease in COD reduction efficiency. Not withs tanding 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 limiteddue 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_1). 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_1) to the wetland with a notable decrease in concentration at the exit (P_2) 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_2) of the wetland (5.69 mg/L) whencompared to the entrance (P_1) (4.22 mg/L). This result could be due to several reasons. Firstly,elementssuch 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 bothmacro 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. Asabsorptionis 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.



	M1	M2	M3	M4	M5
Total phosphorus Entrance	3.34	3.27	4.22	3.04	5.41
Total phosphorus Exit	1.51	1.64	5.69	1.57	2.84

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

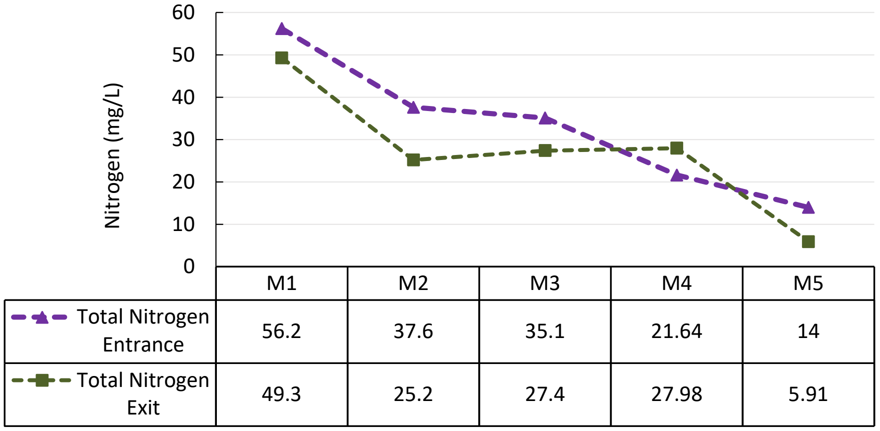


Fig. 8: Nitrogen content of the treated and untreated effluents of the 5 sampling

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-Górna*et al*. (2020) evaluated several species, including Salix (*Salix viminalis* L.) and water cabbage (*Phragmites australis*) in several different seasons. They found thatthe 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 developvegetativegrowthquickly. Thehigh 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 numberper 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 wetlandin 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

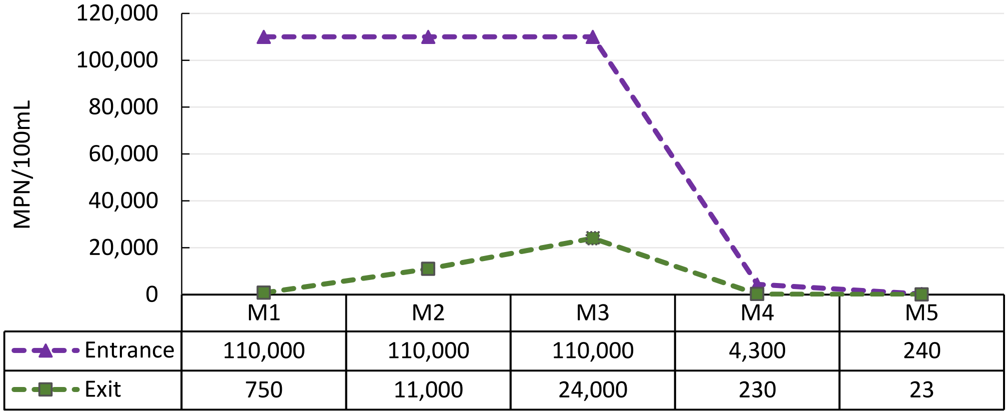


Fig. 9: Content of treated and untreated fecal coliforms in the 5 samplings

fecal coliforms present in wastewater were efficiently reduced in the first sampling. In addition, these results confirm Samudioet *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 thepurification 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 valuewas 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 expectedbecause 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 obtainedin 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 occured for BOD$_5$, 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$_5$ 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 inoverall 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_5	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 enviromental 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 thatsome 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_5) 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 areduction of the valueswas achieved in most of the parameters studied. In some cases, such asphosphorus, 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 accordingto the limits established in Article 7, the treated wastewater is considered to be within the limits for all the parametersstudied. 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.

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CONFLICT OF INTEREST

Theauthors declare no potentialconflict of interestregardingthepublication of thiswork. In addition, theethicalissuesincludingplagiarism, informedconsent, misconduct, data fabrication and, orfalsification, doublepublication and, orsubmission, and redundancyhavebeencompletelywitnessedbytheauthors.

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PUBLISHER'S NOTE

ABBREVIATIONS

%	Percent
°	Degree
ʻ	Minute
ʺ	Second
°C	Degrees Celsius
=	Same
-	Subtract
x	multiply
Abs.	Absorvance
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^2	Square kilometers
m	Meter
m^2	Square meter
mgO_2/L	Milligram of Oxygen per liter
mg/L	Milligram per Liter
mm	Millimeter
mL	Milliliter
MPN/100mL	Most probable number per 100 milliliters
MxP_1	Sample of point 1
MxP_2	Sample of point 2
N_2	Nitrogen
nm	nanometer
pH	Hydrogenpotential
P_1	Point 1
P_2	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

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