# Stockholm Junior Water Prize Ecuador 2020

# *A Hybrid Artificial Wetland System, for the Treatment of Domestic Wastewater in Rural Areas*

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***Abstract***. *Wastewater generation is a current environmental and public health problem. In this project, the influence of the species Canna indica and Racinaea fraseri on the removal of contaminants present in domestic wastewater was studied, through artificial wetlands, using concrete filtering media. The methodology was based on an experimental model of a hybrid continuous system wetland, fed with wastewater with 2 individuals of Canna indica and two of Racinaea fraseri. The system was monitored for five weeks using physical-chemical parameters such as: pH, chemical oxygen demand, phosphates, ammoniacal nitrogen, nitrates, and total suspended solids. Simultaneously, the apical growth of the plant was monitored. The results demonstrated that plants capture nutrients from the water, therefore contributing to the elimination of contaminants (especially nutrients) in the wetland.*

## 1. Introduction

Wastewater generation is a current environmental and public health problem. According to data from AQUASTAT (FAO, 2016) the world's freshwater withdrawals correspond to 3,928 km³/year, of which 56% (2,212 km3 per year) are discharged into rivers as municipal, industrial and agricultural drainage wastewater (WWAP, 2017). Some international organizations point out that 80% of the wastewater produced worldwide does not receive an adequate treatment (UNESCO, 2014). According to the United Nations, 6 out of 10 people lack access to sanitation facilities, at least 892 million people continue with the unhealthy practice of open defecation and every day, and around 1,000 children die from diarrheal diseases associated with lack of hygiene. In Latin America the picture is similar, since it is estimated that 70% of wastewater is returned to rivers without prior treatment (Yee-Batista, 2013). In Ecuador, the volume of water consumed is close to 414,000,173 $m^3$/year and the total volume of wastewater that receives treatment corresponds to 61,928,393 $m^3$/year corresponding to 15%. It is worth mentioning that 75% of the treated water in Ecuador comes from the urban area (INEC, 2013).

In the province of Imbabura, several freshwater bodies have been affected by wastewater discharges. According to an article of Diario El Norte (2019), it was found that in San Pablo and San Rafael, domestic wastewater discharges go directly to streams and ditches that end in Lake San Pablo. This lake is a cultural symbol, especially for the indigenous people, who historically have carried out rituals and ceremonies on its banks (Navarrete, 2013). Likewise, it is reported that the Peguche waterfall is contaminated. In this place, the kwichuas people of the area perform the ritual bath of the Inti Raymi; however, due to the quality of the water it is not suitable for direct contact (El Norte, 2019). On the other hand, Yahuarcocha lagoon is facing an environmental crisis materialized in a greenish, thick and bad-smelling color of the waters due to wastewater discharges from hotel and tourist sites, and the runoff that allows the entry of nutrients into the lagoon (El Norte, 2020). Therefore, the search for suitable and appropriable alternatives for the rural area is a priority. Rural wastewater generally has a status of domestic wastewater because it mainly comes from human domestic and/or subsistence livestock activities (Espigares and Pérez, 2015).

Artificial wetlands have proven to be a good alternative to remove organic matter and dangerous substances present in wastewater. These natural systems act as ecological reactors that retain suspended solids and favor biological and physicochemical processes that produce the elimination of nitrogen and phosphorus (López, 2016)

Consequently, the treatment of domestic wastewater emerges as the viable alternative to avoid the problems described above and even reuse these treated waters in agriculture, especially in rural areas (WWAP, 2017).

## 2. Theoretical framework

### 2.1 Domestic wastewater

Average per capita production of domestic wastewater is between 90 to 110 L/inhab-d (Niño and Martinez, 2013). According to moderate habits in rural areas, these values are lower, reaching average ranges between 50 to 90 L/inhab-d (Golda et al., 2014). The physicochemical characteristics of domestic wastewater varies depending on the habits of the generating population and its socio-economic level. In general, this type of liquid waste is characterized by the presence of wastewater from toilets, bathrooms, and gray water belonging to washing and food preparation activities (Golda A et al., 2014). Table 1 shows the primary physico-chemical characteristics of wastewater.

**Table 1.** Characterization of domestic wastewater

| Parameter | High (mg/L) | Medium (mg/L) | Low (mg/L) |
|---|---|---|---|
| COD | 1000 | 500 | 300 |
| BOD | 560 | 350 | 230 |
| Total Nitrogen | 100 | 60 | 30 |
| Ammonia-N | 75 | 45 | 20 |
| P Total | 25 | 15 | 6 |
| Ortho-P | 15 | 10 | 4 |
| Total suspended solids | 1200 | 700 | 350 |
| Total Coliforms UFC/100 mL | $10^6$-$10^7$ | $10^7$-$10^8$ | $10^8$-$10^9$ |
| pH | 5 | 7 | 8 |
| Turbidity, NTU | 150 | 80 | 20 |

**Source:** Pacheco, 2015

### 2.1.1 Environmental impacts of the generation of domestic wastewater

The direct discharge of domestic wastewater has caused environmental concern. The physicochemical characteristics of these waters make it possible for this type of liquid waste to potentially affect 245,000 km2 of marine ecosystems, with a 20% increase estimated in 2050 due to the eutrophication of lakes with harmful algal blooms (UNESCO, 2015). The organic matter present would also increase bacterial agglomeration in rivers, increasing the oxygen demand and causing anoxia (Martin, 1989). Nutrients (nitrogen and phosphorous) are responsible for increasing the population of primary producers in bodies of surface water, causing an imbalance in the aquatic food chain (UNESCO, 2014).

In agriculture, both the organic matter and the salts contained in domestic wastewater, when used during irrigation, change the physicochemical properties of the soil and waterproof it in the long term (Núñez, 2015). The soil is affected by the long-term disposal of water with salt and sodium content that cause salinization, destroying and reducing its productivity (Núñez, 2015). Air pollution occurs during wastewater storage with the generation of methane that corresponds to 7% of global methane emissions of anthropogenic origin, as well as odors due to the presence of volatile compounds such as $NH_3$ (Global Methane Initiative, 2010). Public health problems derive from the presence of pathogenic microorganisms and compounds with toxic potential, due to the consumption or use of wastewater for food irrigation, a practice that is common in various sectors of the country (Winward et al., 2008; FAO, 2016).

## 2.2 Domestic Wastewater Treatmentwate

For the treatment of domestic wastewater, the activated sludge is the most used conventional technology for the removal of organic matter and partially nutrients (Silva and Madera, 2008). However, this type of technology can present disadvantages in these areas. Table 2 shows the comparison of two types of treatment plant in rural areas of the Quito Metropolitan District. Hence, in rural areas its use is not economically feasible. The use of passive treatments such as artificial wetlands could be an option.

**Table 2.** Environmental and economic indicators of different wastewater treatment plants

| Place | Ingapi (Pacto) | Nono |
|---|---|---|
| **Wastewater treatment plant** | **Artificial wetland + disinfection** | **Activated sludge** |
| Occupied area | 3.89 m2/inhab | 0.45 m2/inhab |
| Energy | 0.1 kW-h/m3 | 70.46 kW-h/m3 |
| Sludge generated | 0.05 m3/inhab.year | 0.66 m3/inhab.year |
| Chemical products | 0.37 kg/inhab.year | 0.36 kg/inhab.year |
| Effluent quality with respect to TULSMA | 80% good | 92% good |
| Investment | 119.46 USD/inhab | 139.81 USD/inhab |
| Operation and maintenance | 26.83 USD/inhab.year | 81.78 USD/inhab.year |

**Source:** García, 2018

Artificial wetlands emerge as an attractive alternative for rural areas, due to the use of minimal external energy, lower investment and maintenance costs, as well as their environmental friendliness due to the lack of or low generation of sludge. (García and Corzo, 2008; Araya, 2012).

Most of the investment cost for the construction of wetlands corresponds to the support material, including transportation. Table 3 indicates the percentages of the cost corresponding to different components in the construction of wetlands.

**Table 3.** Construction component costs of an artificial wetland

| Ítem | Cost (%) |
|---|---|
| Excavation | 7-27 |
| Gravel | 27-53 |
| Cover | 13-33 |
| Plants | 2-12 |
| Plumbing | 6-12 |

**Source:** Guachamin, 2018

## 2.2.1 Artificial wetlands

Wetlands help improve water quality and they are also reservoirs of biodiversity and can accumulate carbon and other greenhouse gases (Araya, 2012)

Artificial wetlands are passive systems, based on the treatment of water via biogeochemical processes that simulate the natural processes of purifying water (Marín and Correa, 2010). Artificial wetlands according to their typology, are divided into superficial and sub-superficial systems (horizontal and vertical) (Delgadillo et al., 2010). Both horizontal subsurface-flow artificial wetlands (HFAW) and vertical subsurface-flow artificial wetlands (VFAW) are efficient at removing organic matter, but differ in terms of nitrogen removal (Vymazal, 2005). The organic matter removal efficiencies (COD) for HFAW and VFAW are 75% and 90%, respectively (Vymazal, 2010).

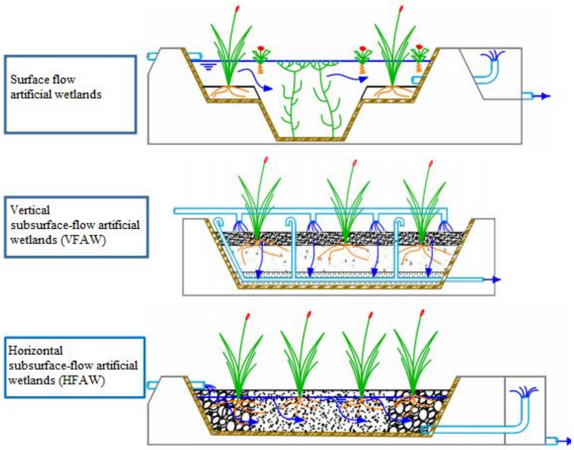


**Figure 1.** Types of artificial wetlands.

**Source:** Vera, 2012

The processes involved in the treatment with sub-surface flow wetlands are based on two components: a biotic component consisting of aquatic plants and rhizome bacteria, and an abiotic component given by the filter material (Yocum, 2005).

The different parts of the plants provide benefits within the wetland; the aerial parts provide an aesthetic function and store nutrients. Additionally, they generate a link with wildlife by providing habitats (Morales et al.al,, 2013). Meanwhile, the roots and rhizomes of the plant have a filtering effect, reducing the speed of the current, increasing the rate of sedimentation, and reducing the risk of material re-suspension; they also provide oxygen to the rhizosphere favoring aerobic degradation, contribute to the removal of nutrients (Vymazal, 2011).

The main function of the abiotic component in an artificial wetland is sedimentation, adsorption, and flocculation (Bohórquez, 2015), in addition to providing a surface where microorganisms are responsible for degrading contaminating matter under aerobic and anaerobic conditions (Cortés, 2015). The filter media most used in artificial wetlands are those consisting of sand and gravel (Bohórquez, 2015).

## 2.3 Plants used in artificial wetlands

Plants usable in artificial wetlands must have certain characteristics: they must tolerate high organic loads whose values are between 3 and 25 g BOD5 / $m^2$d, have abundant roots and rhizomes, and possess high aerial biomass to assimilate nutrients (Morales et al., 2013)

The most used plant genera within artificial wetlands for the purification of domestic wastewater are: *Typha spp., Phragmites spp. and Scirpus spp, Schoenoplectus spp, Phragmites australis* (Curt, 2005; Morales et al., 2013). These species are characterized by being hyperaccumulators of nutrients, storing them in roots until their translocation at maturity (Peña, 2013).

The use of ornamental species for the treatment of wastewater by means of artificial wetlands, is not frequent. However, some studies report the use of *Colocasia esculenta, Zantedeschia aethiopica, Heliconia psittacorum* and *Canna indica* (Peña, 2013; Morales et al., 2013). Studies carried out with sub-surface-flow artificial wetlands with the genus *Canna indica* show that they are capable of favoring the removal of over 70% of the organic matter (Morales et al., 2013); however, no studies on the use of *Racinaea fraseri* are recorded in artificial wetlands.

### 2.3.1. *Canna indica*

*Canna indica* is native to Ecuador (Caicedo et al., 2003). It is a perennial plant of 1.5 to 3m in height belonging to the Cannaceae family (Peña and Infante, 2012). *Canna indica* is known as achira and can be cultivated from sea level to 2800 masl; however, there is greater productivity in the subtropical valleys that are between 500 and 1700 masl (Ministry of Culture and Heritage of Ecuador, 2016) The purpose of this project is to analyze the influence of this plant in the treatment of domestic wastewater on wetlands built with subsurface flow, due to the aesthetic contribution that can be made.

**Figure 2.** *Canna indica*
**Source:** Bonells, 2017

**2.3.2. *Racinaea fraseri***

*Racinaea fraseri* belongs to the *Bromeliaceae* family. *Bromeliaceae* in Ecuador are represented by 172 endemic species, which represents 35.1% of the total species in the country (León et al., 2019). Due to the destruction of their habitat by deforestation, 78% of the known bromeliad species in Ecuador are in some IUCN threat category (Pihuave, 2010). Due to their ornamental attractiveness due to the beauty of their flowers, bromeliads have been in constant danger. Being Ecuador a flower exporting country, bromeliads are not consider account for this purpose (Chicaiza 2012), which is why this study aims to give an ornamental use to this type of plant.

**Figure 3.** *Racineae fresari*
**Source:** Tristam, 2019

## 2.4 Filter media used in artificial wetlands.

Phosphorous within domestic wastewater is at concentrations of 4 to 15 mg / l. When discharged into bodies of surface water, it constitutes the most worrying limiting factor in eutrophication problems (UNESCO, 2014). Therefore, the treatment of this nutrient is a priority to avoid regulatory problems (<10 mg / L) that later influence environmental problems.

The filter medium in artificial wetlands favors the adsorption processes depending on their physicochemical composition (Bohórquez, 2015). The phosphorus elimination processes in 86% depend on the adsorption capacity of the medium, although around 7% of the phosphorus is eliminated by plant/microbial assimilation (Reyes et al., 2011). Filter media within artificial wetland systems, must have some characteristics, such as permeability to allow water to pass through it, the size of the granular medium (40-80 mm), its porosity (80-90%) and the cation exchange that affects the adsorption of pollutants and surface area (300 $m^2/m^3$) (Delgadillo et al., 2010; Diaz, 2014; Vohla et al., 2011).

In artificial wetlands, the filter medium constitutes the direct phosphorus retention barrier. The search for support means that favor and optimize the process within these passive treatments, will favor an increase of values greater than 50% in the phosphorus removal efficiencies (López, 2016). Furthermore, from a practical point of view, the filter medium inside an artificial wetland constitutes the most expensive input, equivalent to between 50% and 53% of the construction costs of this type of technology (Vera, et al., 2016; Guachamín, 2018).

The search for a material with better physical (surface area, porosity), chemical (anion composition) and provenance (by-product or residue) characteristics, would favor the implementation and operation of artificial wetlands (Delgadillo et al., 2010)

**2.4.1 Concrete**

Concrete is made up of the three minerals of interest for its interaction with orthophosphate: Al, Fe, and Ca. If the pH is below 6, its interaction with $H_xPO_4^n$ leads it to Fe, if they have intervals between 6 and 8 it binds with Al and if it is greater than 8 its interaction is with Ca. Concrete has an additional advantage that is a residue resulting from construction demolition. In the year 2016, in Quito City, 2,002,870.73 $m^3$ of concrete were deposited in authorized dumps equivalent to 770 kg.inhab/year. However, this value is estimated and presumably less than the actual value (Cabezas, 2018).

# 3. Methodology

## 3.1 Experimental design

The cleaning process of the plants was performed in order to remove dust and other impurities of the leaves and stems, as well as the removal of the parts of the plant that were not in good condition was also proceed. Once the plants were prepared, they adapted to the environment with wastewater, with a duration of 4 weeks (Hernández, 2017).

Keeping in mind the composition of domestic wastewater in carbohydrate, protein and lipid requirements, we worked with a synthetic wastewater to feed the wetlands according to the methodology described by Pacheco, R. (2015). For practical application, a wastewater sample was used, obtained on the fifth week of experimentation at a point prior to the treatment plant of the Universidad de las Américas.


**Figure 4a.** Manufacture of synthetic wastewater

**Figure 4b.** Wastewater

Two wetlands were built on a laboratory scale, consisting of a one series system. Each system consisted of a VFAW and an HFAW. The dimensions of the wetland were 0.4 m in length, 0.2 m in width, and 0.2 m in height. Concrete with a diameter of ¾ to 1 inch was used as support medium, occupying a height of 15 cm. Figure 5 shows the distribution of the concrete depending on its inflow.

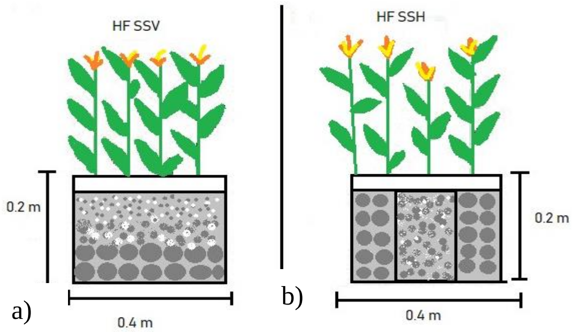


**Figure 5.** Distribution of concrete in wetlands.

a) Distribution of gravel in VFAW
b) Distribution of gravel in HFAW

**Source:** Guachamín, 2018

The hybrid wetland system was divided into two stages: The first stage was a system with oxygenation under conditions of a vertical subsurface flow wetland, with a retention time of 3 days. The second stage was made up of a horizontal subsurface flow wetland with a retention time of 4 days.

Each wetland has two individuals of *Canna indica* and two individuals of *Racinaea fraseri*. The vertical wetland was fed with 3.5 liters of wastewater, that is, to a height of approximately 0.10 m. After 3 days, the water was removed from the VFAW with the help of plastic garden faucets and the resulting effluent was fed to the HFAW. In addition, the two wetlands were lined with a black plastic sheath to prevent light from entering the concrete and thus prevent the proliferation of harmful algae.

**Figure 6.** Pilot plant. Artificial hybrid wetland system

## 3.2 Process diagram

Samples were taken at the entrance (influent) and exit (effluent) of each wetland and were subjected to physicochemical analyzes for characterization in the Environmental Laboratory of the Universidad de las Américas. The evaluation of the chemical parameters was carried out by means of the NANOCOLOR® kits of the Macherey-Nagel brand. The determination of suspended solids was carried out by the gravimetric method.

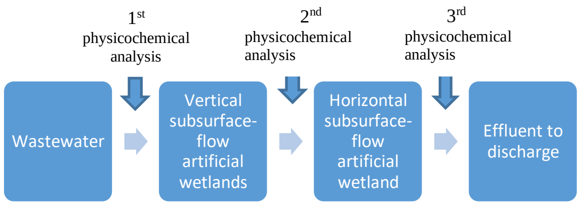


**Figure 7.** Diagram of the hybrid artificial wetland system process

# 4. Results and discussion

## 4. 1 Analysis of the efficiency of the hybrid wetland system.

### 4.1.1 Physicochemical characterization of the synthetic wastewater.

The system was monitored for 4 weeks, the conditions in which the experiment ran were at an average room temperature of 18 °C. Table 4 shows the different results of the physicochemical characterization of the synthetic wastewater.

According to the results obtained from organic matter and nutrients, the synthetic wastewater fed to the wetlands has an average concentration of pollutants in domestic wastewater according to Pacheco, R. (2015).

**Table 4.** Physicochemical characterization of synthetic wastewater

| Parameter | Synthetic wastewater | |
|---|---|---|
| | **Average** | **Rank** |
| COD (mg/L) | 499 | 328-988 |
| pH | 6.29 | 5.43-7.05 |
| Turbidity (NTU) | 82.7 | 57.9-109.7 |
| TSS (mg/L) | 112.75 | 71-225 |
| Electric Conductivity (µs/cm) | 590.5 | 318-832 |
| Phosphates (mg/L) | 63.25 | 56-70 |
| TP (mg/L) | 20.7 | 18.2-23.1 |
| $NH_4$-N (mg/L) | 39.5 | 36-43 |
| $NO_3$ (mg/L) | 2.71 | 1.37 – 4.05 |

### 4.1.2 Physicochemical characterization of the effluent

Table 5 shows the values of the physicochemical concentrations of the effluent of the vertical and horizontal wetland, together with the efficiency of each one. When comparing with the Ecuadorian regulations for discharge to freshwater bodies, values are lower than the permissible limits according to book VI annex 1 of the TULSMA (The Unified Text of Secondary Environmental Laws).

The increase in pH in the first 4 weeks is due to the presence of appreciable amounts of calcium in the filter material. Similarly, the conductivity values increase as they pass through each wetland. According to Bernal et al. (2003), salts are released by friction with the wastewater as it flows through the system.

The turbidity values obtained an efficiency of 86.60% in the vertical wetland and 20.29% in the horizontal wetland. These results are clearly reflected when comparing the transparency of the influent and the effluent of each wetland, mainly due to the adsorption properties of the porous medium and the roots of the plants (Núñez, 2016).

**Figure 8.** Turbidity of treated synthetic wastewater in the hybrid artificial wetland system.

The average efficiency of removal of organic matter from the hybrid system of artificial wetlands was 81.80%, a value close to the average found in this type of wetland with *Canna indica*, according to Peña and Infante (2012), however, it is less compared to the studies presented by Hernández (2017) with efficiencies of 88.65%.

The VFAW had a removal efficiency of 83.62% compared to the -21.40% efficiency of the HFAW. The high efficiencies of the VFAW are generally due to the oxygenation and filtration processes of the filter bed (Guachamín, 2018).

**Table 5.** PhysicOchemical characterization of the effluent of the vertical and horizontal wetlands

| Parameter | VFAW (Effluent 1) | | VFAW | HFAW (Effluent 2) | | HFAW | Maximum permissible limit to discharge to freshwater bodies |
|---|---|---|---|---|---|---|---|
| | **Average** | **Range** | **Efficiency (%)** | **Average** | **Range** | **Efficiency (%)** | |
| COD (mg/L) | 82.23 | 50-165 | 83.62 | 86.75 | 67.7-122.5 | -21.40 | 250 |
| pH | 7.44 | 7.25-7.5 | - | 7.38 | 7.2-7.5 | - | 6-9 |
| Turbidity (NTU) | 10.6 | 4.5-19.7 | 86.60 | 6.9 | 4.7-8.7 | 20.29 | - |
| TSS (mg/L) | 28.25 | 17.5 –52.5 | 73.89 | 25.75 | 12.5-32.5 | -15.24 | 100 |
| Electric conductivity (µs/cm) | 877 | 825-955 | -64.83 | 1132 | 1070-1197 | -29.28 | - |
| Phosphates (mg/L) | 19.05 | 15.2-22.1 | 69.96 | 3.02 | 2.11-4.14 | 83.93 | - |
| TP (mg/L) | 6.1 | 4.93-7.22 | 70.64 | 1.03 | 0.81-1.35 | 82.93 | 10 |
| *$NH_4$-N (mg/L) | 31.35 | 29.5-33.2 | 20.42 | 0.01 | 0.01 | 99.97 | - |
| **$NO_3$ (mg/L) | 0.89 | - | 78.05 | 2.5 | - | -181.22 | 10 |

* Due to errors with the chemical method used to determine $NH_4$-N, the compound was monitored for two weeks.

** Due to errors with the chemical method used to determine $NO_3$, the compound was monitored for one week.

Figure 9 shows how in the case of the vertical wetland the COD concentration decreases as time passes. On the contrary, in the case of the horizontal wetland in the first three weeks the COD concentration at the exit of the wetland increases. This can be attributed to the decomposition of root debris from *Canna indica* individuals, which got detached during experimentation. However, from the fourth week onwards, these COD concentrations began to decrease. The decomposition of these plant residues increases the amount of organic matter in the reactor.

The effluent that leaves the hybrid wetland system does not exceed 250 mg/l throughout the sampling period, thus complying with the permissible limits that must be met by the water for discharge to a freshwater body given by Ecuadorian regulations according to Annex 1 of the TULSMA (2015).

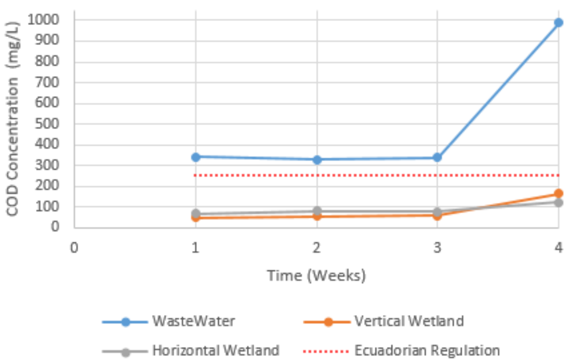


**Figure 9.** COD concentration of the hybrid artificial wetland system.

The performance in the removal of total suspended solids, reached efficiency average values of 73.89% in the vertical wetland, mainly due to sedimentation and the low speed of water circulation (García and Corzo, 2008). For the horizontal wetland, an efficiency of –15.24% was obtained, due to the plant debris that could appear during the first weeks of experimentation. Figure 10 shows the results obtained in the experimentation, reaching values less than 100 mg/L, complying with Ecuadorian regulations according to Annex 1 of the TULSMA (2015).

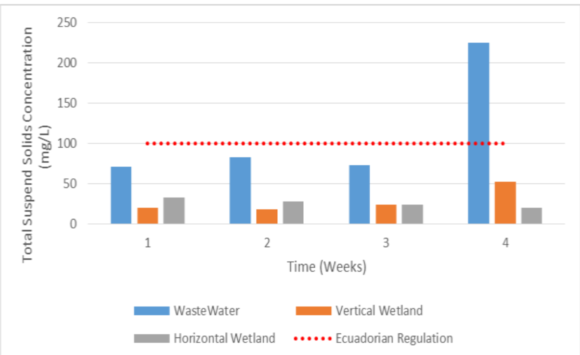


**Figure 10.** Total suspended solids concentration in the hybrid wetland system

As for phosphorus, in wetlands it is in the form of phosphates ($PO_4^{-3}$). Phosphates stimulate algae growth which can cause rapid concentration. In this way, as plants and algae grow, they can drown other organisms. Phosphate is the cause of eutrophication in lakes and lagoons (Romero, 2002). The removal of phosphates has an average efficiency of 69.96% and 83.93% for the vertical and horizontal wetlands, respectively, reaching an efficiency in the entire system of 95.17%. Its removal can occur mainly through the adsorption of the filter medium, it can also be caused by precipitation or retention by the plants. Figure 11 shows the values obtained.

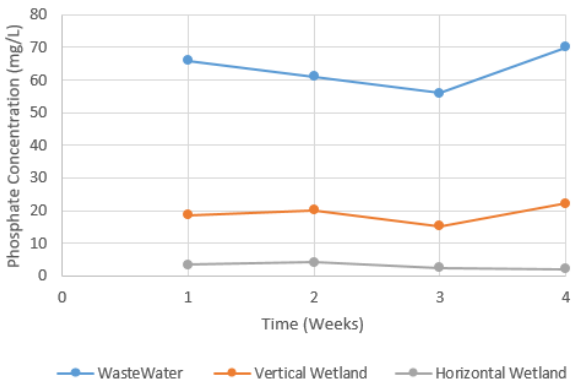


**Figure 11.** $PO_4^{-3}$ concentration of the hybrid wetland system

As can be seen in Table 5 there is a decrease in the $NH_4$-N concentration in the two types of wetlands, while nitrate showed a decrease in the vertical wetland and an increase for the horizontal wetland. The results in the VFAW can be attributed to the presence of anoxic zones that promoted denitrification and by the assimilation of nitrogen by plants and bacteria. While the increase in nitrates in the horizontal wetland was probably due, in part, to good nitrification, nitrate removed by denitrification was immediately replaced by nitrate produced by nitrification. The final nitrate concentration was sensitive to nitrification because the $NH_4$-N concentration was greater than the $NO_3$ concentration in the inflow (Zurita, 2009).

## 4.2 Analysis of the efficiency of the hybrid wetland system in practical applications.

To analyze the operation of the hybrid wetland in a practical case, in the fifth week the wetland was fed with wastewater from: toilets, food preparation and washing from the Universidad de las Américas. Table 6 shows the initial characterization parameters of the wastewater and the effluent of both the vertical and horizontal subsurface wetlands.

**Table 6.** Physicochemical characterization of the artificial hybrid wetland system in practical application

| Parameter | Wastewater | VFAW (Efluente 1) | HFAW (Efluente 2) | Maximum permissible limit to discharge to freshwater bodies |
|---|---|---|---|---|
| COD (mg/L) | 755 | 121.5 | 88.3 | 250 |
| pH | 8.4 | 6.8 | 6.71 | 6-9 |
| Turbidity (NTU) | 144.5 | 8,7 | 2.9 | - |
| TSS (mg/L) | 97.5 | 26.5 | 12.5 | 100 |
| Electric Conductivity (µs/cm) | 1333 | 1486 | 1239 | - |
| Phosphates (mg/L) | 73 | 21.1 | 2.11 | - |
| TP (mg/L) | 24 | 6,89 | 0.687 | 10 |
| $NH_4$-N (mg/L) | 149 | 76,4 | 1 | - |
| $NO_3$ (mg/L) | 6.15 | 1.37 | 1.6 | 10 |

It can be seen that the effluent from both the vertical and horizontal wetlands is below the maximum permissible limit mentioned in Ecuadorian environmental regulations.

Figure 12 shows the efficiency obtained in the vertical and horizontal wetland applied to a sample of wastewater from the Universidad de las Américas during week 5 of experimentation.

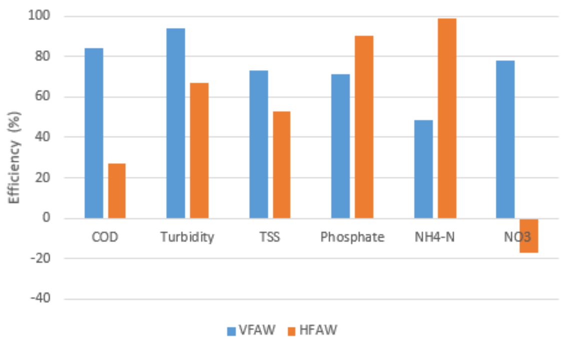


**Figure 12.** Vertical and horizontal wetland efficiency with a wastewater sample

In the practical application, similar efficiencies were obtained for the vertical subsurface-flow artificial wetland. However, the efficiencies of the horizontal subsurface-flow artificial wetland, with the exception of $NH_4$-N and $NO_3$, are greater than those reported using synthetic wastewater. As mentioned previously, this can be attributed to the decomposition of the plant's root remains within the first few weeks, while by week 5 the system was already adapting. Figure 13 shows the turbidity of the wastewater before and after having passed through each of the artificial wetlands.

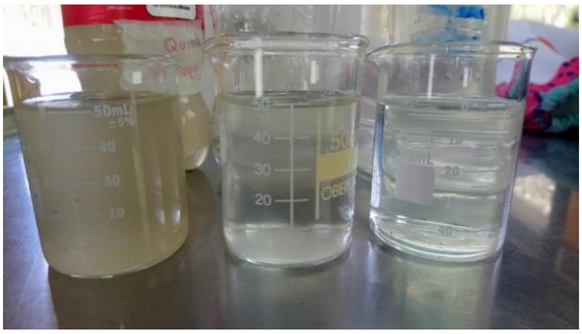

**Figure 13.** Turbidity of the treated wastewater in the hybrid system of artificial wetlands.

## 4.3 Plant evolution

Figure 14 shows the evolution of plants. During the first 5 weeks the plants grew and reproduced with the water served as food, with a maximum value of apical growth of 45 cm for the vertical wetland and 73 cm for the horizontal wetland. In the sixth week of operation, one individual was found to have flourished in the horizontal wetland.

According to the initial concentrations of $NH_4$-N and the behavior of plants in wetlands, the elimination is demonstrated of this contaminant in the vertical wetland is related to the increase in microbial biomass in the support material, which grew due to the supply of nutrients. In the case of the horizontal wetland, the removal of $NH_4$-N is related to the growth of plants (Guachamín, 2018).

**Figure 14.** Pilot plant. Artificial hybrid wetland system after 6 weeks of experimentation

On the other hand, Figure 15 shows the increase in individuals and leaves that is observed due to natural processes of the plants is observed.

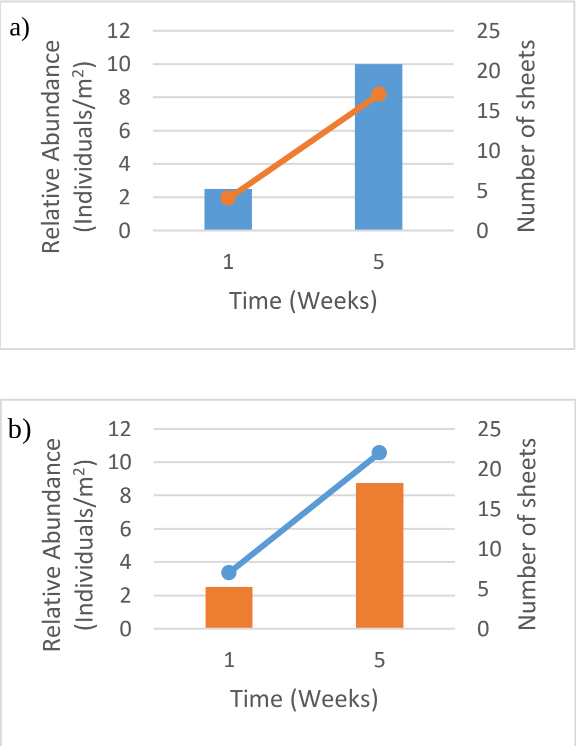


**Figure 15a).** Relative abundance and number of *Canna indica* leaves in the vertical wetland.

**Figure 15b).** Relative abundance and number of *Canna indica* leaves in the horizontal wetland.

Figure 16 shows the water losses in the wetland; a loss of 20.72% was obtained in the vertical wetland compared to 45.01% in the horizontal wetland. These results are related to the growth of plants with higher water consumption and higher biomass production. Moreover, it can be concluded that plants capture nutrients from water, thus contributing to the elimination of contaminants (especially nutrients) in the wetland (Guachamín, 2018).

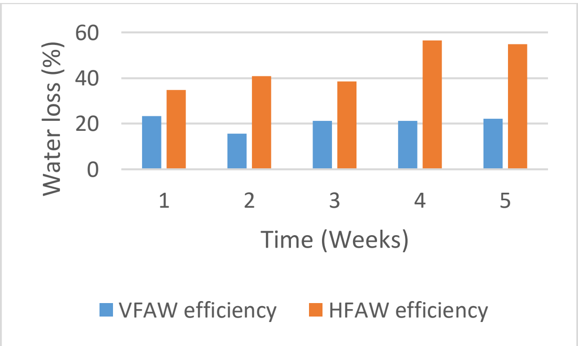


**Figure 16.** Percentage of water loss in the hybrid wetland system

## 5. Conclusions

The design of hybrid subsurface-flow artificial wetlands with the species *Canna indica* and *Racinaea fraseri* reduces the contamination of domestic wastewater

Based on the analyzes carried out in the pilot system of the artificial hybrid wetland, the removal of COD had an efficiency of 81.80%, that of suspended solids of 69.95% and that of phosphates of 95.17%, and a decrease in nitrates and ammoniacal nitrogen obtaining values that are within the current environmental regulations for the discharge of fresh and marine water.

The practical application of the pilot system with wastewater from the Universidad de las Américas presented similar efficiencies to those applied with synthetic wastewater; hence, it would be feasible to use these unconventional systems in rural areas.

The water treated with this technology can be used again in irrigation activities for tall-stem, ornamental plants.

Concrete can be considered as an alternative to use it as a support material in subsurface wetlands, since it is a residue that can be reused and has a high phosphate adsorption capacity.

Finally, artificial wetlands with concrete support medium and *Canna indica* and *Racinaea fraseri* plants can be used in rural areas due to their low investment costs of 59.73 USD/inhab and operating costs of 23.86 USD/inhab.year.

## 6. Recommendations

A more detailed monitoring of nitrogen is recommended to analyze the causes of its elimination.

It is necessary to provide an adaptation time of 2 weeks to the plants to subsequently carry out the physicochemical analyzes.

Washing the concrete is recommended before placing it inside the wetland in order to clean the existing fine particles and avoid possible interferences in the laboratory results.

The vegetation to be incorporated must have certain requirements, including that only the best specimens be selected, free of genetic malformations.

It is also recommended to carry out a dry weight analysis of the plants to analyze the amount of biomass of the plant.

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