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PROPOSAL OF ALTERNATIVES FOR WASTEWATER TREATMENT IN RURAL AREAS OF ECUADOR USING ARTIFICIAL WETLANDS

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Wastewater treatment is a problem that requires urgent attention, especially in the rural mountainous areas of Ecuador, since these areas have particular conditions. These include the complex topography, which does not allow sewage networks to adequately cover the territory, the low temperature that limits the purification processes, and the need for simple, low-cost and highly efficient treatment systems due to the social, economic and environmental conditions that are present. Due to these considerations, several artificial wetland systems for the treatment of urban wastewater have been evaluated through pilot applications, in order to identify operating conditions before the wetlands are extrapolated and constructed. Different plant species, hydraulic retention times, pretreatments and substrate variations have been evaluated. The best combination turned out to be the Equisetum species (horsetail), using biochar as substrate. Elimination percentages of 100% for organic matter, 99% for phosphates, 90% for nitrates, 60% for suspended solids and 55% for fecal coliforms were obtained, demonstrating that it is a great alternative in terms of discharge limits and that it meets the conditions for use in the areas analyzed.

Keywords: waste water; rural areas; Ecuador andean

PROPUESTA DE ALTERNATIVAS PARA DEPURACIÓN DE AGUAS RESIDUALES EN ZONAS RURALES DEL ECUADOR MEDIANTE APLICACIÓN DE HUMEDALES ARTIFICIALES

La depuración de aguas residuales es una problemática de atención urgente, más aún en las zonas rurales montañosas del Ecuador, ya que estas tienen condicionantes particulares. Se puede mencionar su compleja topografía que no permite que redes de saneamiento cubran adecuadamente el territorio, la baja temperatura que limita los procesos de depuración, y la necesidad de sistemas de tratamiento simple, de bajo costo y elevada eficiencia por las condiciones sociales, económicas y ambientales que se presentan. Por estas consideraciones se han evaluado varios sistemas de humedales artificiales para el tratamiento de aguas residuales urbanas mediante aplicaciones con pilotajes, de esta manera se logra identificar condiciones de operación previo a que los humedales sean extrapolables y construidos. Se han evaluado diferentes especies vegetales, tiempos de retención de hidráulica, pretratamientos y variación de sustratos. La mejor combinación resultó ser la de la especie Equisetum (cola de caballo), utilizando biochar como sustrato. Se han obtenido porcentajes de eliminación del 100% para materia orgánica, 99% para fosfatos, 90% para nitratos, 60% para sólidos suspendidos y 55% para coliformes fecales; demostrando ser una gran alternativa en cuanto a límites de vertido y que cumple con las condiciones para ser empleados en las zonas analizadas.

Palabras clave: aguas residuales; zonas rurales; andes de Ecuador

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1. Introduction

Artificial wetlands have emerged as an attractive alternative for treating wastewater due to their ability to mimic natural processes, their low energy consumption, and their low maintenance costs (Vymazal, 2014). The two main types of artificial wetlands are subsurface flow wetlands and surface flow wetlands, with hybrid wetlands combining both subsurface and surface flow mechanisms to achieve higher treatment efficiency (Kassa, 2019) (Nivala et al., 2020). The effectiveness of artificial wetlands in treating different types of wastewater, such as domestic, agricultural, and industrial wastewater, has been demonstrated in numerous studies (Khajah et al., 2023).

Artificial wetlands have several advantages over traditional wastewater treatment methods. They require lower energy and chemical inputs, produce less sludge, and provide a habitat for wildlife (Vymazal, 2010). However, they also have some limitations, such as requiring a large land area and their performance being affected by factors such as temperature and pH. For this reason, it is interesting to carry out pilot tests to evaluate the performance of the different combinations. This saves space for testing prior to construction in the intervention areas.

There are four types of constructed wetland systems: (i) subsurface flow system (SSF), (ii) free surface water system (FWS), (iii) floating treatment wetland (FTW), and (iv) hybrid system (Zidan et al., 2015). Primary wastewater treatment is necessary for the FWS system to prevent the filter media from clogging. Depending on the flow direction, the wastewater flows horizontally or vertically through the substrate in the systems, which stimulates plant growth. Horizontal subsurface flow (HSSF) and vertical subsurface flow (VSSF) systems can be classified based on the flow direction (Al-Isawi et al., 2015)(Al-Isawi et al., 2017). Contaminant removal in CW SSFs results from biological activities in which bacteria attach to plant roots, which provide the necessary surface area for bacteria to grow and supply oxygen.

Despite their potential advantages, artificial wetlands still face several challenges. One of the main challenges is to optimize their design and operation to achieve higher treatment efficiency (Zhang et al., 2021). Another challenge is to develop cost-effective and scalable methods for constructing artificial wetlands. Additionally, more research is needed to understand the long-term performance and sustainability of artificial wetlands (Parde et al., 2021).

A subsurface flow subsurface flow system (SSF) artificial wetland (HSSF) has been constructed on a pilot scale to demonstrate the operation and performance that can be obtained in this type of system for the treatment of wastewater in rural areas of the Ecuadorian Andes.

This research contributes with specific knowledge on the application of artificial wetlands for wastewater treatment in rural areas of the ecuadorian andes. It is seen as an optimal alternative in function of the particular reality of the area, such as the lack of access to sewage systems, economic needs, contamination and public health.

2. Methodology

2.1 Design and Operation:

Artificial wetlands are designed to promote the growth of microorganisms that can break down and remove pollutants from wastewater. The two main types of artificial wetlands are subsurface flow wetlands and surface flow wetlands. Subsurface flow wetlands rely on a bed of gravel or other porous media to support the growth of microorganisms. In contrast, surface flow wetlands use plants to provide a surface for microbial growth. Hybrid wetlands combine both subsurface and surface flow mechanisms to achieve higher treatment efficiency. In this research, several types of substrate and vegetation mixtures have been tested to find the optimum performance in contaminant removal. The combinations tested are listed in Table 1:

Table 1. Pilot-tested wetland combinations.

ID	Plant name	Type of CW	HTR	Granular medium
CW1	Equisetum	Horizontal subsurface flow	5	Gravel
CW2	Equisetum	Horizontal subsurface flow	4.3	Gravel and sand
CW3	Zantedeschia aethiopica	Horizontal subsurface flow	4.4	Volcanic rock
CW4	Equisetum	Horizontal subsurface flow	4.8	Biochar
CW5	Zantedeschia aethiopica	Horizontal subsurface flow	5	Grava sílica

For all combinations, domestic wastewater is used. All the piles have the same dimension, since the same structure was used, but their inlet flow rate varies slightly due to the inlet control, so the retention time is different.
The design of the HSSFCW was based by the methodology established by (Delgadillo et al., 2010). Firstly, the sizing was based on the number of local residents and the input flow. The biological system starts calculating the reaction rate constant kT (0.778) based on the water temperature (14°C), 5 days of retention were considered, although this value varied slightly during the operation. The depth of the substrate was 0.20 m, for all granular media tested; considering an intermediate value, if the substrate is too deep it creates an anaerobic area in the bottom of the biological system and the reduction of organic matter can be reduced. Table 2 summarizes the design parameters of the HSSFCW systems.

Table 2. Design parameters of the pilot systems.

Parameter	Value	Unit
Flow	0.32	$m^3\ d^{-1}$
Depth	0.8	m
Area	2	m^2
Long	2	m
Width	1	m
Slope	2	%

After building the VSSFCW and planting the species studied, the plants were allowed to grow for about two months, after which a constant flow of wastewater was fed into each treatment unit. The experiment began in July and ended in August, trying to perform the analysis during the low rainfall period.

Figure 1 shows the wetland construction process.

Figure 1. HSSF wetland implementation process.

2.1 Performance and monitoring program:

Artificial wetlands have been proven effective in removing a wide range of pollutants from wastewater, including organic matter, nitrogen, and phosphorus. The removal efficiency of artificial wetlands is influenced by a variety of factors, such as hydraulic loading rate, retention time, and plant species. The effectiveness of artificial wetlands in treating different types of wastewater, such as domestic, agricultural, and industrial wastewater, has been demonstrated in numerous studies. To test the performance of the constructed pilot wetlands, a characterization of the incoming wastewater was carried out by taking daily composite samples obtained from the mixture of hourly samples. This is done for a period of 7 days to know the variability of the incoming wastewater that can enter a wetland once it is in operation (Table 3). The wetlands were subsequently monitored for thirty days, with weekly inlet and outlet monitoring of water quality parameters, between the month of July and the month of August.
Samples were collected in 1 L plastic bottles for physicochemical parameters, 500 ml amber bottles for organic matter, and 50 ml containers for microbiological parameters. Temperature, pH and conductivity were measured in situ using a Hach multiparameter model HQ50d. Preservation was not necessary because the wetland construction site is continuous with the water quality laboratory of the HYDROLAB department of the Catholic University of Cuenca.

3. Results and discussion
3.1 Results of wastewater characterization

The mean value of the monitored parameters, using composite samples, is shown in Table 3:

Table 3. Results of wastewater characterization

Parameter	Units	Value
pH		
Temperature	°C	7.15 ± 0.01
Conductivity	µS cm^{-1}	725.30 ± 13.03
Suspended Solid	mg L^{-1}	245.10 ± 15.10
BOD_5	mg L^{-1}	255.5 ± 22.5
COD	mg L^{-1}	350 ± 17.1
Nitrates	mg L^{-1}	1.5 ± 0.5
Ammoniacal Nitrogen	mg L^{-1}	30.1 ± 1.10
Total Phosphorus	mg L^{-1}	8.5 ± 1.50
Fecal Coliforms	MPN 100 L^{-1}	1850 ± 5.50

According to the data presented in the previous table, it can be seen that the water quality ranges to be treated by the wetlands are typical ranges for municipal wastewater (Sikosana et al., 2019) (Ya'acob et al., 2022).

3.2. Removal percentages obtained with the application of pilot wetlands

The average value of the purification efficiency of wastewater treated with each of the pilots applied are explained in Table 4.

Table 4. Comparison of pollutant cleanup percentages.

Parameter	CW 1 (%)	CW 2 (%)	CW 3 (%)	CW 4 (%)	CW 5 (%)
pH	5.5	5.6	5.35	4.6	4.9
Temperature	- 1.3	- 0.5	- 0.85	- 1.2	- 0.55
Conductivity	60	30	34	59	35
Suspended Solid	60	55	63	60	58
BOD_5	95	98	91	100	90
COD	85	88	88	100	92
Nitrates	80	83	85	90	89
Ammoniacal Nitrogen	55	56	60	88	80
Total Phosphorus	80	80	81	99	85
Fecal Coliforms	40	55	53	55	50

In all the parameters analyzed, the CW constructed wetland with the best results is CW4, which combines Equisetum as plant and Biochar as substrate. Reductions in organic matter parameters (BOD_5 and COD) of up to 100% can be seen, and for phosphorus, purification reaches 99%. Another interesting purification value is that of nitrates with a percentage of 90%.

Within the study of wetlands there is a large amount of research carried out, for this reason we have chosen to make a comparison table of authors with results obtained in the elimination of pollutants from wastewater. Table 5 shows the results of other studies with some specific considerations such as the plants used and the granular medium and compared to the CW4 wetland pilot, which has been the best performing wetland in this research.

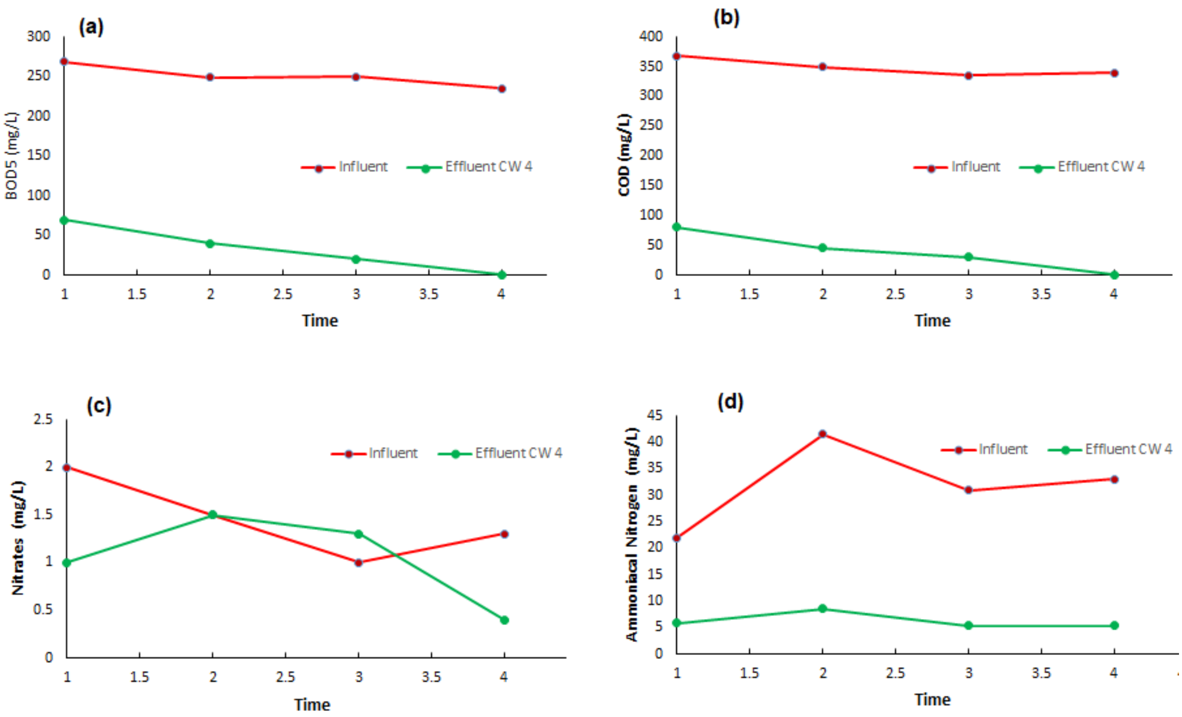
Table 5. Comparison of results from different authors

NH_4 (%)	NO_3 (%)	COD (%)	BOD_5 (%)	TP (%)	Author	plants and granular medium
91.77	-	36.46	47.5	71.79	(Xu et al., 2014)	Phragmites australis and gravel
90.9	-	93.8	98.3	85.1	(Weedon, 2010)	
54	-	64	65	-	(Yadav et al., 2018)	Typha angustata, Canna indica and gravel
89.2	-	84.5	88.1	30.2	(Dąbrowski et al., 2017)	Phragmites australis and gravel
-	90	70	81	50	(García-Ávila et al., 2019)	Phragmites spp and gravel
-	-	92	-	-	(Orozco, C.; Cruz, A.; Rodríguez, M.; Pohlan, 2006)	Saccharum spp, gravel and sand
-	67	-	-	74	(Macci et al., 2015)	Canna spp and volcanic rock
-	90	70	81	50	(García-Ávila et al., 2019)	Equisetum and gravel
66	69	-	-	-	(de Rozari et al., 2018)	Biochar
-	-	70	52	85	(Kizito et al., 2017)	Biochar
88	90	100	100	99	CW4	Equisetum and biochar

The application of biochar produced from various elements and used as a substrate in constructed wetlands for wastewater treatment can be innovative and give very high efficiency results (Deng et al., 2021). This can be seen in our research, with the high efficiency values.

Figure 2 shows the values of the weekly monitoring carried out. the data of the best treatment obtained (CW4) are presented, showing the percentages of purification analyzed for the parameters of organic matter and nitrogen.

Figure 2. Comparison between influent and effluent for CW4.



Despite their potential advantages, artificial wetlands still face several challenges. One of the main challenges is to optimize their design and operation to achieve higher treatment efficiency. Another challenge is to develop cost-effective and scalable methods for constructing artificial wetlands. Additionally, more research is needed to understand the long-term performance and sustainability of artificial wetlands.

In addition to carrying out pilot construction processes before the implementation and operation of wetlands, there are other techniques to evaluate performance, such as machine learning algorithms. In Salem et al., (2022), the random forest was used to assess the performance of constructed wetlands, providing alternatives for continuous improvement.

5. Conclusions

This study provides a tool and an adequate vision of the usefulness and efficacy of artificial wetlands with an overview of territorial sustainability in an area with difficult access to sanitation. The study contributes to the understanding of the use of specific vegetation on the site (and that possibly has been used very little in other studies of artificial wetlands) for the purification of wastewater - the use of vegetation that is specific to the area (and that possibly has been used very little in other studies of artificial wetlands) for the purification of wastewater.

Artificial wetlands have several advantages over traditional wastewater treatment methods. They require lower energy and chemical inputs, produce less sludge, and provide a habitat for wildlife. However, they also have some limitations. For example, they require a large land area, and their performance may be affected by factors such as temperature and pH. In this research with pilot wetlands that occupy less space, it has been possible to demonstrate the efficiency they can have with various combinations, reaching high percentages for most of the pollutants analyzed, such as organic matter (100% purification), nitrates, ammonium, phosphorus, solids and even fecal coliforms.

Artificial wetlands have emerged as a promising alternative for treating wastewater due to their low cost, low energy consumption, and low maintenance requirements. They have been proven effective in removing a wide range of pollutants from various types of wastewater. However, there is still a need for further research to optimize their design and operation, and to understand their long-term performance and sustainability. Overall, artificial wetlands have the potential to provide a sustainable and eco-friendly solution for wastewater treatment.

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