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Performance Analysis of Constructed Wetland Configurations for Grey Water Treatment

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Abstract
Constructed wetlands are engineered and managed wetland systems that are increasingly receiving worldwide attention for wastewater treatment and reclamation. Compared to the conventional plants, constructed wetlands are cost effective and easily operated and maintained, and they have a strong potential for application in a small community. Constructed wetland for wastewater treatment have substantially developed in the last decades as an eco-friendly treatment process. constructed wetlands may enable the effective economical and ecological treatment of agricultural, industrial and municipal wastewater. However, sustainable management of wetland system remains a challenge. This experimental investigation aims to provide suitable solution for the performance enhancement and application of constructed wetlands by analyzing the factors affecting the treatment efficiency. The usage of agricultural waste for the treatment of wastewater is also incorporated in the wetland system for providing a sustainable solution for waste management. This system consists of a constructed wetland with Heliconia and Taro Plants aided with bagasse ash, a waste product from Sugarcane industry for the treatment of grey water. The performance of the system exhibited an improvement in performance by the addition of bagasse layer owing to it's adsorption characteristics. The treatment period was selected as 1, 3 and 7 days and the system yielded better results with 3 day period. The reduction in treatment efficiency for 7 day trial may be attributed to the organic layer formation in the system. Filter cleaning mechanism has to be incorporated for maintaining the treatment efficiency of the system.

***Keywords*—Grey water, Constructed wetland, wastewater treatment, Pollution.**

I. INTRODUCTION

A. constructed wetland

Globally, most of the developing countries are geographically located in those parts of the world that are or will face water shortages in the near future. Moreover, the existing water sources are contaminated because untreated sewage and industrial wastewater is discharged into surface waters resulting in impairment of water quality. The treatment of wastewater using Constructed Wetland is one of the suitable treatment systems, used in many parts of the world. Wetlands are defined as land where the water surface is near the ground surface long enough each year to maintain saturated soil conditions, along with the related vegetation. Marshes, bogs, and swamps are all examples of naturally occurring wetlands.

Constructed wetlands are engineered and managed wetland systems that are increasingly receiving worldwide attention for wastewater treatment and reclamation. Compared to conventional treatment plants, constructed wetlands are cost-effective and easily operated and maintained, and they have a strong potential for application in a small community. Constructed wetlands for wastewater treatment have substantially developed in the last decades. As an eco-friendly treatment process, constructed wetlands may enable the effective, economical, and ecological treatment of agricultural, industrial, and municipal wastewater. They are designed to take advantage of many of the same processes that occur in natural wetlands but do so within a more controlled environment. They can be simply constructed using local materials and have simple operations and maintenance. It is a complex assemblage of wastewater, substrate, vegetation, and an array of microorganisms. The role of vegetation is an essential component. Emergent plants contribute both directly and indirectly to the treatment processes. Plants also provide micro-organisms for the treatment. Constructed wetlands are based upon the symbiotic relationship between the micro- organisms and pollutants in the wastewater. These systems have potential to treat variety of wastewater by removing organics, suspended solids, pathogens, nutrients, and heavy Metals. It used for wastewater treatment may be classified according to the life form of the dominating macrophyte, into systems with free-floating, floating leaved, root emergent and submerged macrophytes. Further division could be made according to the wetland hydrology (free water surface and subsurface systems) and subsurface flow CWs could be classified according to the flow direction. (Gunasekara et.al,2022)

B. Types of constructed wetlands

Constructed wetlands are usually divided into 2 forms as per the wetland hydrologic processes: free water surface flow and subsurface flow. Free water surface flow structures are closer to natural wetlands where wastewater flows shallowly over polluted substrates. In subsurface flow structures, wastewater passes horizontally or vertically across the substratum that encourages plant production. It is large gravel and sand filled basin that is planted with wetland vegetation. It can be also separated into vertical flow along with horizontal flow constructed wetlands on the ground of the stream route. A mixture of multiple wetland technologies is recognized as hybrid constructed wetlands. Vertical flow wetlands are further divide into up-flow, down- flow and tidal flow Free water surface flow constructed wetland is a series of flooded planted channels or basins. It aims to replicate the naturally occurring processes of natural wetland, marsh or swamps. It is divided into emergent plants, submerged plants, free floating plants and floating leaved plants. (Jaya et al.,2021)

C. Horizontal subsurface flow of constructed wetlands

Horizontal subsurface flow constructed wetlands (HSSF CWs) are innovative systems for wastewater treatment. Wastewater enters at one end and moves horizontally through a bed of porous media, such as gravel or rock, planted with wetland vegetation. This flow pattern promotes biological, physical, and chemical processes that remove pollutants. The system's design creates aerobic, anoxic, and anaerobic zones, enhancing treatment efficiency. Microbial communities in the media break down contaminants, while wetland plants oxygenate the water and aid in nutrient uptake. HSSF CWs effectively remove a variety of pollutants, including nutrients, organic matter, and pathogens. They require larger vegetated bed areas but offer advantages like efficient organic matter and suspended solids removal. The system's horizontal flow design increases contact time between wastewater and treatment media, improving overall treatment effectiveness. Furthermore, the wetland vegetation adds aesthetic value and provides wildlife habitat, integrating these systems into natural environments. (Jaya et al.,2021)

D. vertical flow of constructed wetland

Vertical flow constructed wetlands are a type of subsurface flow wetland were watershed is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter media. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. However, the primary role of vegetation is to maintain permeability in the filter and provide habitat for microorganisms. Vertical Subsurface Flow Constructed Wetlands (VSSF CWs) represent a sophisticated approach to wastewater treatment that leverages the principles of natural wetland ecosystems in a controlled and engineered environment. In these systems, wastewater percolates vertically through a substrate, typically composed of gravel or rock, creating an environment conducive to the removal of contaminants through physical, chemical, and biological processes. In a VSSF CW, the wastewater enters the system and moves downward through the substrate, allowing for prolonged contact time with the treatment media. Microbial communities thrive in this oxygen-rich environment, breaking down organic matter and transforming pollutants. The porous substrate also facilitates the removal of suspended solids and the adsorption of certain contaminants, contributing to the overall purification process. (Jaya et al.,2021)

E. purpose

Constructed wetlands are versatile ecosystems that serve multiple purposes, including wastewater treatment, stormwater management, biodiversity conservation, and habitat creation. By mimicking the functions of natural wetlands, they effectively filter pollutants, reduce erosion, and provide habitats for various plant and animal species. These wetlands play a vital role in wastewater treatment by utilizing natural processes to remove contaminants from domestic, agricultural, and industrial wastewater. Additionally, they help mitigate the impacts of urbanization by capturing and slowing down stormwater runoff, thus reducing flooding and improving water quality. Constructed wetlands also support biodiversity conservation by providing habitats for a diverse range of species, and they offer recreational and educational opportunities, contributing to the aesthetic and cultural value of landscapes. Overall, constructed wetlands are integral components of sustainable water management and ecosystem conservation efforts.

F. Sustainability

Constructed wetlands offer a sustainable solution for various environmental challenges by replicating the natural processes found in wetland ecosystems. These engineered systems are designed to treat wastewater, manage stormwater, and restore degraded habitats while minimizing energy consumption and chemical usage. By harnessing the natural processes of filtration, sedimentation, and microbial degradation, constructed wetlands can effectively remove pollutants and nutrients from water, improving its quality. Additionally, they provide habitat for diverse plant and animal species, enhancing biodiversity and ecological resilience. The sustainability of constructed wetlands hinges on careful planning, appropriate design, and ongoing maintenance to ensure optimal performance and longevity. Community engagement and stakeholder involvement are also essential for fostering local support and ensuring the continued success of these environmentally friendly solutions.

II. MATERIALS AND METHODS

A. Constructed wetland sysytems

The wetland model is constructed in two rectangular transparent canisters, on which a half inch pipe is fitted at 5 cm from the bottom to collect the water filtered through the substrates. The pipe is then sealed tight to prevent leakage of any kind. The two canisters are provided with different vegetations in each of them. In one canister the vegetation provided is Heliconia psittacorum and in the other canister the vegetation is Taro. The canisters are filled with bed medium consisting of three different substrates. The bottom layer is filled up to 10 cm with well graded coarse aggregate. Middle layer is filled with treated sugarcane bagasse of 15cm and river sand for 10 cm. Top layer is filled with top soil up to 10 cm for the proper growth of vegetation which is essential for the treatment of wastewater. The plants are given a maturity period and the water is then poured into this wetland setup.

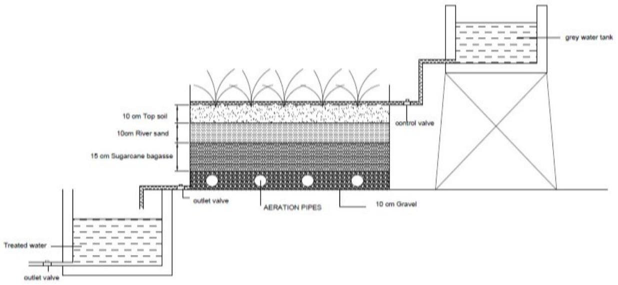

Fig 1. Schematic Diagram of Experimental Setup

Fig 2. Experimental setup

B. Processing of sugarcane bagasse

Sugarcane bagasse can be used as a carbon source and filler for biological wastewater treatment processes. Sugarcane bagasse has good properties such as high surface area, porosity, cellulose and hemicellulose content, carbon-release and biofilm-hanging ability. It is also a low-cost and renewable agricultural waste that can be easily obtained and processed. The sugarcane bagasse is treated before it is used as the substrate component. It has to undergo certain processes to increase its efficiency and prevent the decay which will affect the purification densely. There are several methods that is in practice to treat the Sugarcane bagasse for feeding it as an effective bio adsorbent. And the most common are physical method which is followed by chemical treatment. Here the Sugarcane bagasse is treated in suitable way to increase its efficiency as follows. The Sugarcane bagasse which is of 15 kg was washed and sun dried to remove its remaining sweetness and impurities that were present. It was well dried and is grounded into considerably medium sized pieces. This grounded piece has considerably high surface area considered to the non-grounded pieces which aids to adsorption. This grounded Sugarcane bagasse was then heated in the oven for 24 hours at 100°C. It was then taken out and examined which came out as the effect of effective sun drying only. So, to make it effective and to prevent decaying it was slightly charred by heating it in containers which came out well and was ready to use.

Fig 3. Grounded and sun-dried Sugarcane Bagasse

This grounded Sugarcane bagasse was then heated in the oven for 24 hours at 100°C. It was then taken out and examined which came out as the effect of effective sun drying only. So, to make it effective and to prevent decaying it was slightly charred by heating it in containers which came out well and was ready to use.

Fig 4. Charred sugarcane bagasse

C. Experimental procedure

The experimental procedure involved setting up two identical canisters for constructing wetlands, each with specific dimensions and suitable substrates. The collected materials included Heliconia psittacorum and Taro for vegetation, topsoil, river sand, and sugarcane bagasse for substrates, along with canisters for holding the wetland setup. Any defects in the materials were rectified, and improvements were made if economical and reliable. Sugarcane bagasse was treated to activate it before use as the bottom substrate of the wetland. The wetland setup began with treating the sugarcane bagasse and arranging the wetland in the two canisters, each fitted with a half-inch pipe at the bottom to prevent possible leakage. The bottom layer consisted of gravel with a thickness of 10 cm, followed by sugarcane bagasse up to 15 cm thickness, mainly for absorption. The middle layer comprised river sand up to 10 cm for filtration, and the top layer was topsoil for vegetation growth, with a height of 10 cm. After setting the substrates, plants were planted in the wetland, with one wetland containing Heliconia psittacorum and the other containing Taro as vegetation. After the plants matured, the wetland was used for wastewater treatment. The experimental setup aimed to compare the efficiency of the two wetland setups, one with Heliconia psittacorum and the other with taro, in treating wastewater. The experiment included analyzing water quality and the removal capacity of the plants at different retention times (1, 3, and 7 days). Results showed that the wetland with taro exhibited better efficiency, especially at 3 days when it was maturing and experiencing peak growth. This indicates higher nutrient uptake and better removal. In contrast, the wetland with Heliconia psittacorum showed decreased efficiency. The water sample at 7 days showed less removal, likely due to the plant reaching peak growth and reduced absorption. However, the wetland with Heliconia psittacorum stabilized pH levels. Overall, the wetland setup containing Taro demonstrated greater efficiency, especially at 3 days when it was maturing and experiencing peak growth. This small-scale wetland setup proved feasible for urban areas due to its economic and space-efficient nature. The vegetation choice, Taro, was recommended for its ability to thrive in adverse conditions and provide treated water.

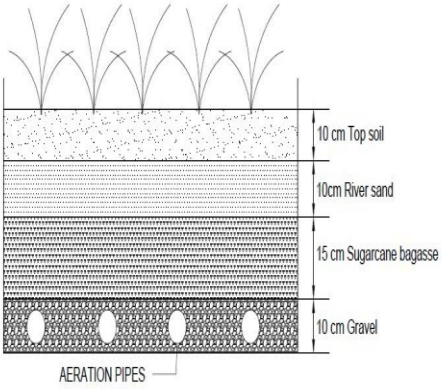

Fig 5. Layers of the Wetland system

III. RESULTS AND DISCUSSIONS

A. Preparation of synthetic grey water

Greywater is a type of wastewater used for various activities like washing purpose, kitchen, and showers etc. excluding excreta arise from toilets. Hair's traces food constituents, household products and dirt can be observed in the composition of greywater. It may even appear unclean, but at the same time in some cases it can be a valuable for plants. The availability of nutritious elements in greywater released from homes are the basic cause of pollution, and these nutritious elements can be a productive fertilizer for plants . In this study, the synthetic greywater was prepared from components usually present in greywater. The constituents including, 70 mg/L of yeast extract, 55 mg/L of each starchy food and washing soda, 30 mg/L of washing powder, 10 ml/L of settled sewage and 0.1 ml/L of each shampoo and oil . The initial characterization of synthetic greywater was analyzed on 5 liters, while for the final application of iron chloride based-AC in combination with sand bed filter 30 liters of synthetic greywater was prepared. The recipe of synthetic greywater used in this study to analyze the efficiency $FeCl_3$-AC and sand bed filter was nearly of the same nature as real grey water

TABLE 1. INGREDIENTS OF SYNTHETIC GREY WATER
(MIAN JAWADUDDIN ET.AL 2019)

SL.NO.	Ingredients	Quantity
1	Yeast extract	70 mg/litre
2	Flour(starchy food)	55 mg/litre
3	Washing soda	55 mg/litre
4	Washing powder	30 mg/litre
5	Shampoo	0.1 ml/litre
6	Cooking oil	0.1 ml/litre

B. Test result of synthetic greywater

TABLE 2. TEST RESULTS OF SYNTHETIC GREY WATER

SL NO	PARAMETER	RESULT	UNITS
1	pH	8.9	
2	Hardness	280	mg/l
3	Turbidity	88	mg/l
4	COD	228	mg/l
5	Chloride	400.87	mg/l

The synthetic greywater sample exhibits certain characteristics based on the provided results. The pH value of 8.9 indicates an alkaline nature, which can influence its compatibility with certain treatment processes and its potential impact on the environment. The hardness level of 280 mg/l suggests a high concentration of dissolved minerals, primarily calcium and magnesium, which could lead to scaling issues in pipes and appliances if not treated appropriately. The turbidity value of 88 mg/l indicates the presence of suspended particles in the water, which can affect its clarity and may require filtration or settling processes for removal. The COD (Chemical Oxygen Demand) value of 228 mg/l indicate moderate level of pollution, indicating the presence of biodegradable substances that can consume oxygen in water bodies, potentially leading to oxygen depletion and harming aquatic life. The chloride concentration of 400.87 mg/l is relatively high and could be indicative of contamination from sources such as sewage or industrial discharge, which can have detrimental effects on water quality and health. Overall, the synthetic greywater sample exhibits characteristics that may require treatment or management to ensure its safe disposal or reuse, highlighting the importance of proper wastewater management practices

C. Constructed Wetland system (with charred bagasse)

A constructed wetland model for greywater treatment with charred bagasse involves a system that mimics natural wetland processes to treat wastewater. Greywater, from activities like bathing and laundry, is directed into the system. It consists of shallow basins filled with gravel, sand, soil, and charred bagasse. Charred bagasse, the fibrous residue from sugarcane processing, acts as a biofilter due to its porosity and adsorption capacity. As greywater flows through, physical, chemical, and biological processes occur. Charred bagasse supports microbial growth, breaking down organic matter. Gravel, sand, and soil layers further filter through sedimentation and adsorption. This model offers an effective, low-cost, and eco-friendly solution for greywater treatment, producing water suitable for non-potable uses like irrigation.

Fig 6. Constructed wetland model

D. Water treated by using heliconia psittacorum

In constructed wetland systems using Heliconia psittacorum for greywater treatment, the treatment efficiency evolves over time, emphasizing the importance of plant growth and maintenance. Initially, in the one-day filtration period, treatment is suboptimal due to incomplete root zone engagement. This limits impurity absorption. However, over three days, treatment efficiency significantly improves as the root zone establishes, enhancing impurity absorption. By seven days, treatment may decline due to fouling, highlighting the need for regular maintenance. Maintenance practices such as backwashing and monitoring filtration media conditions are crucial for optimal treatment performance. These practices help prevent fouling, ensuring continuous and efficient treatment. Additionally, optimizing factors such as plant selection, retention times, and maintenance practices can enhance treatment efficiency and ensure sustainable greywater treatment. Heliconia psittacorum's use in constructed wetlands offers benefits beyond treatment efficiency. It adds aesthetic value and attracts wildlife, enhancing the ecological appeal of the system. Moreover, its ability to thrive in diverse conditions makes it suitable for various greywater treatment settings. constructed wetland systems using Heliconia psittacorum can efficiently treat greywater with proper optimization of plant growth and maintenance practices. This sustainable solution not only improves treatment efficiency but also adds aesthetic and ecological value to the treatment process.

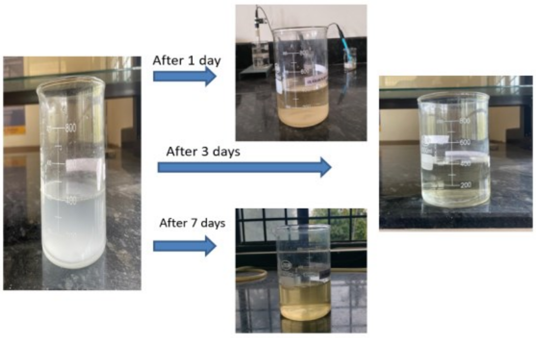

Fig 7. Water treated by using heliconia psittacorum

TABLE 3. TEST RESULTS OF HELICONIA PSITTACORUM

SL NO	PARAMETER	RESULT AFTER 1 DAY	RESULT AFTER 3 DAY	RESULT AFTER 7 DAY	UNITS
1	pH	8.1	7.3	6.5	
2	HARDNESS	114	70	128	mg/l
3	TURBIDITY	30	18	54	mg/l
4	COD	160	72	176	mg/l
5	CHLORIDE	290.91	171.94	341.89	mg/l

The effluent properties of treated greywater are crucial indicators of treatment effectiveness. Comparing test results after 1, 3, and 7 days reveals trends in pH, hardness, turbidity, COD, and chloride levels. pH decreases from 8.1 to 6.5, indicating reduced alkalinity. Hardness decreases from 114 mg/l to 70 mg/l at 3 days but rises to 128 mg/l at 7 days. Turbidity decreases from 30 mg/l to 18 mg/l at 3 days but increases to 54 mg/l at 7 days. COD decreases from 160 mg/l to 72 mg/l at 3 days but rises to 176 mg/l at 7 days. Chloride decreases from 290.91 mg/l to 171.94 mg/l at 3 days but rises to 341.89 mg/l at 7 days. The 3-day result is most effective, with significant reductions in hardness, turbidity, COD, and chloride levels, indicating improved water quality. Monitoring and optimizing the treatment process are crucial for maintaining these improvements.

E. Water treated by using Taro

In a constructed wetland system using Taro for greywater treatment, the treatment process evolves over time. Initially, during the one-day filtration period, treatment outcomes are limited due to incomplete root zone engagement. This restricts the plant's ability to absorb impurities efficiently. However, at three days, significant improvements are observed as the Taro's root zone becomes more established, allowing for better absorption of impurities. But at seven days, treatment efficiency may decline due to fouling of the filtration media. Proper maintenance practices like backwashing are crucial to address fouling and maintain optimal performance. Compared to Heliconia psittacorum, Taro is often more effective in removing contaminants due to its robust root system. Taro's dense and fibrous roots provide a larger surface area for absorption and microbial activity, leading to improved water quality. Overall, incorporating Taro into constructed wetland systems can significantly enhance treatment efficiency and produce higher quality effluent suitable for reuse. The effectiveness of Taro in contaminant removal is attributed to its superior root system, which provides a larger surface area for absorption compared to Heliconia psittacorum. Taro roots trap suspended particles and organic matter, reducing turbidity and organic load. Additionally, Taro roots release oxygen and exudates, stimulating microbial activity for pollutant breakdown. Beneficial microorganisms in Taro roots further contribute to contaminant degradation. Overall, Taro's robust root system and microbial activity make it a valuable asset in constructed wetlands for greywater treatment, enhancing treatment efficiency and producing cleaner water.

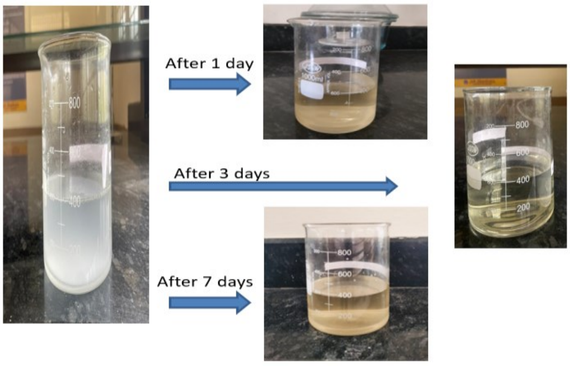

Fig 8. Water treated by using taro

TABLE 4. TEST RESULTS OF TARO PLANT

SL NO	PARAMETER	RESULT AFTER 1 DAY	RESULT AFTER 3 DAY	RESULT AFTER 7 DAY	UNITS
1	pH	8.3	7	6.9	
2	HARDNESS	124	64	134	mg/l
3	TURBIDITY	35	16	38	mg/l
4	COD	176	64	164	mg/l
5	CHLORIDE	310.9	158.95	362.88	mg/l

The effectiveness of a constructed wetland system for greywater treatment can be evaluated by comparing effluent properties over time, specifically after one day, three days, and seven days of treatment. The pH levels decreased from 8.3 to 7.0 to 6.9 over the respective periods, indicating a gradual reduction in alkalinity. Hardness levels decreased from 124 mg/l to 64 mg/l after three days but increased to 134 mg/l after seven days, suggesting effective removal of ions initially but possible saturation later. Turbidity levels improved from 35 mg/l to 16 mg/l after three days but worsened to 38 mg/l after seven days, hinting at declining filtration efficiency or particle accumulation. COD levels decreased from 176 mg/l to 64 mg/l after three days but increased to 164 mg/l after seven days, indicating initial pollutant removal followed by potential efficiency decline. Chloride levels decreased from 310.9 mg/l to 158.95 mg/l after three days but rose to 362.88 mg/l after seven days, showing effective removal initially but later decline. The three-day period showed the most significant improvements in hardness, turbidity, COD, and chloride levels, emphasizing its effectiveness in improving water quality for reuse. Continuous monitoring and maintenance are crucial for sustaining these improvements.

TABLE 5. PERCENTAGE REDUCTION IN BOTH PLANTS

PARAMETERS	% REDUCTION OF HELICONIA PSITTACORUM AFTER 3 DAYS	% REDUCTION OF TARO AFTER 3 DAYS
HARDNESS	75	77.14
TURBIDITY	79.54	81.81
COD	68.42	71.93
CHLORIDE	57.1	60.34

CONCLUSIONS

The use of constructed wetland for experimenting its feasibility for urban area, the water quality analysis and experimenting the usage of the plants taro and heliconia psittacorum in wetlands and their removal capacity was done successfully. The experimentation was done for 1, 3 and 7 days retention time for the water sample those quality was to be analyzed. The two wetland setups one with Taro and the other with heliconia psittacorum shown different results. The wetland with Taro has better efficiency for 3 days where it was maturing and had peak growth, which requires nutrients that is required for its growth and was having better removal. The water sample for 7 days retention time shown less removal since the plant has reached its peak growth and the absorption was less. The wetland with heliconia psittacorum had however shown stabilization of pH. The results had variations due the constraints that was listed. Large areas are usually chosen for the construction for wetlands and usually given retention time of 24 hours or so since the removal takes place well in large surface area. The use of sugarcane bagasse as substrate resulted in the reutilizing of an agricultural waste. This small-scale wetland setup is feasible in case of urban areas as it is economical and has small space requirement and maintenance. The vegetation that can be provided is taro since it thrives through lacking conditions and provide more useful treated water.

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