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Subsurface vertical flow constructed wetland as potential landfill leachate treatment of the solid waste disposal facility of Iligan City, Philippines

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Abstract

The landfill leachate generated in Bonbonon is considered high strength (11,622mg/L BOD_5), posing serious environmental risks. In this paper, an attempt was made to reduce specifically the BOD_5 (~5,000mg/L) as finishing treatment with a Vertical Flow Constructed Wetland (VCFW) planted with Taro (*Colocasia esculenta*) and Cattail (*Typha latifolia*), respectively to render the leachate as effluent amenable for disposal as required by the Philippine Clean Water Act. Raw and treated effluents were sampled and analyzed for various water quality parameters at specific hydraulic retention time (14, 21, 28 days, respectively). Pollutants were removed more effectively by vegetated cells than by the non-vegetated cells. Taro (*Colocasia esculenta*) removed more contaminants than Cattail (*Typha latifolia*), with an average of 99.32% BOD_5 removal and average pH reduction to as low as 7.06 from the average original pH of 7.72. Turbidity reduction is less effective with VFCWs. The system was able to remove 100% of the lead (Pb). Hence, Constructed Wetlands (CWs) with subsurface-vertical flow proved to be a cost-effective phytoremediation treatment technology of the landfill leachate. It is indeed a promising treatment technology that Iligan City can implement to treat its high strength wastewater.

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Introduction

Municipal Solid Waste (MSW) generation and its impacts on the environment are of primary concern in our societies nowadays. MSW usually comes from domestic, commercial, and industrial solid wastes, which contain organic and inorganic compounds, including heavy metals (Jayawardhana *et al.,* 2016; Mshelia *et al.,* 2014). Improper solid waste management poses a serious risk of contamination to both groundwater and surface water quality (Aderemi *et al.,* 2011). Generally, solid waste is disposed of through incineration, composting, landfilling, or any desired combination of these methods (Jayawardhana *et al.,* 2016; Leton & Omotosho, 2004).

In Iligan City, the final disposal site for solid wastes is the Central Material Recovery and Composting Facility (CMRCF) situated in Sitio Bangko, Barangay Bonbonon, Iligan City. The CMRCF is generating leachate, and it was reported that leachates were made to overflow from a leachate pond towards a creek without proper treatment. As reported, the residents noticed black and brown effluent being carried by the flowing water to the nearby Dodiongan Falls (Arevalo, 2016). In addition, from the study of Ramos *et al.* (2017), the leachates from the same source were analyzed of BOD_5, lead, chromium, and mercury contents and were found to be 52,000mg/L, 0.2084mg/L, 0.6575mg/L, and 0.1771mg/L, respectively. These values did not meet the water quality standards set by the Department of Environment and Natural Resources (DENR) Administrative Order (DAO) 2016-08, otherwise known as Water Quality Guidelines and General Effluent Standards of 2016. This leachate concentration is considered to be very strong wastewater and may pose health and environmental risks when released to the bodies of water (Pescod, 1992; USEPA, 2003). This study has been conducted in response to the alarming state of the river water quality and proposed a cost-effective treatment technology using native plant species.

A very promising technology for the treatment of landfill leachates is the use of constructed wetlands. Constructed Wetlands (CWs) are natural, low-cost, eco-technological biological wastewater treatment technology designed to treat wastewater. It is a shallow basin filled with filter materials (substrate), usually made of layers of sand and gravel, and planted with vegetation tolerant to constant inundation. In Verticial Flow Constructed Wetlands (VFCW), the wastewater is introduced into the system and flows vertically through the substrate. The wastewater is treated by means of microbiological degradation of organic matter and other physico-chemical processes occurring in the system. Moreover, the VFCWs are also being used to treat various types of wastewater, including phenol, dairy, livestock, and industrial wastewater (Kadlec & Wallac, 2009; Yalcuk & Ugurlu, 2008; UN-HABITAT, 2008).

In this study, landfill leachate was treated by a vertical flow constructed wetland systems. The objectives of this study were threefold: (1) to determine the physical and biochemical characteristics of the wastewater in terms of turbidity, temperature, heavy metals (lead), pH, and 5-day Biochemical Oxygen Demand (BOD) before and after the treatment; (2) assess the effect of hydraulic retention time to the physical and biochemical characteristics of the water samples; and (3) assess and compare the effects of the two species of hydrophytic plants to the physical and biochemical characteristics of the water samples.

Materials and methods

Location of the Study

Barangay Bonbonon is one of the 44 barangays of Iligan City. Barangay Bonbonon is situated at approximately 8°16'23.2"N 124°18'13.2"E, on the island of Mindanao, Philippines. The elevation of the area is estimated to be 166 meters above mean sea level. The barangay is bounded by the Mandulog River in the south, Barangay Digkilaan in the east, Barangays Kabacsanan and Kiwalan in the north, and Barangay Santa Filomena, Iligan City in the west (PhilAtlas, 2019). The sampling site is located at the Central Material Recovery and Composting Facility (CMRCF) at Sitio Bangko, Barangay Bonbonon (Fig. 1). Grab samples were collected in the first stage of treatment from the leachate ponds.

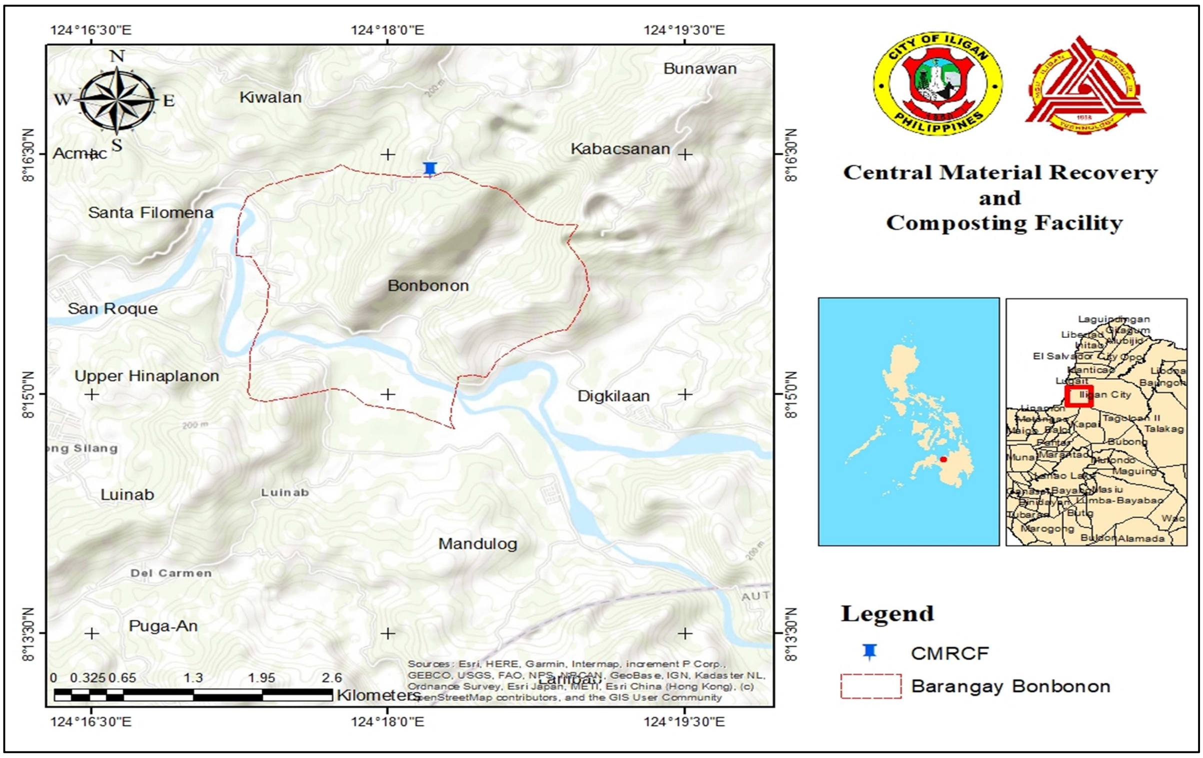

Fig. 1. Map of Mindanao showing the sampling site of Central Material Recovery and Composting Facility (CMRCF) in Iligan City.

Plants Preparation

The Cattail (*Typha latifolia* L.) and Taro *Colocasia esculenta* L.) plants were collected at Brgy. Puga-an and Tambo, Iligan City Philippines. Plants were defoliated and cut according to the desired length, then washed with distilled water to remove the impurities.

Set-up of Cells

Three (3) rows of cell racks were placed in the set-up: two (2) rows composed of nine (9) cells for each plant species, and one (1) row composed of three (3) non-vegetated cells (control). The cell containers in the cell racks were turned upside-down, facing the ground.

The substrates were composed of gravel (4-L) which support the media and serve as an underdrain system. On top of the gravel were the mixed composition of soil and sand (2-L sand and 4-L soil, respectively), as shown in Fig. 2. Cattails and Taro were planted manually. Cells were filled with tap water and were set for stabilization.

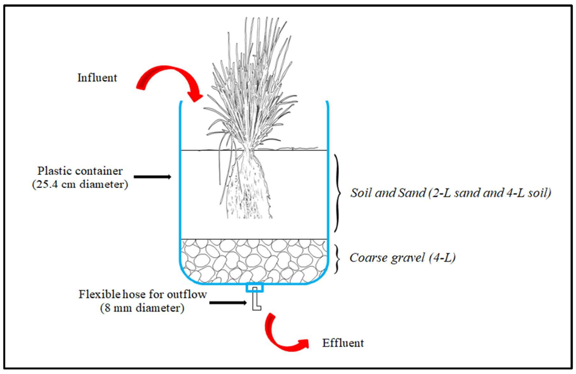

Fig. 2. Schematic cross-sectional view of prototype cell design.

Leachate Sampling

Grab samples were collected in the first stage of treatment from the leachate ponds in the Iligan City CMRCF, as shown in Fig. 3. Samples were taken between 0900-1100 hours, and leachate samples were collected using polyethylene containers. Containers were rinsed with the sample first before the sampling was done. Twenty (20) liters of leachate were collected and transported from the sampling site to the set-up at Barangay Puga-an, Iligan City, Philippines.

Fig. 3. Landfill leachate holding pond.

Leachate Loading

Leachate was diluted to a ten percent (10%) concentration, enough for the plants to tolerate and survive. This concentration was met by diluting 20L of pure leachate to 200L of tap water. Lead (II) chloride ($PbCl_2$) was added after dilution at 0.02mg/l Pb to test the capability of the set-up to reduce heavy metals and test the plants' ability to absorb metals.

Actual loading of diluted landfill leachate into each cell started after 9-weeks of stabilization of the plants. Direct pouring was applied in transferring the leachate into each cell. The cell was fed with 8-L of wastewater, and cell containers were marked according to this volume. The marked height was maintained after seven days of acclimation.

Treated Wastewater Sampling

Samples (effluent) for analyses were collected every after seven (7) days for three (3) weeks starting from 14 days after leachate loading. The collection of leachate samples for biological oxygen demand (BOD) utilized clean 300-mL BOD bottles. For other parameters, clean 1000-mL polyethylene bottles were used. Three cells each of the Cattail, Taro, and Control, respectively were sampled every retention time to see how the parameter changes throughout the sampling period. The collected water samples were kept at 4°C in an icebox prior to the analyses of the parameters named.

Methods of Analysis

The Department of Environment and Natural Resources (DENR) approved standard methods of analysis were used in the study as stipulated in the Department Administrative Order (DAO) 2016-08 on water quality guidelines and general effluent standards and of the USEPA (US Environment Protection Agency).

Turbidity

The turbidity of the water samples was measured using a HI 93703® microprocessor turbidity meter.

Temperature

The temperature of the water samples was directly measured using a mercury thermometer. The clean probe end of the thermometer was immersed in the water samples for a minute, before the reading was recorded.

pH

The pH of the water samples was determined using the Hi 2211 pH/ORP meter of Hanna Instruments®. The instrument was first calibrated with the standard reagents, and the pH was determined with three (3) replicates per sample.

Lead (Pb)

Flame Atomic Absorption Spectrometry (AAS) is a common and reliable technique for detecting heavy metals in the sand, soil, roots, and water samples (USEPA, 2007). This was done by digestion of the wastewater samples subject to Direct Air-acetylene flame and monochromator. A liquid sample is aspirated, aerosolized, and mixed with combustible gases (acetylene and air). This mixture is then combusted to reduce the element of interest into free atoms that absorb light at a specific wavelength. The concentration of the element can be calculated by measuring the amount of absorbed light according to the Beer-Lambert Law equation. The concentration of Pb in the analyses is determined by preparing a serial dilution with the same volume (5ml) of Pb^{2+} of the analyte but different volumes (Pb^{2+}) of the working standard. The absorbances of the above solutions are plotted using the best-fit line equation. The concentration of Pb in the analyte is then determined according to the best fit line equation. Heavy metals were analyzed in the laboratory of Ostrea Mineral Laboratories, Inc. in Cagayan de Oro City, Philippines.

BOD_5

The BOD_5 was determined by the standard method of analysis, which is the Azide modification with the Winkler method, to minimize the effect of interfering materials found in the biologically treated effluents and the incubated BOD samples (Indian Institute of Technology Delhi, 2012; USEPA, 2012). The amounts of dissolved oxygen (DO) in the water samples were measured before and after five (5) days of incubation in darkness at a temperature of 20°C.

The method was done by titrating the water samples with reagents. From the point of collection, BOD bottles were carefully filled with the water samples in the absence of air before securing the cap. Series of reagents were then added to the water samples to form an acid solution and were titrated with a neutralizing compound until a color change was observed that matched the DO concentration in the samples.

BOD_5 Removal Efficiency

The primary goal of this research is to use VFCW to remove or reduce contaminants in leachate to meet the national water quality standards. The leachate's BOD_5 level is considered high; thus, the efficiency of BOD_5 removal was taken into account. The percent removal efficiency in each cell was calculated given the formula below:

$$\text{Removal Efficiency, \%} = \frac{C_o - C_f}{C_o} \times 100\ \%$$

where C_o the initial concentration of diluted leachate and C_f the final effluent concentrations.

Statistical Analysis

The significant effects of the factors on the responses and their interaction were analyzed using a Two-way Analysis of Variance (ANOVA). Shapiro-Wilk test was used to test for normality of the data set, and Levene's test was used to determine the homogeneity of variances. Mean separation was done using Tukey's Honestly

Significant Difference test at a 95% level of confidence. The results were computed using the Microsoft Excel program and IBM SPSS Statistics for Windows, Version 20.0.

Results and discussions

Substrates characterization

Substrate characterization in terms of organic matter, pH, and lead content was done in this study prior to its usage in the set-up. The organic matter content of the soil was 1.301%, and the pH was 7.9, lower than the typical percent organic matter content and slightly basic, which enabled both species of plants to survive and grow. The lead content in the soil and sand samples have the same values of < 0.1mg/kg, which simply means that it is beyond the detection level of the Atomic Absorption Spectrometer used in the analysis and implies a negative result. In this regard, neither the soil nor the sand contributed to the lead content in the wastewater.

Pure and diluted leachate characteristics

Initial characterization of the leachate before and after dilution was conducted and was compared to the effluent standards for "Class C" based on the classification of the receiving body of water which is the Dodiongan Falls. The dilution was done by diluting the pure leachate in a ten percent (10%) concentration, with one (1) volume part of pure leachate to nine (9) volume parts tap water. According to DENR effluent standards, BOD_5 exceeded the allowable value of 30mg/L for both pure and diluted leachate. Lead content for diluted leachate exceeded the allowable value of 0.01mg/L while the temperature and pH are within the allowable limits of 3°C change in temperature and pH between 6 and 9. Table 1 shows the results of the analysis for both pure and diluted leachate. In reference to the study of Aziz (2013), the typical BOD concentration of young and intermediate landfill leachates ranges from 1,000mg/L-57,000mg/L, where the data show that the CMRCF leachate is 11,622mg/L and 2,348mg/L BOD after dilution, respectively. This leachate concentration is regarded as high strength wastewater, posing risks to human health and the environment, particularly with aquatic organisms (Bhalla *et al.,* 2012).

Table 1. Pure and diluted leachate analysis with a dilution factor of 1:10.

Parameters	Pure leachate	Diluted leachate
Temperature (°C):	32	29
Turbidity (NTU)	53	34.32
pH	7.72	7.60
Lead (mg/L):	<0.01	0.20
BOD_5 (mg/L):	11, 622	2, 348

Turbidity in the wastewater is considered low, with concentrations ranging from 34.32 NTU to 53 NTU. The pH is alkaline, and the temperature is slightly high but commonly within the temperature range of typical wastewater. The lead concentration of 0.20mg/L of the diluted leachate was purposely added in the study to test the capability of the set-up in metal removal, while the lead content of the pure leachate is beyond the detection level of the Atomic Absorption Spectrometer used in the analysis.

Effluents Physical and Biochemical Characteristics

Temperature

The temperatures in all cells range from 29°C to 31°C, which are within the allowable level of 3°C change from the background value of 30°C receiving stream, as shown in Fig. 4. The temperature background value refers to the temperature of the receiving body of water, which in this case is a 30°C stream flowing down to Dodiongan Falls. However, no statistical validations of these findings were made as temperatures between vegetation types were comparable. Also, there were no temperature differences in the analysis regardless of hydraulic retention time as samples were collected at the same time of the day.

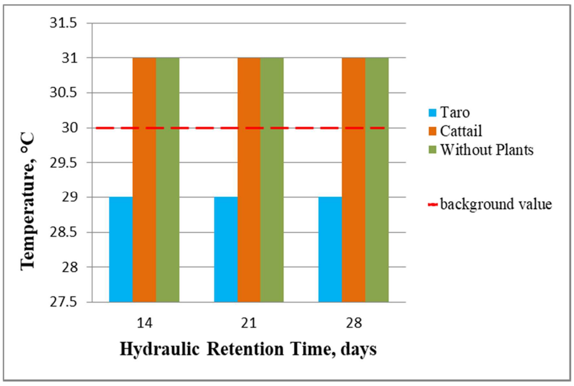

Fig. 4. Mean temperature levels of Taro, Cattail, and without plants in every retention time.

Temperature plays an important role in wastewater treatment because of its effects on biological and chemical reactions. It was observed that the actual experiment operates at mesophilic conditions at temperatures ranging from 20°C to 45°C, where most aerobic biological treatment processes take place (Schiraldi & De Rosa, 2014). According to the study of Lutosławski *et al.* (2017), lower temperatures ranging from 27°C to 36°C are best suited for wastewater treatment. This temperature allows the water to hold as much dissolved oxygen as possible for uptake by aquatic organisms and is an ideal temperature for microbial organisms involved in reducing pollutants, particularly BOD, for as high as 99% reduction. Temperature can also influence compound toxicity in water, high temperatures increase heavy metals solubility and thus increase compounds toxicity, whereas at low temperatures (4°C - 32°C) in a given pH can play a role in shifting ammonia (NH_3) in water to the nontoxic ammonium ion (NH_4^+) (Fondriest Environmental, Inc., 2014; Hach, 2020).

Turbidity

Turbidity is a measure of the clarity of the water. Sources of turbidity include soil, microbes, sand, and other substances. A high level of turbidity restricts light penetration into the water (Fondriest Environmental, Inc., 2014). It could have negative impacts, such as increasing water temperature, which reduces dissolved oxygen, hindering aquatic plant photosynthesis, and clogging fish gills (USEPA, 2012). This makes turbidity a critical water quality parameter.

In this study, a significant effect of hydraulic retention time (HRT) on the Turbidity values was detected ($p < 0.01$). It was observed that 33.5% of the variation in turbidity can be attributed to HRT. Turbidity in the water samples with respect to hydraulic retention time shows the following trend: 28 days (293.78 NTU) > 21 days (137.63 NTU) > 14 days (133.68 NTU). Moreover, the highest effluent turbidity value was recorded during 28-days HRT ($\bar{x}$=402.67 NTU) in cells without plants, while the lowest turbidity value was recorded during 14-days HRT ($\bar{x}$=11.43 NTU) in cells planted with Taro. There was a significant effect of Vegetation Type on Turbidity contributing to 47% of the variation. Cells without plants, on average, have a response that is 223.15 NTU higher than Taro and 192.79 NTU higher than Cattail. However, no significant interactions between HRT & Vegetation type were detected ($p>0.05$). The Analysis of Variance (ANOVA) is shown in Table 2.

Table 2. Effects of hydraulic retention time (HRT) and vegetation type on turbidity.

Source	F	Sig.	Partial Eta Squared
HRT	4.537	0.025	0.335
Vegetation Type	7.969	0.003	0.470
HRT*Vegetation Type	1.216	0.339	0.213

R Squared = 0.624 (Adjusted R Squared = 0.457)

In general, turbidity in Cattail and Taro was lesser than in non-vegetated cells, as shown in Fig. 5. This is similar to the study of Mustapha *et al.* (2015), in which a vegetated wetland performed significantly better than one without plants. However, the system was unable to reduce the turbidity of the diluted leachate (34.32 NTU) but instead added to it.

The increase in turbidity was linked to a number of factors. The volume of gravel used, for example, is insufficient to hold the substrates and to serve as an underdrain system that filters the soil media. Another factor is that as HRT increases, the amount of water in the cells decreases. As a result, very little water is left in the cell during sampling, causing more solids to drift and mix with the water. Hence, for a better turbidity reduction in wastewater, it requires changes in the system design (e.g., substrate and water volume) as well as a longer retention time of the wastewater in the set-up.

pH

A significant main effect of HRT on pH value was found ($p < 0.01$). The highest pH value of effluents was recorded during 14-days HRT ($\bar{x}$=7.92), while the lowest pH value was in 28-days HRT ($\bar{x}$=7.06). The mean values of pH in all effluents decreased as HRT increases. 14-days HRT has a higher mean pH ($\bar{x}$= 7.65, 7.92, 7.733) among all of the retention times, while 21-days have a higher average pH ($\bar{x}$= 7.14, 7.853, 7.427, respectively) value compared to the 28-days HRT ($\bar{x}$= 7.06, 7.077, 7.07, respectively). There is a significant effect also of the vegetation type on the concentration of pH showing 89.7% of the variation. Cells without plants, on average, have measured a pH that is 0.13 higher than Taro and 0.21 lower than Cattail. In addition, the interaction of HRT and the Vegetation type has a significant effect on the decreased pH ($p < 0.01$), indicating that the relationship between Vegetation type and pH is affected by HRT value. When both the HRT and Vegetation types are considered, the Adjusted R squared resulted in a value of 0.980, implying that both predictors have a significant effect on pH level variations. Table 3 shows the statistical analysis done.

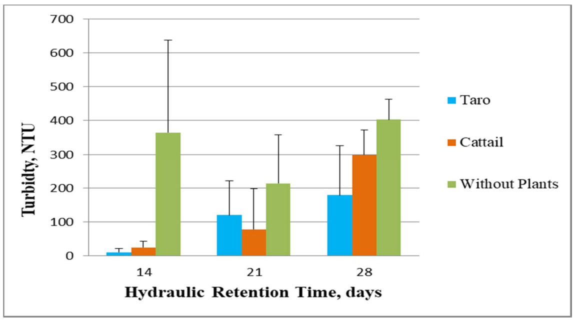

Fig. 5. Mean turbidity levels of Taro, Cattail, and without plants in every retention time.

Table 3. ANOVA showing the effects of HRT and Vegetation type on pH.

Source	F	Sig.	Partial Eta Squared
HRT	460.988	0.000	0.981
Vegetation Type	106.003	0.000	0.922
HRT*Vegetation Type	39.374	0.000	0.897

R Squared = 0.986 (Adjusted R Squared = 0.980)

The pH values of all effluent samples are within the allowable range of 6.5-9.0 pH set by DENR Water Quality Standard for the effluent to be discharged to surface water (Fig. 6).

These pH values are suitable for the survival of most aquatic life; an increase or decrease from this optimum range can put pressure and reduce species survival rates (Yokogawa, 2014). Chemical toxicity, heavy metal solubility, and DO concentration in water are also dependent on pH, making it an important water quality parameter (Fondriest Environmental, Inc., 2013).

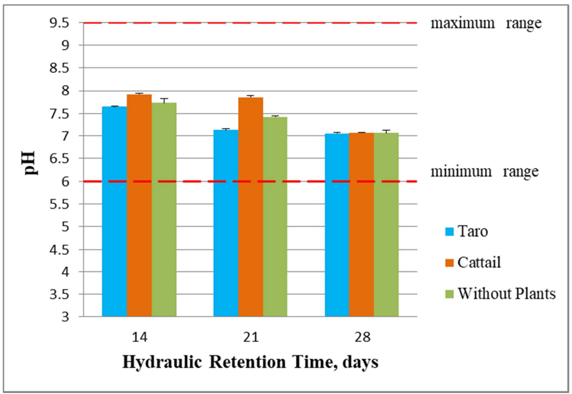

Fig. 6. Mean pH levels of Taro, Cattail, and without plants in every retention time.

BOD_5

A significant main effect of HRT on BOD_5 value was found ($p < 0.01$). Table 4 shows the analysis of variance (ANOVA) done. The highest BOD_5 value of the effluents was recorded during 14-days HRT ($\bar{x}$= 91.27 mg/L) while the lowest BOD_5 value in 28-days HRT ($\bar{x}$= 15.88 mg/L). After 14 days of exposure in the set-up, there was a significant decrease in the BOD_5 from the initial concentration of 2,348 mg/L of the diluted leachate to the average value of 71.13 mg/L, 83.89 mg/L, and 91.27 mg/L in Taro, Cattail, and without plants, respectively. The mean values of BOD_5 in all effluents decreased significantly as HRT increases. 14-days HRT has the highest mean BOD_5 recorded ($\bar{x}$= 71.13, 83.89, 91.27 mg/L) among all of the retention times, while 21-days have a higher average BOD_5 ($\bar{x}$= 27.52, 34.227, 36.243 mg/L) value than 28-days HRT ($\bar{x}$= 15.88, 24.16, 26.85 mg/L).

A significant interaction between the two main effects (HRT and the vegetation type) was observed ($p < 0.05$). Thus, as the HRT increases, the BOD_5 reduction of each plant species also increases. It can be observed from the graph (Fig. 7) that the trend of BOD_5 removal in Taro and Cattail is slightly lower than non-vegetated cells ($p < 0.01$).

Table 4. ANOVA showing the effects of HRT and Vegetation type on BOD_5.

Source	F	Sig.	Partial Eta Squared
HRT	1359.720	0.000	0.993
Vegetation Type	62.554	0.000	0.874
HRT*Vegetation Type	4.130	0.015	0.479

R Squared = 0.994 (Adjusted R Squared = 0.991)

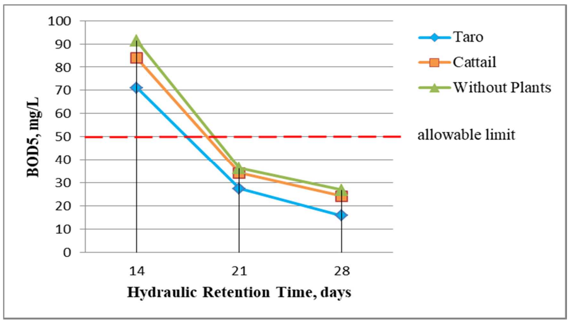

Fig. 7. Mean BOD_5 levels of wastewater planted with Taro, Cattail, and without plants in every retention time.

BOD_5 Removal Efficiency

Increases in removal rates of BOD_5 on vegetated and non-vegetated cells were observed as the HRT increases. Table 5 presents the data of % BOD_5 removal against HRT and vegetation type. The highest removal rate was recorded during 28-days HRT at 99.32% of the Taro plant, while the lowest removal rate was observed during 14-days HRT at 96.11% of the non-vegetated cells. Longer exposure of the wastewater in the set-up is believed to be the common cause of the increased removal rates.

Table 5. BOD_5 removal efficiency, %.

Vegetation Type	Hydraulic Retention Time 14	Mean Removal efficiency,%	21	Mean Removal efficiency,%	28	Mean Removal efficiency,%
Taro	96.83	96.97	98.89	98.83	99.23	99.32
	97.00		98.80		99.37	
	97.08		98.80		99.37	
Cattail	96.40	96.43	98.63	98.54	98.97	98.91
	96.31		98.46		99.06	
	96.57		98.54		98.80	
Without plants	96.14	96.11	98.54	98.46	98.97	98.86
	95.97		98.46		98.89	
	96.23		98.37		98.71	

In general, vegetated cells were able to remove higher BOD_5 than the non-vegetated cells (Karathanasis *et al.,* 2003). The ability of the vegetated cells to treat the BOD is due to aerobic and anaerobic microbial degradation at the plant roots (Chandra *et al.,* 2018). In the case between the Taro and Cattail plants, Taro was able to reduce the BOD concentration more than the Cattails (see Fig. 8). One primary reason for this is that Taro roots are longer, branching out more than the Cattail and more fibrous, hence, increase their ability as a host of various microbial organisms responsible for organic decomposition (Shahid *et al.,* 2020). It was also observed that bubbles appear in the cells. The set-up temperature is not high (29°C -31°C); hence this bubble formation is accounted for by other factors. Possibly by the gas transfer (e.g., CO_2, CH_4, and N_2) from the root zone to the water column, a by-product of the biological activity that has taken place (Picek *et al.,* 2007). Another possible factor is the transfer of oxygen from the roots during rhizosphere respiration to the water column (Dong *et al.*, 2014; Wießner *et al.*, 2002) or the development of broad and deep roots, which permeate the filter media, increasing its porosity and potentially allowing more air to enter the water column (Lüthi *et al.,* 2014).

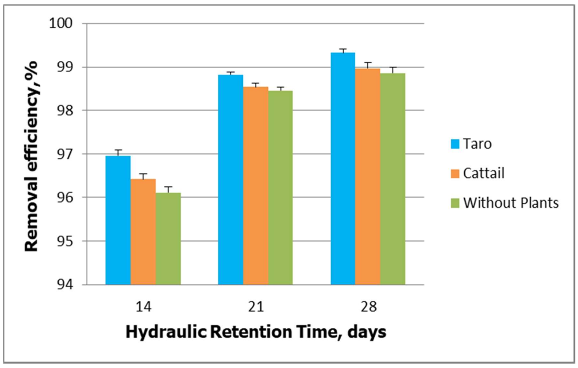

Fig. 8. Removal efficiency of BOD_5 in the wastewater planted with Taro, Cattail, and without plants in every retention time.

Lead

Sources of lead in landfills are derived from batteries, plastics, and pigments subject to water infiltration (Korzun & Heck, 1990). Lead has a very low solubility. As a result, it tends to bind firmly to particles in the environment (e.g., soil, sand, and sludge) and readily precipitates. The aquatic organisms are sensitive to lead concentration, in which their maximum acceptable level ranges from 0.04mg/L to 0.198mg/L. An increase in this concentration can affect organism reproduction or lead to physical deformity (European Commission, 2002). From the study of Ramos *et al.* (2017), the lead concentration of Bonbonon leachate is 0.2048mg/L.

Prior to this study, the characterization of pure leachate used in the set-up was done in which the lead content is <0.01mg/L. Absence or dilution of lead may occur as sampling was done during the rainy days. This study purposely added a known concentration of elemental lead in the diluted wastewater to test the set-up's capability in heavy metal removal.

This was done by adding lead chloride, which resulted in 0.2mg/L Pb concentration in the diluted leachate. The system was then able to remove 100% of the lead content of the diluted leachate, allowing it to be safely discharged into receiving body of water. In light of this, the ability of Vertical Flow Constructed Wetlands (VFCWs) to remove heavy metals is possible in both vegetated (Taro and Cattail) and non-vegetated cells by one order of magnitude from 0.2mg/L to < 0.01mg/L wastewater.

Lead concentrations in all of the cells are within the allowable limits of 0.01mg/L. All of the results were <0.01mg/L which indicate that they were beyond the detection limit of the Atomic Absorption Spectrometer used in the analysis, indicated the Pb content by one order of magnitude. However, no statistical validations of these findings were made as lead content for both the vegetation types and HRT was negligible. Data of lead results are presented in Table 6.

Table 6. Lead content of treated wastewater.

Vegetation Type	Hydraulic Retention Time		
	14	21	28
Taro	<0.01mg/L	<0.01mg/L	<0.01mg/L
Cattail	<0.01mg/L	<0.01mg/L	<0.01mg/L
Without plants	<0.01mg/L	<0.01mg/L	<0.01mg/L

The leachate produced in Bonbonon is regarded to be of high strength (11,622mg/L BOD_5). If released into bodies of water, it poses serious environmental risks. This study revealed that taro and cattail could survive in an engineered environment for more than three months. VCFWs are very effective in reducing the concentrations of BOD_5, pH, and Lead. Based on the statistical analysis, the simulated vertical flow removed 100% of the 0.2mg/ L lead in the diluted leachate regardless of vegetation and HRT. VFCWs were able to reduce slightly the average pH as the HRT increases, while no changes in temperature as HRT increases were observed. Vegetated cells planted with Taro and Cattails are more effective than cells without plants in reducing BOD_5 concentrations to as high as 99.32%. However, there is a significant increase in effluent turbidity, which can be addressed by increasing the volume of the substrate, i.e., gravel, to increase its filtration system and allowing it to settle in a stabilization pond before any discharge into a nearby stream.

The system was able to treat the leachate wastewater to meet the DENR standards, indicating that it is an effective treatment of the Bonbonon landfill leachate. The water classification of the effluents after treatment is Class C based on DAO 2016-08. Where BOD_5 is less than 50mg/L, Lead is less than 0.01mg/L; pH is between 6.0 and 9.0, and 3°C change in temperature of the effluent. It is expected that these results will have positive effects on the receiving bodies of water and the aquatic organisms when sustained over time. It will also benefit the neighboring communities that rely on the receiving stream for irrigation, livestock watering, and other purposes.

Conclusion

The study shows that Constructed Wetlands (CWs) with the sub-surface vertical flow can be used as an effective natural treatment of landfill leachate in terms of its physical and biochemical properties. After treatment, the effluents are classified as Class C in DAO 2016-08 and can be used safely for irrigation, livestock watering, and other purposes.

The research provides evidence that taro and cattail can survive in an engineered vertical flow constructed wetland, where vegetated cells are more capable of removing pollutants than non-vegetated cells. Taro (*Colocasia esculenta*) removed more contaminants than Cattail (*Typha latifolia*), with 99.32% BOD_5 removal and pH reduction to as low as 7.06. Furthermore, whether vegetated or not, VFCWs can remove lead (Pb) from wastewater at concentrations as high as 0.2mg/L. Therefore, Taro (*Colocasia esculenta*) and Cattail (*Typha latifolia*) can be used as potential phytoremediation species of plants.

Recommendations

Before any discharge into the nearby stream, the treated effluent needs further treatment, like introducing it into a stabilization pond to further decrease the turbidity, which can be attributed to the total suspended solids remaining in the effluent. This additional treatment allows the suspended solids to settle to the bottom of the pond through natural flocculation and settlement.

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Abbreviations:

5-day Biochemical Oxygen Demand (BOD_5), Hydraulic Retention Time (HRT)

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