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Assessment of a Gravel Bed Filter Enhanced with Carbonized Rice Hull and Water Spinach (*Ipomoea aquatica)* For Fishpond Wastewater Treatment

Fhian B. Taluban[1], Engr. Ilde B. Deloria[2]
[1]Bachelor of Science in Sanitary Engineering, Western Mindanao State University, Zamboanga City, Zamboanga Del Sur, Philippines-7000
[2]Bachelor of Science in Sanitary Engineering, Western Mindanao State University, Zamboanga City, Zamboanga Del Sur, Philippines-7000
Email address: fhiantaluban18@gmail.com

Abstract—*Fishpond wastewater contains high levels of organic pollutants and nutrients, posing environmental risks. This study evaluated a gravel bed filter enhanced with carbonized rice hull (CRH) and water spinach (Ipomoea aquatica) for wastewater treatment. Two setups were tested: a control with gravel only and an experimental setup with gravel, CRH, and water spinach. The study aimed to determine the removal efficiencies of pH, DO, BOD_5, TSS, nitrate, and ammonia, compare the performance of both setups and assess compliance with Class C water quality standards for safe disposal. Statistical tests confirmed normal data distribution (Shapiro-Wilk, $p > 0.05$) and equal variances (Levene's, $p > 0.05$). The experimental setup significantly improved water quality, with reductions in BOD_5 (92.16%, $p = 0.086$, $d = 1.85$), TSS (88.68%, $p = 0.357$, $d = 0.85$), and ammonia (98.5%, $p = 0.7376$, $d = 0.29$). While differences in pH ($p = 0.409$, $d = 0.75$), DO ($p = 0.425$, $d = 0.72$), and nitrate ($p = 0.7349$, $d = 0.3$) were not statistically significant, large effect sizes suggest practical improvements. Nitrate removal exceeded 85% in Trial 2 but increased in Trial 3 due to rainfall dilution. Water spinach initially struggled to adapt but acclimated over time, enhancing nutrient uptake. CRH contributed to microbial activity, improving pollutant breakdown. The treated effluent met Class C standards under DAO 2016-08, demonstrating the effectiveness of CRH and water spinach in gravel bed filters. Future research should explore large-scale applications, optimize component ratios, and assess additional treatment stages such as Waste Stabilization Ponds to further improve wastewater quality.*

Keywords— *Fishpond wastewater, Gravel bed filter, Carbonized rice hull (CRH), Water spinach (Ipomoea aquatica).*

I. INTRODUCTION

Water, as a universal solvent, is highly prone to pollution, as it can dissolve a wide range of substances, leading to contamination of both fresh and saltwater bodies (Schwarzenbach et al., 2010). Effluent from fishponds, typically rich in organic materials like fish waste and uneaten feed, poses a significant environmental threat when released untreated (Crab et al., 2007). In the Philippines, particularly in areas such as Dumanquillas Bay, untreated fishpond wastewater contributes to water quality degradation and marine ecosystem damage (Jumawan et al., 2022). The growing fish farming industry exacerbates these issues, highlighting the need for effective wastewater treatment solutions. Various contaminants, including total suspended solids (TSS), biochemical oxygen demand (BOD_5), ammonia, and nitrates, are key parameters affecting water quality (Boyd & Tucker, 2012). Discharge of untreated fishpond wastewater can cause eutrophication, harming aquatic life and biodiversity (Camargo & Alonso, 2006). The Philippine Clean Water Act mandates wastewater treatment systems in aquaculture facilities, yet there is limited implementation of such systems in regions like Zamboanga City (Republic Act No. 9275, 2004). This study explores an alternative treatment method using a gravel bed filter, carbonized rice hulls (CRH), and water spinach (*Ipomoea aquatica*) to treat fishpond wastewater.

II. METHODOLOGY

2.1 Secondary Data Gathering

The secondary data utilized in this study were gathered from multiple reputable sources, including libraries of government institutions, Western Mindanao State University (WMSU), online academic databases, and laboratory test results from the Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB). These materials provided foundational support to the research through an extensive review of relevant literature, scientific publications, and previous studies on sustainable wastewater treatment systems.

2.2 Research Methodology

The experimental setups were constructed at the researcher's residence in Tugbungan, Zamboanga City. The selected location offered an ideal environment for the study and had a sufficient lot area of 150 square meters to accommodate the gravel bed filter systems. The methodology was guided by the design used in the study by Sosthene et al. (2018), which focused on low-cost filtration systems using gravel bed filters and wetland plants for treating domestic wastewater.

2.3 Source of Wastewater

The wastewater used in this research was sourced from a fishpond located in Purok 7, Tugbungan, Zamboanga City. Prior to collection, formal permission was secured from the local authorities and the fishpond owner, ensuring compliance with ethical research guidelines. A formal request letter outlining the study's objectives and methodology was submitted to facilitate approval.

2.4 Collection of Samples

Wastewater samples were initially collected on October 2, 2024, followed by additional collections on October 9 and 16, 2024. Sampling was conducted between 8:00 to 9:30 AM from the fishpond outlet directly discharging to a river. The collected samples were stored in two 200-liter drums for filtration and two 1000 mL containers designated for laboratory analysis. Proper sample preservation was maintained by using coolers with ice during transport to the laboratories. Influent and effluent water samples were tested to evaluate treatment effectiveness. Parameters such as pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), and total suspended solids (TSS) were analyzed at DENR-EMB, while nitrate and ammonia were tested at ChemPro Laboratory.

2.5 Experimental Setup

Two filter bed systems were constructed: a control setup using gravel only, and an experimental setup enhanced with carbonized rice hull (CRH) and *Ipomoea aquatica* (water spinach). Both systems were designed following pilot-scale wetland standards described by Kadlec and Knight (1996), with overall dimensions of 0.61 m × 2.44 m × 0.61 m. The use of marine plywood walls reduced the internal dimensions slightly to 0.56 m in depth and width, and 2.39 m in length. Each setup was supplied by a 200-liter storage tank elevated above the system to allow gravity-fed inflow. A total of 177 liters of fishpond wastewater was introduced per cycle through a 2.4-meter perforated pipe to ensure even distribution. The Figure 1 and 2 shows the schematic diagram of the experimental and control setup.

Figure 1. Schematic Diagram of the Experimental Setup.

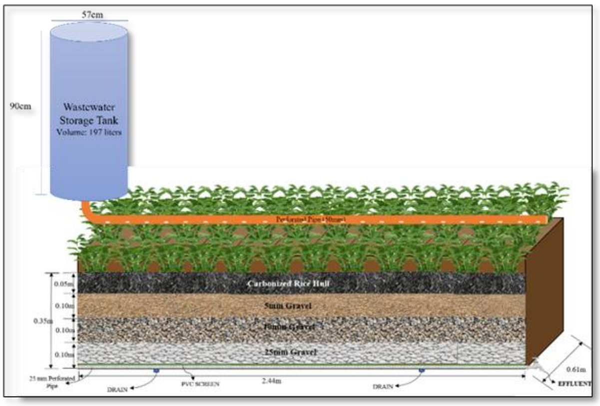
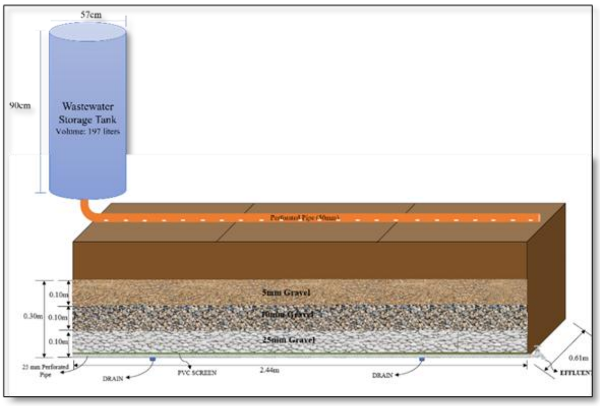


Figure 1. Schematic Diagram of the Control Setup

2.6 Water Spinach (Ipomoea aquatica) Setup

The water spinach setup incorporated 37 healthy *Ipomoea aquatica* plants distributed across the filter bed at optimized spacing to maximize phytoremediation. Each plant had an initial height of 20 cm and an approximate weight of 0.05 kg. This arrangement enabled efficient nutrient uptake and stabilization of the filter system through natural biological processes.



2.6.1 Filtration and Storage Tank Dimensions

Each system was structured with three distinct gravel layers: 25 mm coarse gravel, 10 mm medium gravel, and 5 mm fine gravel, each 0.10 m thick. In the experimental unit, a 5 cm CRH layer was added above the fine gravel to enhance adsorption. The CRH was produced through a three-hour carbonization process, reaching 300–500°C, and stored in airtight containers. The setup also included a flow-controlled perforated inlet pipe and outlet system made of 25-mm PVC with 5-mm holes spaced 10 cm apart, supported by 6-mm PVC screens to prevent clogging.

2.6.2 Inlet Flow Rate and Perforated Pipe Design

Hydraulic calculations determined the inlet flow rate at 0.705 L/s using Manning's formula and standard pipe flow equations. The inlet pipe, with a diameter of 50 mm and 30 holes spaced at 8.1 cm intervals, distributed water uniformly across the gravel bed. The storage tank emptied within 1.16 minutes per cycle, providing a consistent inflow volume to each system.

2.6.3 Construction

Construction emphasized effective flow and structural integrity. All gravel materials were sieved and washed thoroughly to ensure uniformity and remove impurities. The CRH layer was installed evenly above the fine gravel, and *Ipomoea aquatica* plants were carefully transplanted into the system after a rooting period in controlled conditions. To prevent residual contamination, the filter beds included base drains to fully evacuate water between treatment cycles.

2.7 Material Preparation and Planting

CRH was produced from clean rice hulls carbonized on a metal roof using firewood and a controlled low-oxygen process. The resulting material was lightweight, porous, and highly adsorptive. Gravel materials were sorted by size, washed, and dried before installation. Water spinach stems were cut to 20 cm with at least one node and rooted in shallow containers for one to two weeks before transplanting into the system.

2.8 Sampling and Laboratory Analysis

Sterile containers were prepared for sample collection to ensure data accuracy. Prior to starting filtration, raw samples were taken for baseline measurements. Effluent samples were collected after seven days of treatment using the same procedures to maintain consistency. Samples were immediately chilled and transported to DENR-EMB and ChemPro laboratories for analysis. Each test was conducted in triplicate for both influent and effluent water to ensure accuracy and repeatability.

III. RESULTS AND DISCUSSION

This chapter presents a comprehensive summary of the experimental results regarding the treatment of fishpond wastewater using gravel bed filters, both with and without enhancements. The performance of the experimental unit integrated with Carbonized Rice Hull (CRH) and Water Spinach (*Ipomoea aquatica*) was evaluated against the control unit (gravel bed alone). Water quality parameters such as pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), nitrate, and ammonia were assessed. Observations related to plant adaptation and environmental responsiveness are also discussed.

3.1 Adaptation of Water Spinach (Ipomoea aquatica)

During the initial week of the experiment, several water spinach plants exhibited signs of environmental stress and subsequently died. This phenomenon was attributed to the abrupt transition from clean irrigation water (rice field conditions) to nutrient-rich fishpond wastewater. However, by the second week, surviving plants began to exhibit signs of adaptation, and by the third week, healthy growth was evident. This gradual acclimatization is consistent with the findings of Guo et al. (2020) and Duyen et al. (2018), who emphasized the tolerance and nutrient uptake capacity of *Ipomoea aquatica* under high-nutrient aquatic environments.

Table 3.1: Adaptation of Water Spinach

Week	Observation
Week 1	Notable mortality due to shock from sudden environmental transition
Week 2	Surviving plants began to adapt and exhibited growth
Week 3–5	Healthy growth and continued adaptation; full physiological acclimatization

3.2 Performance of Gravel Bed Filters

3.2.1 pH Adjustment

The gravel bed system effectively moderated the influent pH levels, increasing pH toward the neutral range. The experimental unit performed slightly better than the control due to the additional buffering capacity provided by CRH and the biological activity of the plants.

Table 3.2: pH Adjustment in Gravel Bed Filter Systems

T	Influent pH	Control Effluent pH	Experimental Effluent pH	% Increase (Control)	%Increase (Experimental)
1	5.95	7.63	7.71	28.24%	29.58%
2	6.22	7.10	7.35	14.14%	18.17%
3	6.72	7.21	7.42	7.29%	10.42%

Statistical Analysis:

- p-value = 0.409 (not statistically significant)
- Cohen's d = 0.75 (large effect size)

3.2.2 Dissolved Oxygen (DO)

There was a consistent increase in DO levels from influent to effluent in both systems. The experimental setup exhibited higher DO levels, likely due to increased microbial activity and oxygenation facilitated by *Ipomoea aquatica*.

Table 3.3: DO Adjustment in Gravel Bed Filter Systems

T	Influent DO (mg/L)	Control Effluent (mg/L)	Experimental Effluent (mg/L)
1	4.40	5.08	5.90
2	5.78	7.49	7.60
3	4.74	5.33	6.82

Statistical Analysis:

- p-value = 0.425 (not statistically significant)
- Cohen's d = 0.72 (large effect size)

3.2.3 Biochemical Oxygen Demand (BOD_5)

Both systems demonstrated effective BOD_5 reduction. However, the experimental unit showed significantly greater removal efficiency, indicating enhanced degradation of organic matter.

Table 3.4: BOD_5 Adjustment in Gravel Bed Filter Systems

T	Influent BOD_5 (mg/L)	Control Effluent (mg/L)	% Reduction (Control)	Experimental Effluent (mg/L)	% Reduction (Experimental)
1	38.80	10.00	74.2%	6.50	83.24%
2	53.00	11.00	79.25%	5.00	90.56%
3	51.00	6.00	88.24%	4.00	92.16%

Statistical Analysis:

- p-value = 0.086 (marginal significance)
- Cohen's d = 1.85 (very large effect size)

3.2.4 Total Suspended Solids (TSS)

The removal of TSS was highly efficient in both systems, with the experimental unit exhibiting a marginally higher performance. The physical filtration provided by the gravel media was further enhanced by root entrapment and microbial activity.

Table 3.5: TSS Adjustment in Gravel Bed Filter Systems

T	Influent TSS (mg/L)	Control Effluent (mg/L)	% Reduction (Control)	Experimental Effluent (mg/L)	% Reduction (Experimental)
1	92.00	5.50	94.02%	4.50	95.10%
2	43.00	7.00	83.72%	4.50	89.53%
3	43.00	10.20	76.30%	8.00	81.40%

Statistical Analysis:

- p-value = 0.357 (not statistically significant)
- Cohen's d = 0.85 (large effect size)

3.2.5 Ammonia Removal

Ammonia concentrations were substantially reduced in both systems, with the experimental unit achieving the highest removal efficiency. This can be attributed to plant uptake and enhanced microbial nitrification due to the presence of CRH and *Ipomoea aquatica*.

Table 3.6: Ammonia Adjustment in Gravel Bed Filter Systems

T	Influent (mg/L)	Control Effluent	% Reduction	Experimental Effluent	% Reduction (Experimental)

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		(mg/L)	(Control)	(mg/L)	
1	0.70	0.40	42.90%	<0.30	57.10%
2	0.68	0.03	95.60%	<0.01	98.50%
3	0.50	0.08	84.00%	0.05	90.00%

Statistical Analysis:

- p-value = 0.058 (marginal significance)
- Cohen's d = 1.63 (very large effect size)

3.2.6 Nitrate Removal

Nitrate levels varied across trials. In Trial 1, both systems showed higher effluent nitrate concentrations (control: 1.4 mg/L, experimental: 1.9 mg/L) than the influent (0.4 mg/L), likely due to low water spinach uptake. Trial 2 saw a significant reduction in nitrate by both systems (greater than 85%), attributed to the combined effects of CRH and water spinach. Trial 3 showed an increase in nitrate, but the experimental setup had a smaller rise (2.29 mg/L vs. 4.4 mg/L), possibly influenced by rainfall.

The experimental system showed better control of nitrate levels, especially in Trial 2, improving water quality.

Table 3.7: Nitrate Adjustment in Gravel Bed Filter Systems

T	Influent (mg/L)	Control Effluent (mg/L)	Experimental Effluent (mg/L)
1	0.40	1.40	1.90
2	0.70	<0.10	<0.10
3	0.50	4.40	2.29

Statistical Analysis:

- p-value=0.7349 (not significant)
- Cohen's d = 0.3 (small effect size)

3.4 Compliance with Class C Water Quality Standards (DAO 2016-08)

This study assessed the compliance of treated wastewater from both the control and experimental gravel bed systems with the Class C water quality standards outlined in DAO 2016-08, which include pH, dissolved oxygen (DO), biochemical oxygen demand (BOD_5), total suspended solids (TSS), ammonia, and nitrate. Both systems met the required standards for pH, DO, BOD_5, TSS, ammonia, and nitrate, but the experimental setup demonstrated superior performance in several parameters. The pH levels in the experimental setup were more stable, likely due to the buffering effects of CRH and water spinach. Additionally, the experimental system consistently maintained higher DO levels, aided by the photosynthetic activity of water spinach and the microbial support from CRH. Both setups achieved BOD_5 reductions below the Class C limit, with the experimental system showing the most significant reduction, often below 5.0 mg/L, due to the combined effects of water spinach and CRH. The experimental system also outperformed the control in reducing TSS, as the gravel bed, water spinach roots, and CRH worked together to trap suspended solids. Regarding ammonia, the experimental setup maintained lower concentrations more effectively, while both systems kept ammonia below the 0.5 mg/L threshold. Finally, both setups successfully controlled nitrate levels, but the experimental system demonstrated better consistency in reducing nitrate concentrations, especially under high nutrient conditions. Overall, while both systems complied with Class C standards, the experimental setup, incorporating CRH and water spinach, exhibited enhanced efficiency and stability in wastewater treatment.

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