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Series Type Vertical Subsurface Flow Constructed Wetlands for Dairy Farm Wastewater Treatment

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Abstract

Agricultural and livestock farms are the major sources of freshwater pollution in rural areas in the Philippines. Small and unregulated dairy farms operate without appropriate wastewater treatment before discharge because it is too expensive to do so. With this scenario, the emergence of the need for a sustainable and cheaper alternative for wastewater treatment gave rise to the research and development studies of the efficiency of constructed wetlands. The study aims to analyze the treatment efficiency of series type vertical subsurface flow constructed wetlands planted with Napier Grass (Pennisetum Purpureum Schumach) on University of the Philippines Los Baños (UPLB) Dairy Farm wastewater with a focus on fecal coliform concentration, electric conductivity, total dissolved solids content, nitrite and nitrate concentration and pH level. The study showed that after treatment using the vertical subsurface flow constructed wetlands, all the parameters except the fecal coliform concentration were below the standard limits set by the Department of Agriculture with average removal efficiencies of 12.94% on Electric Conductivity (EC), 12.86% on Total Dissolved Solids (TDS), 216.44% on Nitrite (NO2-N), -125.64% on Nitrate (NO3-N), and -25.64% on Fecal Coliforms (FC). With the results of the analysis, a design of series type vertical subsurface flow constructed wetland for dairy farm wastewater treatment is suggested.

Keywords: Wastewater Treatment; Pollution; Nitrite; Wetlands; Total Dissolved Solids;

1. Introduction

Water is an essential resource for all living things and in developing countries, surface water is essentially the main source for water supply [1]. In the Philippines, agricultural production in rural areas is one of the sources of surface water pollution because wastewater from farms is discharged to receiving bodies of water and nearby environment without proper and appropriate treatment. This is because of the main fact that among a series of disadvantages of wastewater treatment is the financial and management aspects of the implementations of these systems in rural and suburban areas, which are smaller in scale and have lower population density [2]. Wastewater from farms contains organic matter, debris, detergents, oils, grease, sludge, and suspended solids [3]. Among the agricultural production industries is the dairy farm industry. According to Environmental Management Bureau of the Department of Environment and Natural Resources (EMB-DENR) [4], agricultural and livestock farms are the major source of

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pollution in rural areas because a small and unregulated dairy farm in the Philippines does not have an appropriate wastewater treatment. Among the reasons on inexistence of wastewater treatment facilities in rural areas is the financial and management cost it requires [5]. With this scenario, there has been an emergence of the need for a sustainable and cheaper alternative for wastewater treatment.

The need for an alternative wastewater treatment gave rise to development of constructed wetlands since they are believed to be cheap and sustainable type of wastewater treatment [6]. Constructed wetlands are man-made wastewater treatment facility that tries to mimic the natural wetlands that are able to clean water passing through them [7]. Constructed wetlands system are among the proven alternative wastewater treatment methods from around the world due to its effectiveness in treating wastewater, and are also proven to be more economical [8]. Treatment of wastewater is important as it can be reused for other purposes like irrigation or some minor usage like cleaning, washing or recreational purposes. The treatment of wastewater also helps prevent contamination of water bodies where it is discharged. And finally, effluent from the constructed wetland can be reused as irrigation minimizing the extraction of freshwater for daily operations of the farm [9].

Constructed wetland is an ideal method for treating agricultural wastewater as it can be built within the farm area and can easily blend to the environment. It does not take up too much space unlike expensive water treatment facilities. This study is beneficial to small dairy farm owners in treating their wastewater either for reuse in irrigation or discharge to bodies of water and adjacent environments. The use of Napier grass is also a beneficial part of the study as it can withstand polluted environments such as that on the constructed wetland. Napier grass species (*Pennisetum purpureum* Schumach) that are naturally growing in the dairy farm was used in the set-up to ensure that it will be able to survive the wetland environment and is adapted to grow within the intended area of the constructed wetlands [10]. As stated in the study of Goorahoo et al. [11] that Napier grass can remove considerable amounts of nutrients, such as nitrogen and phosphorus, from the dairy farm wastewater. Furthermore, Napier grass from the wetland set-up can be harvested and serve as feedstock for the dairy animals in the farm.

Generally, the study aims to analyze the treatment efficiency of a series type vertical subsurface flow constructed wetlands planted with Napier Grass (*Pennisetum purpureum* Schumach) on UPLB Dairy Farm wastewater based on parameters set by the Department of Agriculture on effluent discharged for agricultural use. Ultimately, the study aims to provide a sample design of series type vertical subsurface flow constructed wetland suitable for dairy farm wastewater treatment.

The study is limited to the simulation of series type vertical subsurface flow constructed wetlands planted with Napier Grass on a laboratory set up. The wastewater used for sampling and treatment only came from the dairy farm of the University of the Philippines Los Baños (UPLB) with a retention time of 4hrs in each tank. The effect of rainfall water absorbed by the constructed wetlands was not considered. The study on the laboratory set up of vertical subsurface flow constructed wetlands was conducted at the Innovative Engineering Materials (InEM) Laboratory of the Civil Engineering Department, University of the Philippines Los Baños. Sampling and treatment wastewater were done twice a week for six weeks.

2. Materials and Methods

2.1. Research Methodology

The study is comprised of three major stages namely (1) Data gathering, (2) Analysis, and (3) Design. In the Data gathering stage, Laboratory set-up and operationalization is the key component to ensure proper sample collection. Samples are sent to the laboratory for analysis after collection. The Second stage is the Analysis stage in which laboratory results are integrated and processed to know the efficiency of the contaminant removal. The last stage is the design stage, in which processed data are correlated and used to define design parameters for the Series Type Vertical Subsurface Flow Constructed Wetland. Figure 1 summarizes the process flow.

Figure 1. Research methodology flowchart

2.2. Materials

The materials used in this study were the following: one 56 cm diameter plastic drum with a depth of 90 cm was used as a settling tank for the wastewater; two 75 cm diameter cylindrical tank with a depth of 1.25 m were used as the vertical wetland tanks; A1-in PVC pipe for the drainage of water in the tanks and the delivery of wastewater from settling tank to the cylindrical tank; layers of sand (1-4 mm size in diameter) and gravel (5-10 mm size in diameter) as the filter media of the constructed wetlands; Napier grass (*Pennisetum purpureum Schumach*) for the vegetation; 72 – 500 mL and 36 – 100 mL clean and empty pet bottles for the storage of the wastewater being tested; One 1L beaker for the measurement of wastewater being tested; portable pH meter for measuring pH of the samples; EC-TDS multimeter for measuring the electric conductivity, total dissolved solids and temperature; and distilled water for cleaning the instruments and beaker.

2.3. Laboratory Scale Constructed Wetlands Set-up

The detailed schematic set-up of the laboratory scale constructed wetlands is shown in Figure 2. The grass was planted and scattered to allow a uniform distribution of the plant root system in the filter bed media. The raw wastewater is being placed in a settling tank for 15 hours to allow wastewater particles to settle before it is released to the treatment tank. The wastewater from the settling tank is then released and retained to the first treatment tank for 4 hrs. The treated wastewater from the first treatment tank is again released and retained to the second treatment tank for another 4 hours in order to complete the treatment cycle of the laboratory-scale constructed wetlands setup.

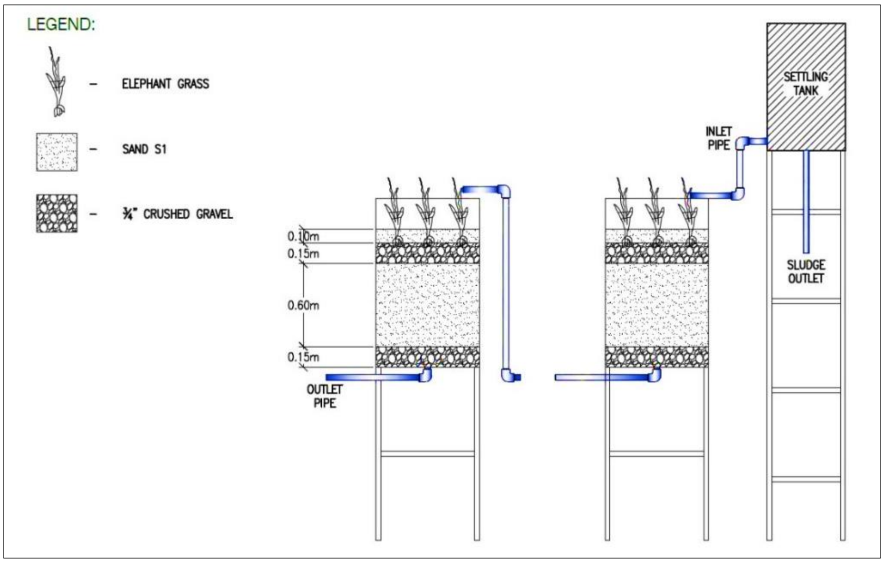

Figure 2. Schematic set-up of laboratory scale constructed wetlands tank

2.4. Sample Collection

Samples were obtained at three points of the treatment process. The first collection from the settling tank is done at 6:00 in the morning before the wastewater is allowed to flow to the first vertical tank. This will be marked as Raw sample. The next collection is scheduled at 10:00 in the morning after retaining the wastewater in the first tank for four hours and before allowing it to flow to the second tank. This is the '10am' sample or the sample of wastewater after passing through the first VSSFCW tank. The last collection is conducted at 2:00 in the afternoon also after retaining the wastewater for four hours in the second tank. This is the final effluent after the treatment in the setup.

2.5. Sample Testing

In each collection, two 500 mL and one 100 mL pet bottles were filled to the brim with the effluent for water quality testing. The benefactor of the study, Laguna Water District Aquatech Resources Corporation (LARC), collected these samples and had it tested at CRL Environmental Corporation Laboratory for its Nitrite, Nitrate, and Fecal Coliform content. A separate effluent collection was done using a 1L beaker for measuring the temperature, pH, electric conductivity, and total dissolved solids content. The measuring instruments used were pH meter, and EC-TDS Multimeter for measuring the said parameters respectively. Sample testing was done immediately after collection in order to ensure the accuracy of the testing results.

2.6. Removal Efficiency

The comparison of the effluent on the second and third collection with the first collection was necessary to determine the effectiveness of the VSSFCW setup. The calculation of the removal efficiency was made using the formula:

$$\% \, Removal = \frac{(C_i - C_e)}{C_i} \times 100 \quad (1)$$

Where; C_i: is the initial concentration of the influent ('Raw' Sample); C_e: is the final concentration of the effluent ('10 A.M.' and '2 P.M.' Samples)

3. Results and Discussion

3.1. Removal Efficiency

3.1.1. Electricity Conductivity (EC) and Total Dissolved Solids (TDS)

The Department of Agriculture (DA) [12] set the effluent limits of EC to 1000 µs/cm for to irrigate food crops that are commercially produced either directly or indirectly consumed. The wastewater sample from the UPLB Dairy farm initially has EC within the standards set by the DA and treatment of the wastewater using VSSFCW did not cause conductivity to rise above the limits as shown in Figure 3.

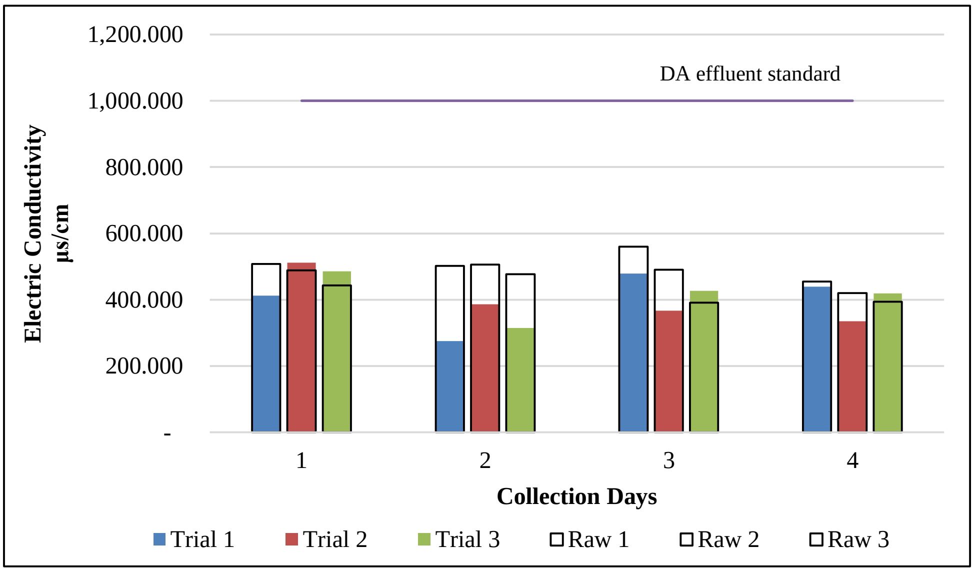

Figure 3. Electrical conductivity of the sample in relation with the DA effluent standard

Figure 4 shows the corresponding TDS concentration of samples collected where the relationship between EC and TDS can be deducted to follow a linear relationship with the equation EC = 2.004×TDS - 0.6905 in the experimental set up. However, it should be noted that when TDS concentration reaches a certain level, it is no longer directly related to the EC. This is due to the formation of ion pairs where each ion pair weakens another's charge [13]. Figure 5 shows the relationship between EC and TDS.

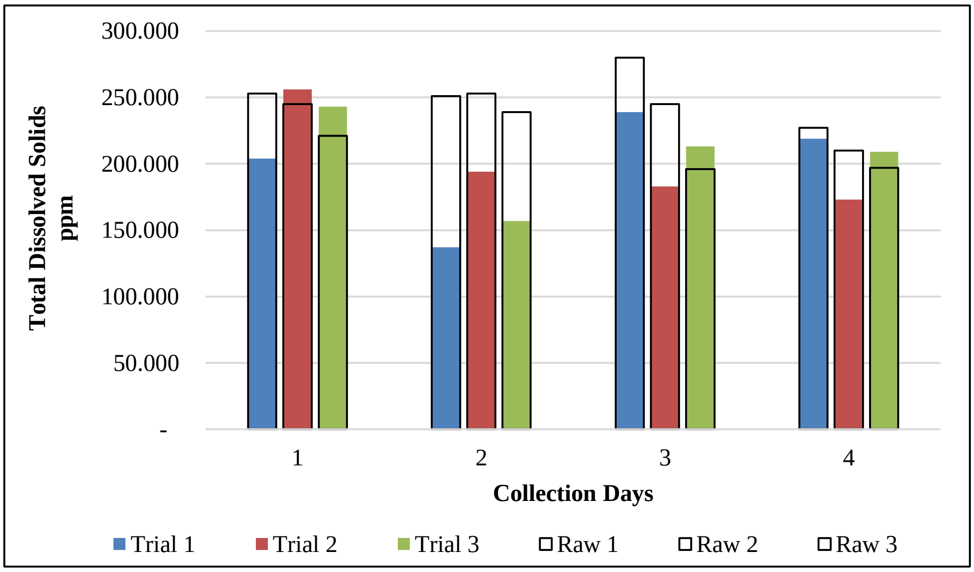

Figure 4.Total dissolved solids concentration of the samples

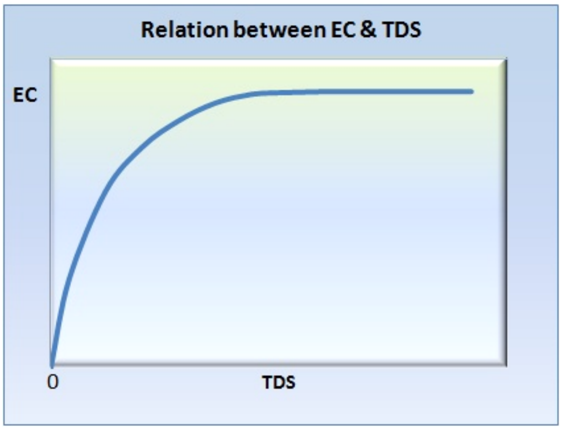

Figure 5. Relationship between EC and TDS [13]

The treatment of wastewater using VSSFCW has caused a reduction to the EC of the sample. The removal efficiency of the VSSFCW on the EC is shown in Figure 6. The removal efficiency on the EC does not follow a trend with four (4) of the samples having a negative removal efficiency while the maximum removal efficiency obtained is 45.22% during the second collection day. Similarly, the removal efficiency of the VSSFCW for the TDS concentration followed the same trend as the EC since it is linearly proportional to EC as shown in Figure 7. As reported by Gikas and Tsihrintzis [14], removal of the phosphorus salts, a dissolved solid, will consequently lower the EC of the effluent. Furthermore, they also explained that there are many cases where the final EC values may increase due to evapotranspiration and the interactions of the filter media and wastewater [14].

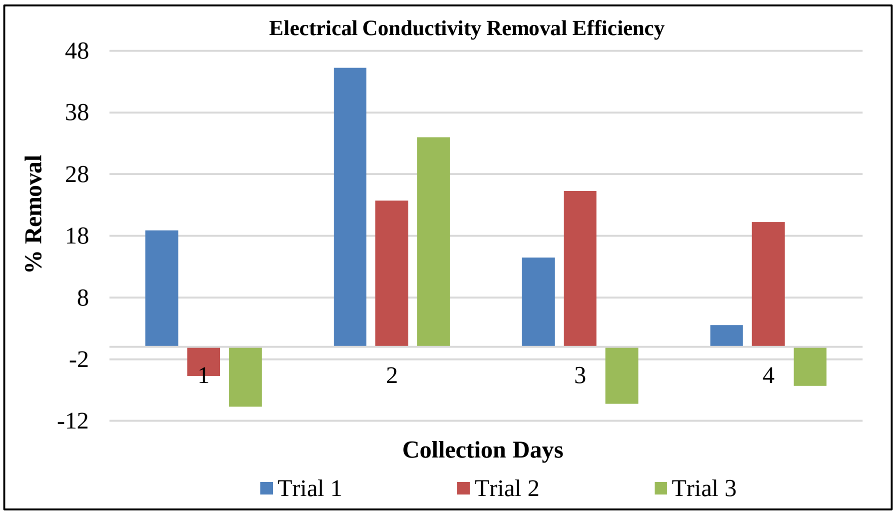

Figure 6. Removal Efficiency on Electrical Conductivity

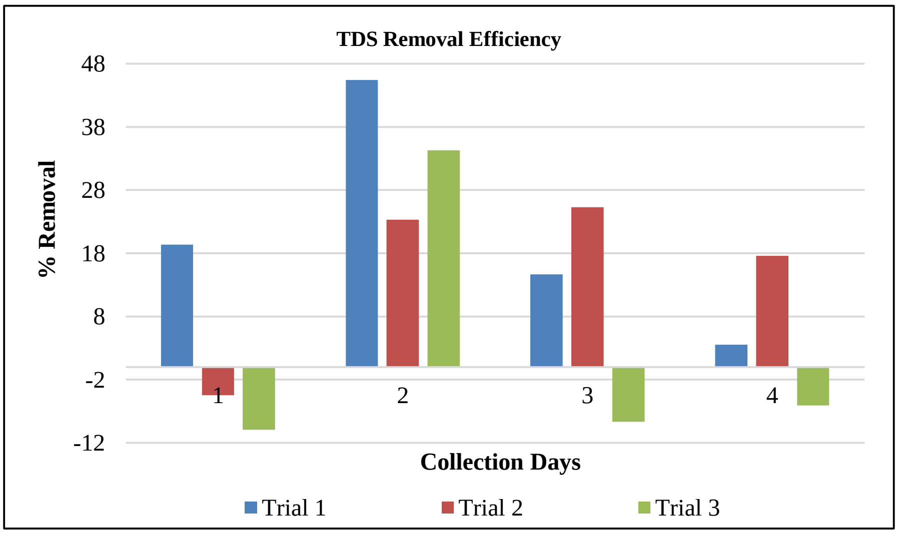

Figure 7. Removal Efficiency for Total Dissolved Solids Concentration

3.1.2. pH Level

The pH level indicates the acidity or basicity of a water. The pH is used to detect abnormalities in the water. When pH level of the irrigation water is outside the accepted range, it may cause an imbalance in nutrient content or the water may contain toxic ions. Low pH value can cause the water to be acidic and contribute in soil acidification resulting to nutritional problems for the plant growth [10]. In this study, the accepted range set by the DA is between 6.5 and 8.0. Figure 8 illustrates the pH level reading of the tested samples. The increase in acidity of the first two samples can be considered as an outlier with it being the only final effluents not within the standard set by the DA. This result may be attributed to the effect of debris from the construction of the wetlands that may have affected the pH of the water.

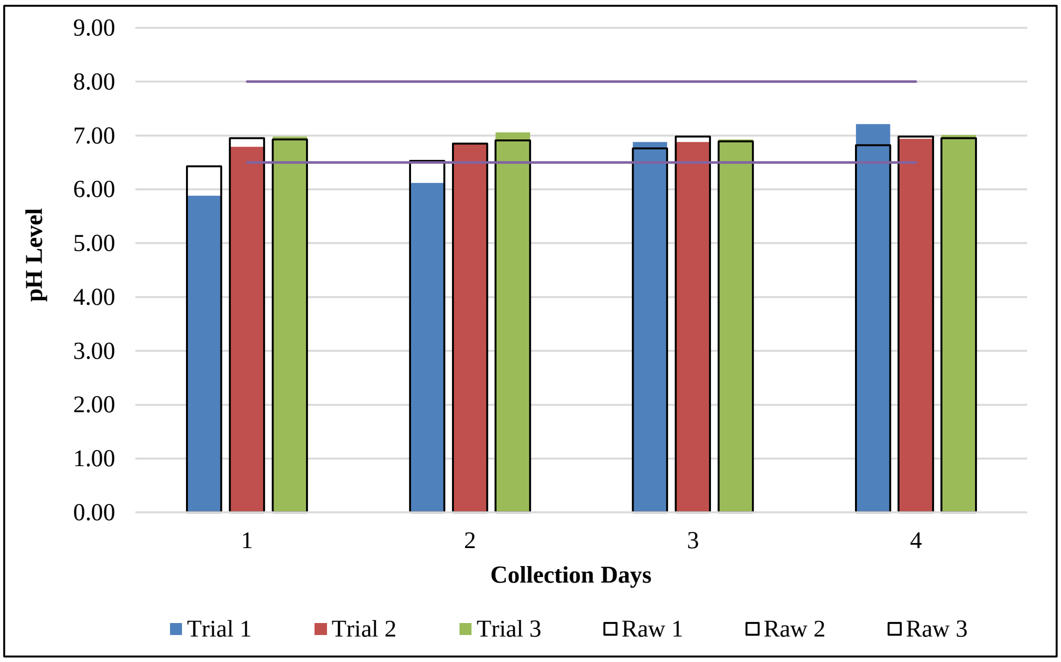

Figure 8. pH level of the sample in relation with the DA effluent standard

3.1.4. Nitrate and Nitrite

Too much Nitrogen in irrigation water can cause detrimental effects in crops therefore, the DA has set the effluent standard for Nitrogen content of irrigation water by 30 mg/L. Figures 9 and 10 shows the Nitrite and Nitrate concentration observed from the samples respectively. Even by combining the concentration of Nitrite and nitrate of the effluent, it is still within the effluent standard set by the DA for Nitrogen content.

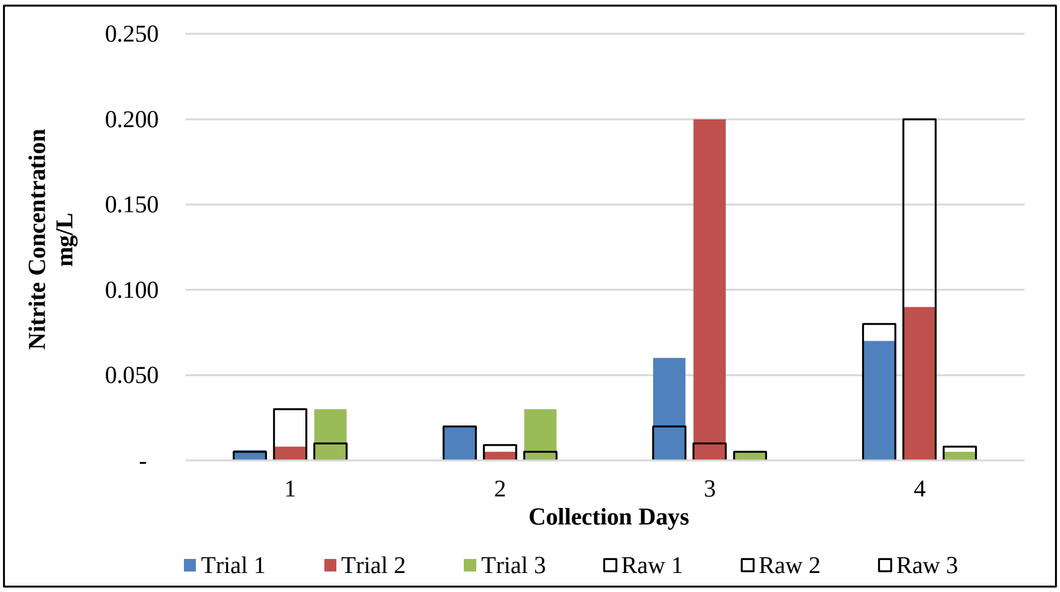

Figure 9. Nitrite Concentration

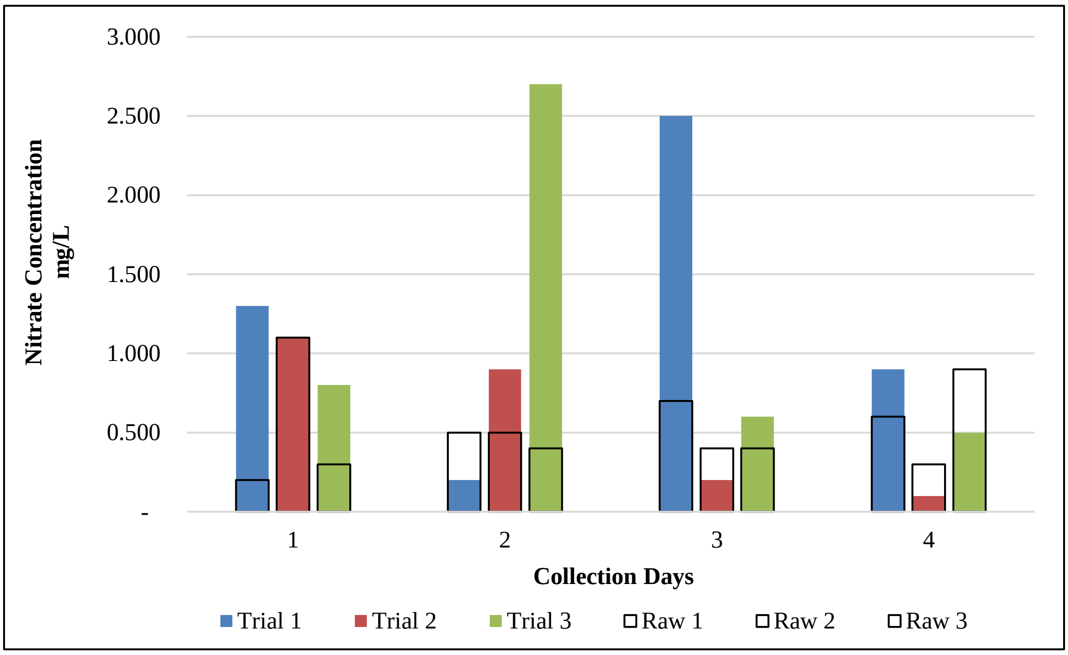

Figure 10. Nitrate concentration of the sample

The treatment of wastewater using the VSSFCW has most of the time if not a small percentage of removal efficiency, has yielded a negative removal efficiency for both the nitrite and nitrate concentration. Figures 11 and 12 shows the removal efficiency of the VSSFCW on nitrite and nitrate concentration respectively. The average removal efficiency for nitrite and nitrate is -216.44% and -125.64% respectively. This increase in nitrite and nitrate concentration can be explain by the aerobic environment that the VSSFCW offers. Under this condition, nitrification, a biological process where nitrogen-fixing bacteria converts ammonia to nitrite and nitrite to nitrate [15]. However, under the same condition, denitrification will not be able to take place as this process requires anoxic condition in order to convert nitrates into nitrogen and oxygen gases [16]. Due to this condition, the nitrite and nitrate concentration of the water will intensify as shown in the results of the study. The positive removal efficiency for Nitrites on some of the samples is due to the nitrification of nitrite, where more nitrites is converted to nitrates than ammonia into nitrites [17].

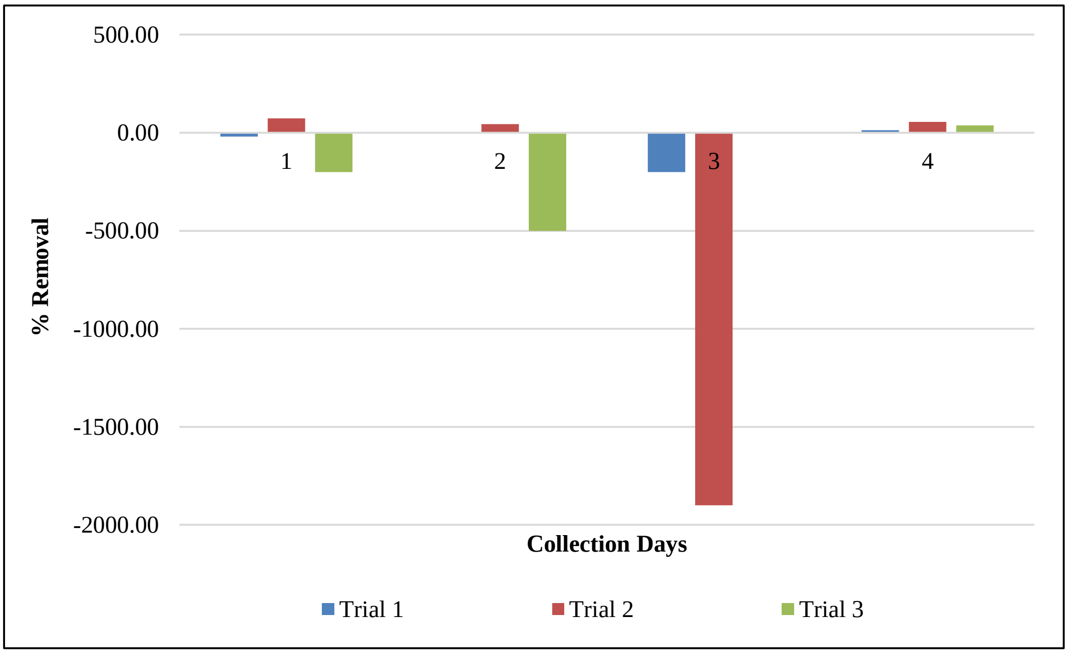

Figure 11. Removal Efficiency for Nitrite Concentration

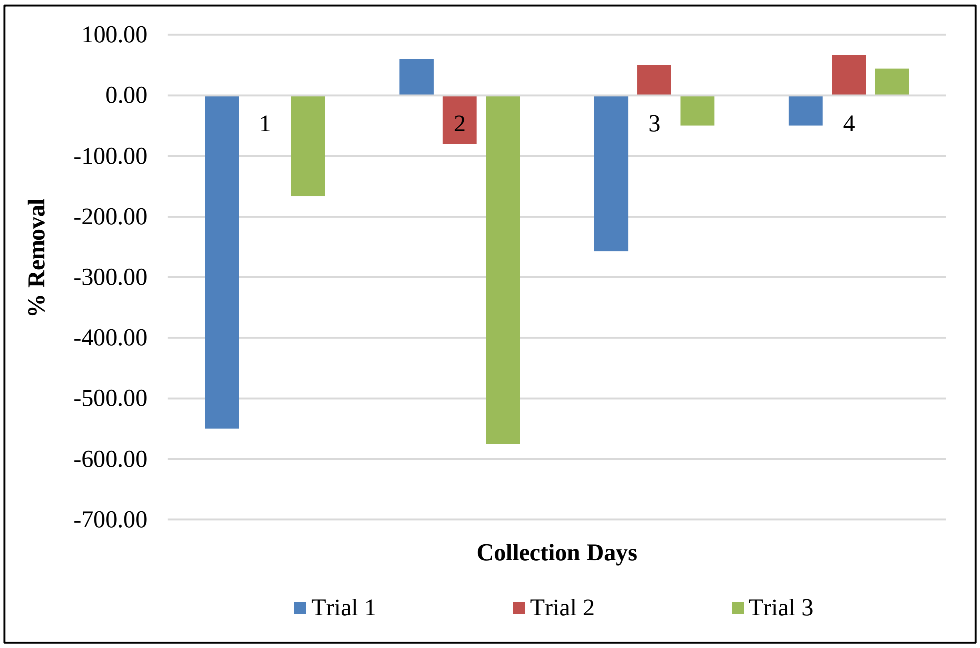

Figure 12. Removal Efficiency for Nitrate Concentration

3.1.5. Fecal Colifirm

The DA set the effluent parameter for food crops eaten raw and not commercially processed to not detectable since fecal coliform can directly affect the health of consumers of food. For the study, effluent standard for food crops commercially processed was considered where fecal coliform concentration should be less than 200 MPN/mL. Figure 13 shows the fecal coliform concentration of the samples.

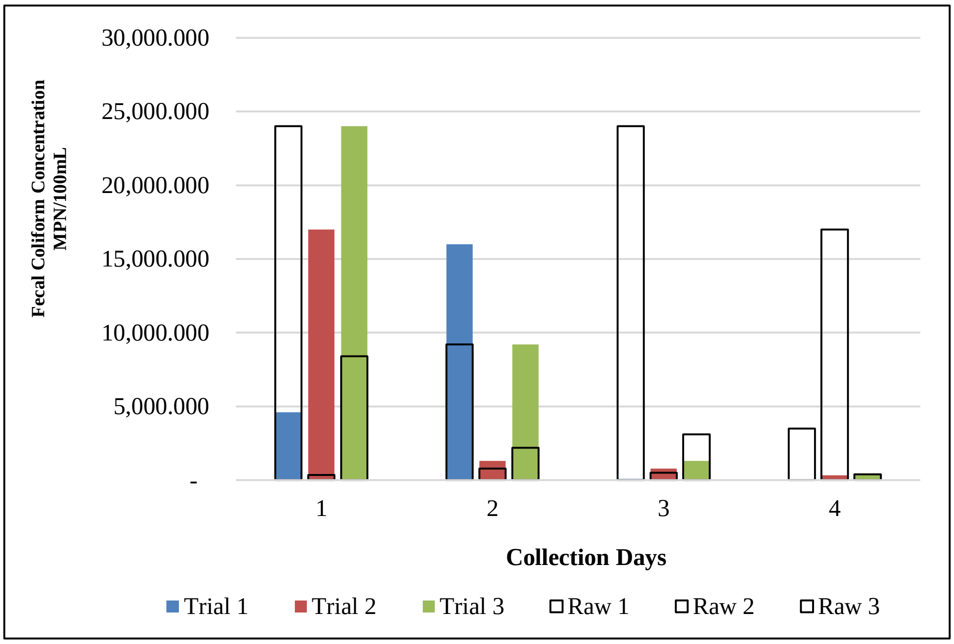

Figure 13. Fecal Coliform concentration

Figure 14 shows the removal efficiency of the fecal coliform. From this pool of data, the removal efficiency for fecal coliform is fluctuating with inclination to negative removal efficiency. The primary process used for pathogen removal is through sedimentation [18]. Through this set up, a large amount of coliforms is amassed to the layers of filter media which shows good removal efficiency. However, there are times when these pathogens were flushed together with the effluent raising the fecal coliform concentration of the water.

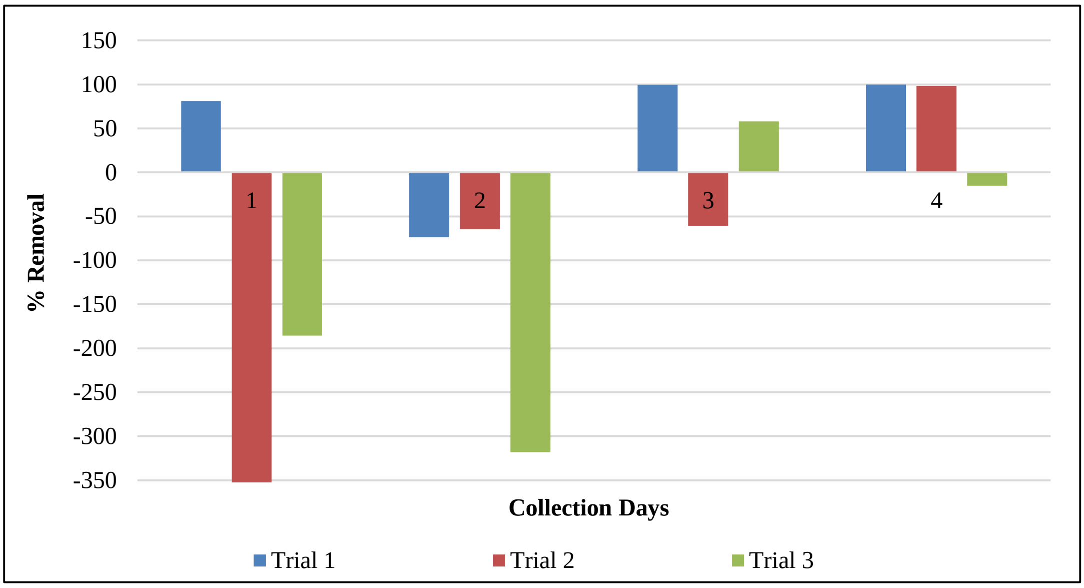

Figure 14. Removal efficiency for fecal coliform

3.2. Operation Design for UPLB Dairy Farm

3.2.1. Actual Wastewater Flow-rate

The wastewater flow rate from the UPLB Dairy Farm was estimated by measuring the discharge of each faucets used in the farm by using gravimetric method. The operating hours of the faucets was considered to obtain the estimated water volume usage of the farm. In addition to the water volume usage, the excreted urines of the cows were added to the volume of the water to determine the wastewater flow-rate of the UPLB Dairy Farm. According to the farm manager, there are 165 cows cultured in the farm in which each cow excretes 15 L of body waste per day. The effect of rainfall will also be considered which will increases the design discharge by 25% [19]. The final calculated volume wastewater discharge of the UPLB Dairy Farm per day is 63.25 m^3.

3.2.2. Settling Tank

The retention time in the settling tank that will be used is 15 hours as used in the experimental set up. This conforms to the minimum retention time possible of 1.5 hours [20]. Similarly, the depth of the settling tank will be patterned with the depth of the laboratory scale settling tank with an additional 10 cm to account for the sludge accumulation, 100 cm to produce the similar results with the set up. To contain the daily wastewater production of the UPLB Dairy Farm, the settling tank must be able to contain 63.25 m^3 of wastewater and will have a bed slope of 1% to facilitate wastewater flow. Six (6) inches in diameter pipes will be used for inlet, outlet and sludge outlet pipes. The dimensions needed for the settling tank is shown in Figure 15.

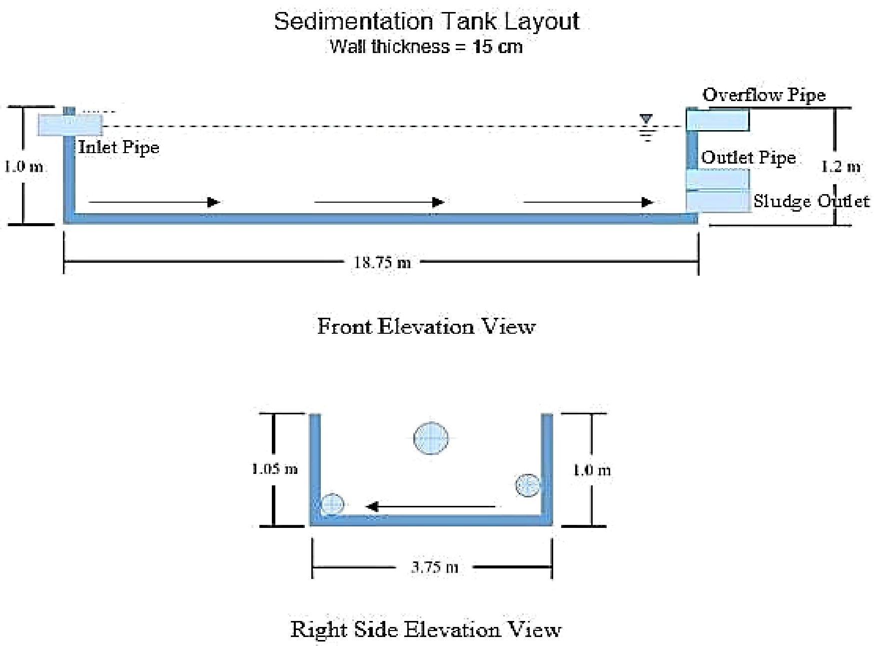

Figure 15. Sedimentation Tank Layout

3.2.3. Constructed Wetlands

The design considered usage of same filter media, depth of filter media, and retention time from the laboratory set up. This is done to ensure that the design will yield the same results with the laboratory set up. Using the wastewater flow-rate of the UPLB Dairy Farm computed and the area of field and wastewater flow-rate in the laboratory set up, the required area for each tank of constructed wetlands is 195.116 m^2. The dimensions needed for the design of the constructed wetlands is shown in Figure 16. The bed slope will be set to 1% in which the longitudinal direction of the wetlands will incline from center to both sides. The pipes that will distribute the wastewater into the wetlands will have a 1" diameter at 60 cm center-to-center spacing along the longitudinal direction of the wetlands.

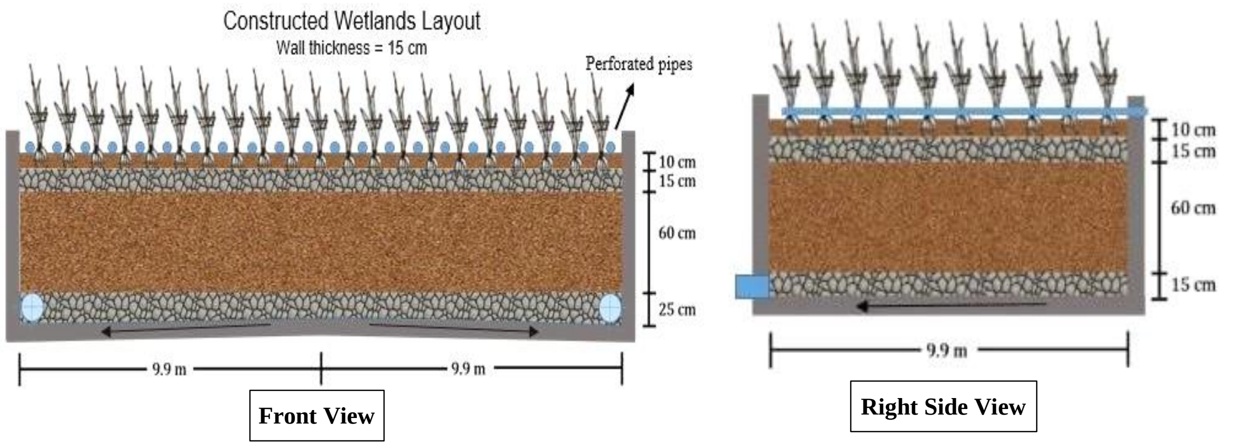

Figure 16. Constructed Wetlands Layout

3.2.4. Disinfection Tank

Tertiary treatment is deemed necessary when the water effluent after passing through the secondary treatment still does not pass the effluent standard set by the Department of Agriculture. The experiment on constructed wetlands showed that constructed wetlands is not enough to remove fecal coliforms from the wastewater to an acceptable level therefore arising the need for disinfection. Chlorination is one of the most effective and economical method of disinfection. Since the chlorination also works through settling of particles, the design of the disinfection tank will be patterned to the design of the settling tank as shown in Figure 15.

3.2.5. Operation Scheme

For the operation of the design wastewater treatment facility, an every-other-day operating scheme will be proposed to allow resting period for the wetlands. Due to this set up, there will be two (2) sets of treatment system. Furthermore, this operating scheme will allow continuous operation during maintenance and repairs. The total area required for the treatment facility is approximately 1200 m^2. The flow of wastewater from intake into primary treatment to discharge from tertiary treatment will be facilitated through gravity for a more economic design. The process of the treatment system will follow the process employed in the laboratory set up. The proposed location of the treatment facility is shown in Figure 17.

Figure 17. Proposed location of the designed treatment facility

4. Conclusion

Series type vertical subsurface flow constructed wetlands is an effective and economical way of treating dairy farm wastewater. The study explored the use of series type vertical subsurface flow constructed wetlands (VSSFCW) planted with Napier grass in treating dairy farm wastewater with the objectives. A laboratory set up for vertical subsurface flow constructed wetlands planted with Napier grass was simulated to treat the wastewater from the UPLB Dairy Farm. The wastewater first passed through the settling tank with the retention time of 15 hours before allowing it to pass through the wetlands with 4 hours retention time each. In the treatment done, aside from the fecal coliform concentration, the remaining parameters all passed the Department of Agriculture's effluent standard for irrigation. The VSSFCW planted with Napier grass having average reduction efficiencies of 12.94% on Electric Conductivity (EC), 12.86% on Total Dissolved Solids (TDS), -216.44% on Nitrite (NO2-N), -125.64% on Nitrate (NO3-N), and -25.64% on Fecal Coliforms (FC) whereas an outlier data in fecal coliform concentration was omitted. Furthermore, there is a lack of experimental data to conclude the removal efficiency of the wetlands on nitrite and nitrate content since the ammonia concentration - part of the nitrification and denitrification process for removal of nitrogen content was not considered in the study.

It can be concluded that series type vertical subsurface flow constructed wetlands planted with Napier grass is not enough to treat the UPLB dairy farm wastewater into irrigation water due to fecal coliform concentration of the effluent that is above the standards set by the Department of Agriculture. Therefore, the design of the wastewater treatment facility for the UPLB dairy farm must include a disinfection tank.

5. Recommendation

It is recommended that the ammonia concentration which is related to nitrite and nitrate content be considered in this study to further improve the understanding in the treatment capabilities of series type vertical subsurface constructed wetlands planted with Napier grass. It is also recommended that other treatment functions like hydraulic loading rate be considered in conducting the study to relate its effect on the removal efficiency of the set up. Filter media can also be further improved by adding more layers of filter media of different type that may cause significant difference in the outcome of the study. It is also recommended that a longer duration of the study be conducted to allow the wetlands to have an acclimatization period and to gather further experimental data for a more reliable findings.

In the study conducted, the fecal coliform did not reached the required effluent standard set by the Department of Agriculture therefore, thus a study on constructed wetlands with more than two treatment tanks is of great interest to determine its conformity to effluent standard for irrigation water.

6. Declarations

6.1. Data Availability Statement

Data is contained within the article or supplementary material: The data presented in this study are available in article.

6.2. Funding

This study was funded by Laguna Water District Aquatech Resources Corporation (LARC).

6.3. Acknowledgements

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6.4. Conflicts of Interest

The authors declare no conflict of interest.

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