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Research paper

Feasibility Study of Pollutant Removal in Ringlet Reservoir using Lily Canna

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Abstract

A pilot study utilizing ornamental plants as a pollutant removal agent with varying attributes such as plant density and water conditions was conducted in Universiti Tenaga Nasional, Bangi, Malaysia. Lily canna was selected in this study for its abundance and suitable growth due to ideal Malaysian tropical climates. Lily cannas were placed on floating rafts through a 6-week experimental period in water samples collected from Ringlet Reservoir, Cameron Highlands, Pahang. This study was carried out to investigate the relationship between density of lily canna plants with its corresponding pollutant removal efficiencies. The efficiency of pollutant removal was evaluated in terms of percentage removal of several parameters such as Total Suspended Solids (TSS), Turbidity and Nitrate Concentrations. The results obtained showed that removal efficiencies of up to 83.3% for TSS, 97.8% for Turbidity, 90.7% for Colour, and 85.7% for Nitrate Concentrations could be achieved within the experimental period. The tests were conducted with compliance to standard laboratory tests such as Total Suspended Solids Test, Turbidity Test and Nitrate Cadmium Reduction Method for the determination of nitrate concentrations. To conclude, the quality of treated water proved that lily canna has promising abilities to remove pollutants from water bodies in small communities.

Keywords: *floating wetland; lily canna; nitrate; Ringlet Reservoir; TSS; turbidity.*

1. Introduction

The Ringlet reservoir which is part of Tenaga Nasional Berhad's Cameron Highlands – Batang Padang Hydroelectric Scheme is currently filled with water hyacinth due to the presence of nutrients and pollutants such as phosphate (PO_4), nitrate (NO_3^-), fertilisers and pesticides. These phosphate and nitrate are conducive in supplying nutrients required for growth which contributes to the development of aquatic plants. Since Cameron Highlands is currently being developed rapidly with its agricultural activities, the use of pesticides and fertilisers are on the rise. With the presence of fertilisers and pesticides in the vicinity of the agricultural areas, the movement of these chemicals into the rivers are aided by rainfall and surface runoff. The aquatic hyacinths floating on the surface of the reservoir pose a potential hazard to the intake structure of the scheme, where the intakes play a vital role in supplying water into the penstock to run the turbines which in turn generates electricity. The growth of water hyacinth in the reservoir may potentially clog up the intake, inhibiting proper and adequate flow of water into the penstock of the power station.

The Ringlet Reservoir is formed by the construction of Sultan Abu Bakar Dam on Sg. Bertam in Cameron Highlands. The reservoir at Full Supply Level (FSL) has an area of 0.56 km^2 with an original gross storage of 6.7 million m^3 which has been reduced substantially by sedimentation. The FSL is at an elevated level (EL) of 1070.8 m (3513 ft). The reservoir first filled in January 1962 with normal operating ranges between EL 1070.8 m (3515 ft) and EL 1058.9 m (3474 ft).

Dredging can pollute the water due to agitation of the sediments which would affect aquatic organisms. Chemically, the sediments accumulate certain pesticides and the disturbance of sediments in the lake will activate dispersion of pesticides within the aquatic environment. Dredging works will degrade the water quality in Sg. Ringlet and Sg. Khazanah from Class I and II to Class III and IV.

In order to overcome this problem, it is important to tackle the root cause of this problem, which is presence of nutrients in the reservoir water. These nutrients are the contributing factor to the growth of water hyacinths. By placing ornamental plants which would function as a nutrient removal plant into the reservoir, the nutrients could be absorbed by these plants, reducing the potentially hazardous floating water hyacinth. Furthermore, the use of ornamental plants in the reservoir may also contribute to the improvement of the reservoir's aesthetic values [1]. Ornamental plants which are readily available here in Malaysia such as Canna and Heliconia are widely used in wetlands for the purpose of improving aesthetic values [2]. This enhanced aesthetics of the reservoir could possibly lead to it turning into a public attraction, and if care is given adequately, it could also serve as a tourist attraction spot. The use of ornamental plants in this case not only improves visual appearance, but removal of nutrients via these plants also aids in maintaining the water quality while preventing undesired water hyacinths from growing in the reservoir [3].

One possible plant which is readily available here in Malaysia that can be used for this purpose would be lily canna. A Constructed Wetland (CW) containing lily canna can be placed in the reservoir to allow nutrient uptake and anchored to the banks of the reservoir to prevent the floating wetland from flowing with the current and consequently choke the intakes. The lily canna will absorb the nutrients, reducing nutrient supply to the water hyacinth hence retarding its growth. Cannas are chosen for this project because according to Cao, they grow in a relatively low-temperature environment with healthy roots [4]. As Canna grows faster and can remove more nutrients compared to most ornamental plants, Canna is preferred species from a treatment perspective. Canna has shown high potential to grow well in the domestic wastewater. It has higher growth rate than Heliconia. Thus, Canna has higher total-N removal rate compared to Heliconia. Due to Canna's vigorous growth it is a more preferred species in water treatment. However, Heliconia has an economic potential as cut flowers are popular in various cases to be used in flower-decoration. Canna grows faster in tropical climate because of the warm temperature and all year long. Thus, significant N removal rate can be observed [3]. The main objectives of this study is to reduce the concentration of TSS, turbidity and nitrates (NO_3^-) in the water sample using lily canna in a floating wetland. Besides that, the effect of stagnant water and flowing water conditions and its consequence on water quality is also studied.

Bioremediation of nitrogenous compounds are well known for their high nutrient removal ability and low costs. However, their major setback of using plants to remove nitrates is that firstly, they occupy large spaces and they also display disadvantage in nitrogen removal [4]. This is because generally eutrophic waters lack biodegradable organic matter which can be efficiently used by denitrifying bacteria which causes low nitrogenous compounds removal efficiency. These conditions still require further studies to be conducted in order to fully understand the characteristics of eutrophic water with nutrient removal capability as new technology development in using microorganism for nutrient removal has been stagnant for decades [5].

This project delivers a comprehensive model for the removal of pollutants using ornamental plants. The novelty of this project is the ability of removing pollutants from water sample using biological processes of lily canna without the intervention of chemical substances. Also, the compact setup of the floating constructed wetlands makes it different from readily available conventional floating wetlands. There are several promising proposals that can be applied commercially in removing nutrients such as the entrapment of microorganisms in polysaccharide gels and combinations of several organisms for simultaneous treatment of the wastewater. Though there is potential, most of these methods incorporate some sort of chemicals in its processes [6].

2. Methodology

2.1. Sample Collections

2.1.1 Water Sample Collection

The water sample required for this project was obtained from Ringlet Reservoir (4°26'08.8"N 101°23'19.3"E) located in Cameron Highlands, Pahang, Malaysia. This was to ensure that the project would simulate the reservoir conditions in the lab where analytical tests would be carried out. The water collected was stored in a plastic container which also acted as the tank in the project. The tank measured 0.35 m in depth, 0.57 m in breadth and 0.41 m in length. The tank volume was approximately 0.08 m^3 but only 75% of the tank was filled with water sample to prevent spillage during transportation. Thus, the water sample had a volume of 0.06 m^3 per tank. This project utilised 3 tanks per phase, which meant a total of 0.24 m^3 or 240 litres were required to be obtained from the reservoir in total.

2.1.2 Plant Collection

Lily Canna was selected to be used as the ornamental plant for this project. The plants were obtained around Kajang, Selangor and were made sure to be from the similar area to minimise variations in nutrient availability and sunlight. The three tanks simulating the reservoir, namely Tank A, Tank B and Tank C had 1, 4 and 8 plants respectively. Since this project was conducted to simulate two different reservoir conditions under two phases, a total of 26 lily canna plants of similar size was used. The height of the plants selected were approximately between 50 cm to 67 cm while the diameter of the stem was ensured to be not more than 3 cm. It was also important to select lily canna which had a healthy look, almost similar number of leaves, no shrivelled leaves or stem, and with maturity of similar age. Lily canna which were in its beginning of its life cycle was preferred as nutrient uptake have been said to be higher in younger vegetation stands according to Zheng et al. [7].

2.2 Sample Preparation

2.2.1 Water Sample Preparation

The collected water sample was stored in the refrigerator at a temperature of 4°C overnight to demobilize active organisms and preserve the quantity of microbes in the sample before the experiment could be set up. Prior to setting up the water samples in the tanks and conducting necessary tests, the refrigerated water was left to warm to room temperature as temperature plays an important role in determining the presence of microorganisms in the water. Based on a study conducted by Chang et al. [8], it is important to control the temperature of the water as it affects the efficiency of nutrient removal.

2.2.2 Plant Sample Preparation

The lily cannas obtained from the soil was required to be cleaned to prevent foreign materials such as sand and dirt from interfering with the original content of the water sample. This was done by gently washing the roots under running water allowing the soil to be washed out without causing any damage to the fibrous roots.

2.3 Reservoir Simulation Setup

2.3.1 Introduction

This project was conducted to simulate Ringlet Reservoir under two conditions, with stagnant water and flowing water. These two conditions were divided into two phases, namely Phase I and Phase II. Phase I was to study the effect of stagnant water in the tanks, and Phase II to study the effect of flowing water within the three individual tanks. Each phase consisted of three tanks viz; Tank A, Tank B and Tank C where the number of lily cannas placed in each tank acted as the manipulated variable in the experiment. Tank A had the minimum amount, holding one (1) lily canna, Tank B had four (4) and consequently Tank C had the highest number with eight (8) lily cannas. This configuration was adapted due to the fact that lily canna grows quite rapidly generating extra weight and an increase in number of plants would cause the floating wetland to sink. The tanks were placed outside where full sunlight was available at the same time ensuring foreign elements which may alter the organic composition of the water sample such as rainwater does not enter the tank.

2.3.2 Number of Tanks

There were three tanks in this set-up, namely Tanks A, B and C with 1, 4 and 8 plants placed in them respectively. With the three tanks, there was a floating raft in each tank to accommodate the mentioned number of plants. The volume of water in each tank was set to be constant, with a fixed initial volume of 60 litres in each tank.

2.3.3 Floating Wetland

A floating wetland is made up of a buoyant structure, where vegetation grows on the upper region of the floating mat, while the roots grow downwards and are mostly submerged underwater. Thus, the vegetation system grows hydroponically, while taking in the nutrients from the water.

The primary purpose of the floating wetland is to act as a support medium for the plants to grow in the water sample. This facilitates the uptake of nutrients from the water as the plant grows. Besides that, the structure itself if left in an uncontrolled environment may serve as a habitat to aquatic and land animals such as fish and birds [6].

The floating wetland used in this project was made of readily available materials such as Polyvinyl chloride (PVC) conduits, Ethylene-vinyl acetate (EVA) foams, mesh cups and agricultural net. The PVC conduit serves as a structural member in order to place the EVA foam on the water and hold the plants above it. Buoyancy plays an important role in the construction of a floating wetland, and thus EVA foam was selected to be used as the base for its buoyant capability. Polystyrene mesh cups were placed underneath the EVA foam base as an anchor to hold the roots in place, avoiding the plant from collapsing. An agricultural net was placed around the stem of the lily canna to act as a secondary anchor support. However, the main purpose of this net was to provide an area for shrivelled leaves to fall, preventing them from falling into the water. This was important as shrivelled leaves that fall into the water may increase the content of denitrification bacteria thus causing an increase in nitrate concentrations [7].

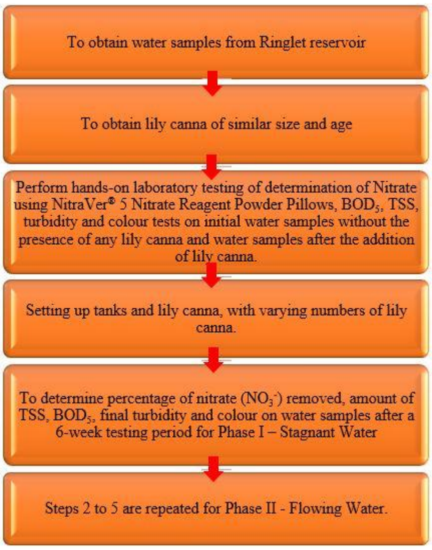

Fig. 1: A step-by-step guide on the research methodology of the project

2.4 Experimental Tests

2.4.1 Water Sampling

Water samples were collected every week at around mid-day from the three tanks prior to conducting experiments. Sampling was performed by immersing a 100 ml graduated cylinder into the water sample at mid-depth at three different locations inside the tank. Samples from the three different locations are then combined into one graduated cylinder to attain a homogeneous sample from each tank. Water samples in Tank A, B and C were sampled a total of 7 times over a 6-week duration, where the first sample was taken on week 0 (prior to introduction of lily canna) followed by sampling on week 1 to week 6.

2.4.2 Total Suspended Solids

Total suspended solids (TSS) refers to matters suspended in water or wastewater [9]. The composition of suspended particulates in the water may affect water quality in many ways. The aesthetic suitability of water for daily use reduces significantly with high amounts of TSS primarily due to the colour. Besides that, it is important to maintain a low concentration of solids in the water as palatable water has a maximum limit of 500 mg/L dissolved solids for it to be safe for human consumption. Testing for TSS helps in assessing the quality of water and wastewater in accordance to the regulations set by the respective agencies [10].

The procedure to conduct this test was to first insert a Whatman glass-fiber filter paper Grade C into a laboratory chamber furnace (CWF 1300, Carbolite Gero Ltd, United Kingdom) at 550°C to burn off all excess volatile materials on the filter paper. The filter paper was then weighed using an analytical balance (GR-200, A&D Company Limited, Japan) to obtain the initial weight of the filter paper, M_1. The wrinkled side of the filter paper was placed facing upwards into the filtration apparatus, in this case a Buchner Funnel. The Buchner apparatus was turned on to apply vacuum and a small amount of distilled water was poured onto the filter paper disk for it to be able to sit properly without movement. The disk was then washed down with 50 ml volume water sample, denoted as V, and left to filter until all the water has passed through the filter paper with the assistance of the vacuum pump. Three successive 10 ml distilled water was then poured consecutively into the graduated cylinder to allow complete drainage cleansing all solids which may have been left over in the cylinder.

The suction was continued for 3 minutes or until all traces of water was no longer visible. The washings collected in the Buchner conical flask was discarded. Once filtration was complete, the filter paper was removed using forceps. Care was taken while removing the filter paper as the forceps may tear the delicate sides of the filter paper ensuing a difference of mass of the filter paper. Once the filter paper was removed, it was dried in an oven (UM200 Cooled Vacuum Oven, Memmert GmbH + Co., Germany) at 103 to 105°C for 1 hour. After an hour, the filter paper was left to cool in a desiccator to balance the temperature and weight. The weight of the dried filter paper, M_2 was then recorded. The equation used to derive the amount of Total Suspended Solids (TSS) is as follows:

$$TSS = \frac{M_2 - M_1}{\text{Volume of Sample}, V} \quad (1)$$

The removal efficiency of Total Suspended Solids from the water sample was calculated as shown in the equation below:
Removal Efficiency,

$$TSS\ (\%) = \left(\frac{C_i - C_f}{C_i}\right) \times 100\% \quad (2)$$

where C_i denotes the initial concentration of suspended solids in mg/L and C_f denotes the final concentration of suspended solids in the water sample.

2.4.3 Turbidity

Turbidity is the clarity or how ‘milky’ a sample of water is and an important determinant for the suitability of consumption by humans and many industrial processes. Turbidity is principally caused by suspended solids and colloids floating in water like clay, silt, sand and other microorganisms. Turbidity is measured by the amount of light which can pass through the water sample without being scattered or absorbed due to the suspended particulates in the water [11]. The more scattered the light, the higher the turbidity value. The scattered light of a water sample is compared to a blank subjected to same conditions, which in this case is distilled water. The unit of measurement for turbidity is Nephelomet-

ric Turbidity Unit (NTU). If storing was necessary, the samples were placed in a 4°C refrigerator and are then warmed to room temperature before placing them in the turbiditimeter. This was important as condensation due to temperature changes may occur on the surface of the glass vial and cause an inaccurate reading. It was also important to note that the glass vials need to be shaken prior to placing it into the holder of the turbiditimeter.
Around 20 ml of water sample was first collected from the tank and poured into a transparent glass vial. Air or any other forms of trapped air was removed from the glass sample before measurements were taken. The glass vials are then cleaned with a dry cloth to ensure that the glass surface is free from any substances which may interfere with the path of light while readings are being taken, such as oil residue from fingers, dirt or any form of water droplets. This similar process was repeated using another glass vial, with distilled water filled in it instead of water sample. This is the blank solution. Using a turbiditimeter (HACH DR 900, Hach Company, USA), Program 745 Turbidity was selected and the blank was shaken a few times and placed in the holder. The ZERO tab was then pushed to display 0 FAU (Formazin Attenuation Units). Then, the blank glass vial was replaced with shaken vial with water sample and the READ tab was pushed. The reading which appeared on the screen was recorded and an average of three readings were taken to warrant uniformity.

Table 1: Guide on rounding off turbidity values. [10]

Turbidity Range NTU	Report to the nearest NTU
0-1.0	0.05
1-10	0.1
10-40	1
40-100	5
100-400	10
400-1000	50
>1000	100

The removal efficiency of turbidity from the water sample was calculated as shown in the equation below:

$$\text{Removal Efficiency, Turbidity (\%)} = \left(\frac{C_i - C_f}{C_i}\right) \times 100\% \qquad (3)$$

where C_i denotes the initial turbidity in NTU and C_f denotes the final turbidity in the water sample.

2.4.3 Nitrate Cadmium Reduction Method

The determination of nitrate (NO_3^-) is usually a difficult process as it involves intricate procedures and has many external influences such as concentrations of iron, copper and other metal constituents [10]. The presence of these substances above several milligrams per liter may result in a reduced efficiency of reduction of NO_3^- to nitrite (NO_2^-). The method applied to determine the amount of nitrate in the water sample was adapted using the HACH Method 8039 for water, wastewater and seawater using NitraVer® 5 Nitrate Reagent Powder Pillows or AccuVac® Ampuls. The applicable range for this High Range (HR) test was between 0.3 mg/L to 30.0 mg/L NO_3^-N. It was important to ensure that this test was carried out promptly after sample collection. If storage was necessary, it was kept at 4°C for a maximum duration of 2 days. This test was started by first selecting the appropriate program on the HACH DR 900 instrument, which was 355 N, Nitrate HR PP. Then, 10 ml of water sample was poured into a glass vial. The NitraVer® 5 Nitrate Reagent Powder Pillows were then put into the glass vial and shaken for 1 minute. Following that, the vials were left to react for 5 minutes. The sample turns amber if there was presence of nitrate. While waiting for the 5 minutes reaction to take place, the blank cell was prepared. This blank was distilled water in a similar glass vial, with the surface of the vial properly cleaned to remove unwanted stains which may alter results. The vial was then placed into the HACH DR900 instrument and the ZERO tab was pushed to display 0.0 mg/L NO_3^-N. Within a minute after the water sample has undergone the 5-minute reaction, the glass vial was placed in the instrument and the READ tab was selected. The results shown in mg/L NO_3^-N were recorded.
The removal efficiency of nitrates from the water sample was calculated as shown in the equation below:

$$\text{Removal Efficiency, } NO_3^- \text{ (\%)} = \left(\frac{C_i - C_f}{C_i}\right) \times 100\% \qquad (4)$$

where C_i denotes the initial concentration of nitrates in mg/L and C_f denotes the final concentration of nitrate in the water sample.

Fig. 2: Process flow chart of the project

3. Results and Discussion

3.1. Phase I – Stagnant Water

Phase I of this project tested the ability of lily canna in removing nitrates and improving water quality of the water sample under stagnant water conditions. The three tanks, Tank A, B and C were placed with 1, 4 and 8 lily cannas respectively. There was also a tank set up with no lily canna to act as the control of this test. The findings based on tests performed such as TSS, turbidity and concentration of nitrates are discussed in the following subtopics.

3.1.1 Removal of Total Suspended Solids (TSS)

Total Suspended Solids (TSS) test is conducted as the removal of solids in a water body is an important component in providing the clarity of water. This consequently improves the quality of the water thus providing a better management of water resources. [12]. A lower TSS value also contributes to a better public acceptance for domestic and industrial usage. The TSS test was conducted using a vacuum pump and a Buchner funnel by filtering through 50 ml of water sample. The TSS value was calculated and plotted as in Figure 3.1.

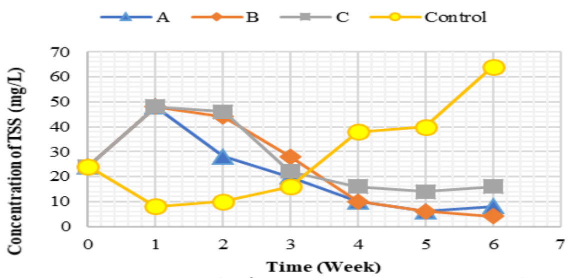

Fig. 3.1: Graph of TSS (mg/L) against time (Week)

As seen from Figure 3.1, the initial reading of suspended solids in Phase I of the water sample was relatively high with an initial value of 24 mg/L. The high initial value can be explained by the fact that the water sample was thoroughly mixed prior to sampling, causing sediments such as soil particles to be suspended in the water tanks. The trend for the suspended solids continues to increase in all three tanks within the first week. This increasing trend can be explained by the fact that growth of microalgae due to the presence of nutrients and sunlight which provided a conducive environment for algal bloom [13]. The existence of microalgae floating in the water sample caused an increase in amount of suspended matter, consequently increasing amount of matter on the filter paper during filtration. The production of micro algae starts to decrease slightly in tanks B and C during week 2, whereas concentration of suspended matter decreased significantly in Tank A. This phenomenon is due to the higher density of lily canna in tanks B and C, providing an increased surface area of roots for higher rate of microalgae growth [14] which increases concentration of suspended solids as compared to Tank A. The trend in tank A continues to decrease while concentration in tanks B and C reduces significantly from week 2 to week 3. The reason for this significant drop in TSS is the effect of continuous growth of microalgae developing to form algae mats. Rapid development of microalgae into algae leads to strong adhesion between algae and the roots which act as a biofilm resulting in the formation of slimy green clumps of algae which attaches to the root surface of the lily cannas [13]. These algae clumps are held firmly onto the roots and does not mix in the water sample when sampling is done. The algae clump can be removed readily by simply removing the lily canna plant. The production of algae mats reduces the amount of free-flowing algae in the water sample. The absence of free floating microalgae in the water sample leads to a decrease in amount of TSS in the following weeks.

Beginning from week 3 onwards, the TSS concentration decreases exponentially within all three tanks until the end of this phase which was in week 6. The decrease of suspended materials in the water is due to the growth of microalgae to macroalgae, while macroalgae forms thicker slimy algae mats. Macroalgae bloom clumps together on the surface of the roots and is no longer suspended in the water body. The bonds between the algae mats and the growth media, which are the fibrous roots of the lily canna in the tank continues to strengthen. At this point of the project, the constituents of suspended solids in the water sample are mainly foreign particles other than algae.

Based on the observation made in Phase I, the production of algae are more rapid and higher in quantity as the density of lily canna increased. This is shown by the graph plotted in Figure 3.1 where it is clearly seen that Tank C has the highest concentration of suspended solids compared to other tanks with lily canna at the end of the 6-week testing period. According to Abdel-Raouf, et al. [15], growth of algae is dependent on several factors including the presence of growth media in the water as well as initial density of algae present in the water sample. Their study stated that algal growth is enhanced with more surface area available for growth and attachment and that a higher the initial concentration of algae, the more accelerated the growth of young algae.

As opposed to the conditions observed in the tanks with lily canna in them, the control tank without any lily canna generally experienced an increase in suspended solids throughout the 6-week testing period, although there is a drop in TSS within the first week due to settlement. This shows that the presence of lily canna in the water sample aids in the removal of TSS as opposed to when there is no lily canna. The increase in TSS in the control tank was possibly due to the introduction of foreign matter such as dead insects and bird droppings.

Tank B with 4 lily cannas exhibit the highest percentage removal of suspended solids, followed by Tank A and finally Tank C with the least removal. This observation may explain that Tank B with 4 lily cannas provided sufficient root surface area for the solids, mainly algae to get trapped in and form a slimy green mat as compared to Tank A with 1 lily canna. Tank C showed the least removal due to its high density of roots, providing more surface area for algal growth, corresponding to more suspended algae in the sample. The algae mats can be easily removed by simply replacing the lily cannas with new ones in the floating raft.

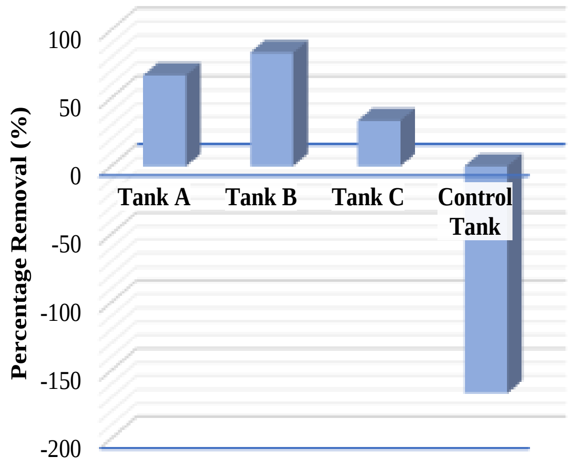

Fig. 3.2: Chart of Percentage TSS Removal in Phase I

3.1.2 Removal of Turbidity

Turbidity test for water samples are conducted to determine the clarity of water in the tanks [16]. There are several factors that contributes to turbidity such as shape, size, colour and the refractive characteristics of the particles in the sample.

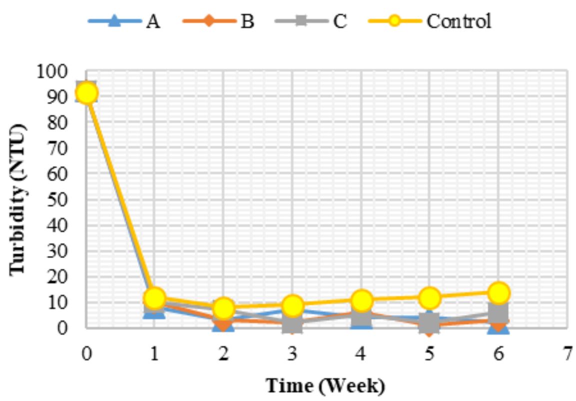

Fig. 3.3: Graph of Turbidity (NTU) against time (Week)

Based on the results obtained, the turbidity for all three tanks are high at 92 NTU at the initial stage prior to placement of plants. This high level of turbidity is caused due to the thorough mixing of the water samples before the lily cannas were placed. The stirring of the water sample was done to obtain the true turbidity values of the water sample from the reservoir and determine if the turbidity is affected by the introduction of lily canna in the tanks. As seen in Figure 3.3, the turbidity value plunges tremendously to 8 NTU for Tank A and 10 NTU for both Tank B and C within the first week. This condition is due to the settlement of the suspended solids, colloids and other microorganisms to the bottom of the tank. The suspended solids present in the water samples mainly consisted of soil particles. Soil particles are denser than the water sample itself which caused them to settle at the bottom of the tank without consuming much time. The settlement of these soil results in a decrease in suspended particles floating in the water sample. Thus, the larger soil particles which may scatter or absorb the ray of light in the spectrophotometer are not attained while sampling was done at mid-depth of the tank. Hence, the turbidity measurement drops significantly in week 1. This is also the case in the control tank. Although Yahyapour, et al. [12] have previously studied that planted vegetation has the ability to reduce the amount of sediments in the water, this removal capacity is mainly related to the decrease in flow velocity of the water, enabling the suspended solids to settle before flowing further into larger lakes and rivers. Abou-Elela also mentioned in their research that the retention time of the water samples are increased because of the growth of a diverse range of roots underwater gets in the water path, reducing velocity [2]. However, this is not the case in this project, as the flow of water is stagnant in Phase I. This is shown in Figure 3.3, where the turbidity of water in the control tank did not show significant differences as compared to the tanks which contained lily canna.

It can also be seen that the turbidity levels of the water samples do not constantly decrease linearly, instead there appears to be a fluctuation in the reading as the weeks pass by. These fluctuations are highly likely to be related to the growth and presence of floating microalgae and attached algal mats in the water sample besides the presence of other foreign matter. The floating microalgae tends to enter the graduated cylinder during the sampling process and may contribute in an increase of turbidity reading while algal mats attached to the roots does not tend to flow into the graduated cylinder during sampling. A reading of 2 NTU, 3 NTU and 6 NTU are obtained for Tank A, B and C respectively by the end of week 6. Tank A which has the least density of plants managed to achieve a lower turbidity reading whereas Tank C with the highest density of lily canna have the highest turbidity. This phenomenon is due to the rapid growth rate of algae in Tank C compared to the algae growth in Tank A, where algae contributes to an increase in floating matter within the sample.

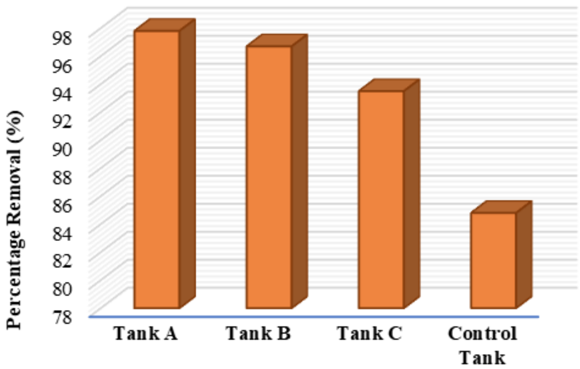

Fig. 3.4: Chart of Percentage Turbidity Removal in Phase I

The figure above shows that Tank A achieved highest turbidity removal of 97.8%, followed by Tank B and C at 96.7% and 93.5% respectively. These numbers indicate that the higher the density of lily canna, the lower the percentage removal of turbidity. However, it is important to note that the difference in percentage removal in the three tanks are not significant, and moreover most of the particles causing turbidity are removed due to sedimentation and not directly linked to the introduction of lily canna.

3.1.3 Removal of Nitrate Concentrations

Nitrate (NO_3^-) is one of the principal forms of nitrogen in water and wastewater [17]. Sources of nitrates in the Ringlet Reservoir water sample may be due to agricultural fertilizers, leachate and animal manure where presence of these substances in excess can lead to eutrophication and cause algal blooms [15]. Removal of nitrates from water is a crucial step to mitigate the risk of developing a eutrophic water body which may further impact aquatic living and public health. Determination of nitrate in the water samples were carried out using the Cadmium Reduction Method (Method 4500 – NO_3^- E.) as stated in the Standard Methods for the Examination of Water and Wastewater by the American Public Health Association (APHA). The principal behind this test is that the presence of Cadmium (Cd) reduces nitrate (NO_3^-) to nitrite (NO_2^-). The reduced nitrite forms a coloured amber dye, which is then measured colourimetrically using a HACH DR900 colorimeter.

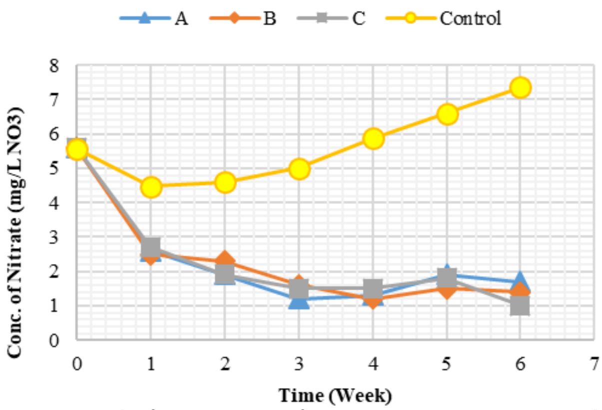

Fig. 3.5: Graph of Concentration of Nitrate (mg/L) against time (Week)

As seen on Figure 3.5, the general trend of concentration of nitrate seems to decrease with time in the tanks with lily canna. On the other hand, the control tank with no lily canna generally experiences an increase in nitrate concentration. There is a swift reduction in nitrate observed within the first week after the introduction of lily canna into the water sample in all four tanks. The concentration of nitrate in the control tank increases after week 1, whereas concentration in water samples A, B and C continue to decrease until week 3, although the reduction is not as significant as it was in the first week. This occurrence is due to the existence and growth of the lily canna's fibrous roots in the tanks. Roots play a vital role in the uptake of nutrients as they are important areas where plants and microorganisms in the water come into direct contact with each other. Activities such as decomposition, microbial attachment and bacterial growth all take place within the rhizosphere of the plant. Lai in his previous research mentioned that compared to thick root plants, plants with fibrous root has a higher growth rate and larger surface area for microbial attachment of denitrifying bacteria such as nitrate and nitrite reductase, corresponding to higher nutrient removal rates from the water [18]. Hence, it can be stated that the larger the root surface area, a higher rate of nitrate removal can be achieved.

Presence of carbon source, such as withered leaves in the system also contributes to the production of denitrification bacteria that aids nitrate removal. Seenivasagan mentioned in his paper that "during the biological denitrification process, the bacteria utilize nitrates as a final electron acceptor in both carbon and organic source thereby reducing it to nitrogen" [19]. Besides uptake by lily canna, the growth of algae in the tanks is a contributing factor to the reduction of nitrate concentrations from week 1 to week 3. Cai stated that microalgae has the ability to remove nitrates from water by assimilating inorganic nitrogen to its organic nature [20]. Although algae is said to affect the quality of water in many aspects, algae actually helps in removing nitrates from water through its biological processes such as photosynthesis. The process of algal photosynthesis makes use of nutrients in the water such as nitrate, in converting solar energy to useful denitrifying bacteria [15]. The process of nitrate reduction to nitrite and further reduction to nitrogen gas is simplified as shown below [21].

$$\text{Nitrate } (NO_3^-) \xrightarrow[\text{Reductase}]{\text{Nitrate}} \text{Nitrite } (NO_2^-) \xrightarrow[\text{Reductase}]{\text{Nitrite}} \text{Nitrogen Gas (N)} \quad (5)$$

It is also important to note that an increase in DO of more than 4 mg/L in the water inhibits denitrification process to take place [7]. When denitrification fails to take place, nitrates cannot be reduced to nitrite, causing an increase in nitrate concentration in the water sample. An increase in DO also reduces BOD_5 due to the reduced competition for oxygen by the microorganisms. Thus, an increase in nitrate concentration can also be triggered due to low BOD_5 reading in the tanks. This theory explains the situation that occurred in week 5, where a relatively low BOD_5 reading reflected a slight spike in nitrate concentration in all three tanks.

At the beginning of week 3, the concentration of nitrate experiences some fluctuations. The amount of nitrate in Tank B continues to decrease as expected, however, nitrate in Tank A experiences an increase and nitrate in Tank C remained constant. These changes are due to the respiration and photosynthesis as respiration of algae utilizes dissolved oxygen present in the water, increasing the BOD_5 in week 4 [22]. When respiration of algae takes place, nitrates (NO_3^-) and carbon dioxide (CO_2) are released back into the water, increasing nitrate concentrations as observed in Tank A from week 3 to week 5 and Tank C from week 4 to week 5. Inversely, when algae undergoes photosynthesis, NO_3^- and CO_2 are consumed, reducing the amount of nitrate present in the water sample. The stoichiometry of the respiration and photosynthesis of algae is as in Equation 4.1 [21].

$$106CO_2 + 16NO_3^- + HPO_4^{2-} + 122H_2O + 18H^+ \underset{\text{Respiration}}{\overset{\text{Photosynthesis}}{\rightleftharpoons}} C_{106}H_{263}O_{110}N_{16}P + 138O_2 \quad (6)$$

It is clearly shown based on the data plotted in Figure 3.5 that the introduction of lily canna into the system helps in the removal of nitrates. This is proven by the fact that the nitrate concentration in the tank with no lily canna experienced an increase in nitrate until the end of the testing period, contrary to those with lily canna.

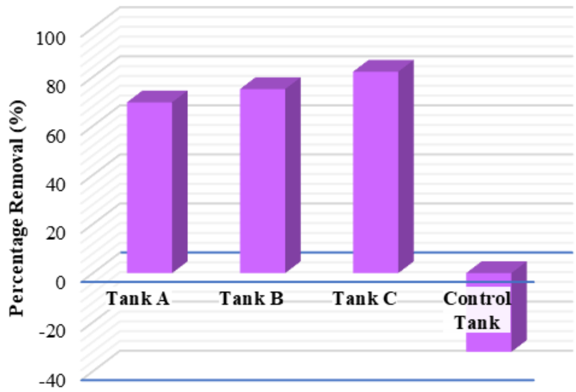

Fig. 3.6: Chart of Percentage Nitrate Removal

Based on the figure above, the percentage removal of nitrate is 69.6% in Tank A, 75.0% in Tank B and 82.1% in Tank C. It is clear that the tank with the highest number of lily cannas achieved a higher percentage of nitrate removal. These observations are due to the several factors as mentioned previously, such as root surface area availability, presence of carbon source and denitrifying bacteria, growth of algae, the photosynthesis and respiration of algae, and the amount of DO in the water. Presence of lily canna helps in the removal of nitrate from the water sample.

3.2 Phase II – Flowing Water

Phase II of this project studies the effect of flowing water on the quality of water. Similar to Phase I, three Tanks A, B and C were set up with 1, 4 and 8 lily cannas placed in them respectively. There was also a tank set up with no lily canna to act as the control of this test. The water was kept flowing using a pump throughout the 6-week experimental period. The pumps kept the water continuously in motion and introduced oxygen to the water via circulation to a certain extent. The test results of TSS, turbidity and nitrate concentrations are discussed in the following subtopics.

3.2.1 Removal of Total Suspended Solids (TSS)

As mentioned in Phase I (see Section 3.1.1), the Total Suspended Solids (TSS) test is carried out to determine the amount of solids in the water sample. The continuous flow of water in the tanks are studied to determine if the water circulation played a role in the reduction of TSS in the water sample. TSS is crucial to be reduced as water with high TSS values are not palatable and induces an undesirable physiological perception by consumers [10].

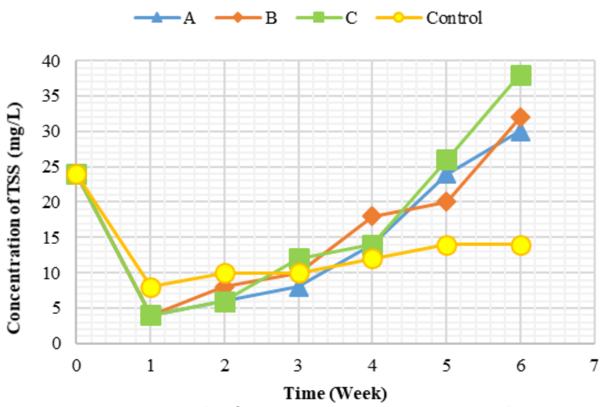

Fig. 3.7: Graph of TSS (mg/L) against time (Week)

The initial TSS reading in all four tanks are high due to thorough mixing of the water sample, introducing solids such as soil particles into the graduated cylinder while sampling is done. Initial TSS reading was at 24 mg/L and plunged to only 4 mg/L within the first week in Tanks A, B and C, whereas it dropped to 8 NTU in the control tank. This finding is due to the settlement of the heavier suspended solids, mainly soil, to the bottom of the tank. As the weeks passed, the TSS values continue to increase at an almost constant rate in the three tanks containing lily canna. This TSS increase in Tanks A, B and C mainly composed of algal bloom instead of soil particles, as the soil particles have settled. In contrast, the TSS concentration in the control tank did not undergo significant increase compared to Tanks A, B and C due to the presence of plant roots and algal bloom. As compared to the TSS observation in Phase I, we can see that the tanks in Phase II, that is under flowing water conditions, achieve a much slower production of algal mat whereas in Phase I, algal mat is apparent and occurred by week 2. This can be proven by the fact that the TSS value in Phase I reached 44 mg/L by week 2 while in Phase II, the reading was only at 6, 8 and 6 mg/L in Tank A, B and C respectively. This shows that the growth of algae is much slower in flowing water conditions as compared to stagnant water.

The absence of plant roots in the control tank causes a slow increase in TSS concentration within the 6 weeks. Although it may generally seem like the presence of lily canna only increases the TSS, this is not exactly the case. The reason behind the increase in TSS is due to the initial bloom of microalgae which are free to float in the water. The growth of algae aids in trapping suspended solids present in the water. Probability of TSS reduction would be higher with the aid of algal mats if this project was carried out throughout a longer duration. However, due to time constraint, only a 6-week experimental period was feasible. In the long run, the bloom of algal mats would grow larger, covering more surface area to trap suspended solids. This would result in a significant TSS drop in the water samples. Nevertheless, this theory needs to be further studied to determine the percentage reduction of TSS and the effectiveness of this approach in reducing TSS.

Based on the observations of this project, flowing water takes longer time to become eutrophic as compared to a stagnant water body of similar conditions. According to Abdel-Raouf, eutrophication is one of the major causes of algal bloom in the water body and rapid algal bloom may lead to production of slimy green algae mats which have high adhesion against each other [15]. This explains why the flow of water caused slower algae bloom corresponding to a lower production of total suspended solids in the water.

The bar chart above yields negative values as the TSS are not removed, instead it increases throughout the experimental period in all three tanks (see Fig. 3.7). This increase shows that the formation of algal mats takes place at a slower rate under flowing water conditions compared to stagnant water conditions. It is important to note that first, the formation of micro algae has to take place, to develop into floating algae, and when these floating algae develops and clumps together, algal mats are formed. The more algae clumps together via adhesion, the bigger the algal mat produced. Formation of algal mats significantly helps in trapping the suspended matter in the water sample, creating higher chances of the trapped sediments to be degraded by bacteria and to be absorbed by the lily canna roots. This finding can be observed in Phase I, where once algal mats are present, the removal of TSS is significantly high compared to presence of only floating microalgae. The TSS removal in this phase could have been significantly high if the experimental period was extended to a longer duration. However, due to time constraints of this project, the data for a longer experimental period could not be obtained.

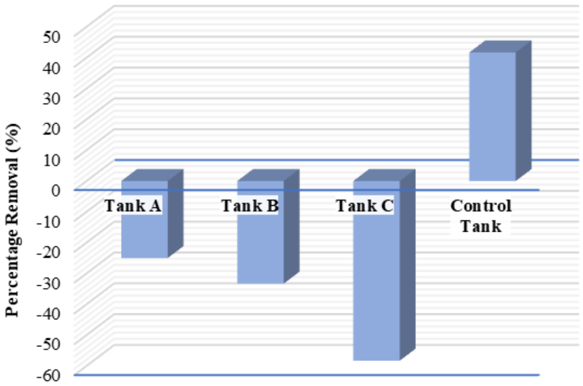

Fig. 3.8: Chart of Percentage TSS Removal in Phase II

3.2.2 Removal of Turbidity

Turbidity is an important parameter in water quality as it gives a strong first impression towards consumers. Water with high turbidity is aesthetically unpleasant and is conducive for the growth of pathogens. A regrowth of pathogens may occur if turbidity is not removed from the water, causing water-borne infections such as gastroenteritis [23]. The effect of flowing water on turbidity levels were studied and is discussed in this section.

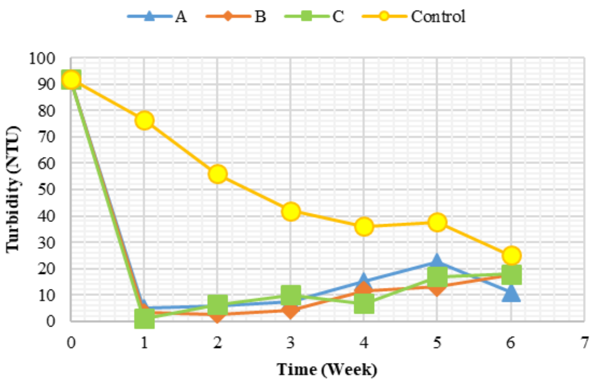

Fig. 3.9: Graph of Turbidity (NTU) against time (Week)

The initial turbidity measurement in Tanks A, B and C was 92 NTU and is relatively high compared to the measurements that follow in the succeeding weeks. As mentioned previously, the high turbidity value is because of the thorough mixing of the water sample prior to sampling. This caused the sediments to be suspended, thus increasing the amount of light diffracting particles in the water yielding a higher turbidity measurement. In this phase, the first week recorded the lowest turbidity reading of 5 NTU, 3 NTU and 1 NTU in Tank A, B and C respectively. As the weeks passed, the turbidity levels in the tanks experienced a fluctuation in reading, however it was nominally in an increasing manner between week-1 up to week-6. The slow increase in turbidity can be explained due to the growth of algae within this period. Based on the explanation provided in Phase I, increase in algae bloom in the water sample causes an increase in turbidity when the algae is attained while sampling is performed. Suspended algae diffracts the ray of light as it is placed in the turbidity meter for measurement. The more algae present in the water, the higher chances of algae to be sampled with the water, consequently diffracting the light ray in the turbidity meter, thus increasing the reading.

As compared to Phase I, turbidity in this phase is higher from week 2 onwards. This is because the algae production in flowing water conditions took a longer time and at a slower rate [24]. According to Darajeh, eutrophic conditions are one of the major factors for algal bloom in water [14]. Aerobic conditions of the water decreased the rate of algal bloom as the water took a longer time to reach a eutrophic state as compared to Phase I.

In contrast to Tanks A, B and C, the control tank experiences a gradual decrease in turbidity from the beginning to the end of the experimental period. This gradual decrease in turbidity is due to the recirculation of suspended solids present in the water sample through the pump. Recirculation agitated the surface of the water causing a longer settlement time.

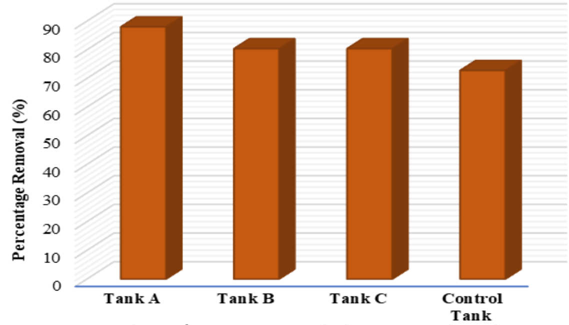

Fig. 3.10: Chart of Percentage Turbidity Removal in Phase II

The percentage removal of turbidity was highest in Tank A because there is lesser algae growth in the tank due to limited root surface area, resulting in lesser microalgae particles in the sample which may diffract the ray of light in the turbidity meter.

3.2.3 Removal of Nitrate Concentrations

Nitrates (NO_3^-) are composed of nitrogen, which is an important component for all living organisms [25]. Water bodies rich in nitrogen are prone to eutrophication and needs to be treated to remove the amount of nitrogen constituents, including nitrates [4]. Current practices include a recirculation of water by replacing nitrate-rich water with fresh water at a rate of 5 to 10% per day to remove these nitrogen constituents [25]. This practice results in loss of nitrates, which has the potential to be utilized as a source of food for plants. Besides losing natural resources, discharge of nitrogen-rich water into existing water bodies such as rivers and lakes may ensue in eutrophication of the water downstream. The flow of water and how it affects nitrate concentrations in varying density of lily canna is studied and discussed in this section.

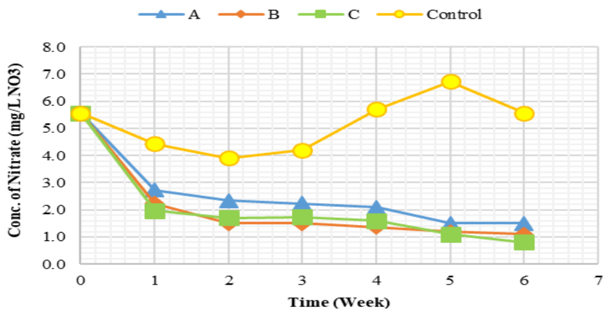

Fig. 3.11: Graph of Nitrate Concentrations (mg/L NO_3) against time (Week)

Based on Figure 3.11, it can be seen that the concentration of nitrates generally follow a decreasing trend throughout the entire 6-week experimental period. Initial nitrate concentrations were at 5.6 mg/L NO_3, which reflects the amount of nitrates present in the water samples obtained from Ringlet Reservoir. Highest rate of decrease in nitrate concentrations are in the first week where the concentrations plunged from 5.6 mg/L NO_3 in all three tanks to 2.7 mg/L NO_3 in Tank A, 2.2 mg/L NO_3 in Tank B and 2.0 mg/L NO_3 in and Tank C. This nitrate reduction of 73% to as high as 85% are due to the addition of lily canna in the water samples. As mentioned by Hu et al., introduction of vegetation into a water body increases the nitrogen utilization efficiency (NUE) due to the presence of various nitrifying bacteria [25]. In their paper, they have also stated that the amount of nitrifying bacteria in the water increases with an increase in root surface area. This is proven by the results produced in this project, where the final concentrations of nitrate were decreasing as the root surface area increased. The final nitrate concentration in Tank A with 1 lily canna is 1.5 mg/L NO_3, Tank B containing 4 lily cannas yielded 1.1 mg/L NO_3, while the densest Tank C with 8 lily cannas produced only 0.8 mg/L NO_3. The decrease in nitrate concentration is also affected by algae growth in the tanks. The tank with the highest density of lily canna (Tank C) produced more algae, by virtue of higher root surface area, leading to a higher rate of nitrate removal. This outcome also supports the theory studied by De-Bashan et al. where their study reported that plant roots were able to remove 75% of nutrients from the water with the aid of bacteria and algae [5].

Compared to Phase I of this project, the flowing water in Phase II is able to achieve a higher nitrate removal efficiency. The condition of water in Phase I is heavily eutrophic, and proper microbial degradation possibly could not take place due to an imbalance in the system. On the other hand, the flowing water in this phase introduced oxygen into the water, preventing it from turning anaerobic and keeping the system balanced which allows for proper degradation of organisms and absorption of nutrients by the lily cannas. This consequently causes the nitrate removal to be more efficient in flowing water conditions as compared to stagnant water.

The introduction of lily canna in water to reduce nitrate contamination can be verified as seen in Figure 3.11. Tanks A, B and C with lily canna managed to remove up to 85.7% nitrates as opposed to the control tank with no lily canna. The control tank experienced an increase in nitrate concentration, a similar case to Phase I.

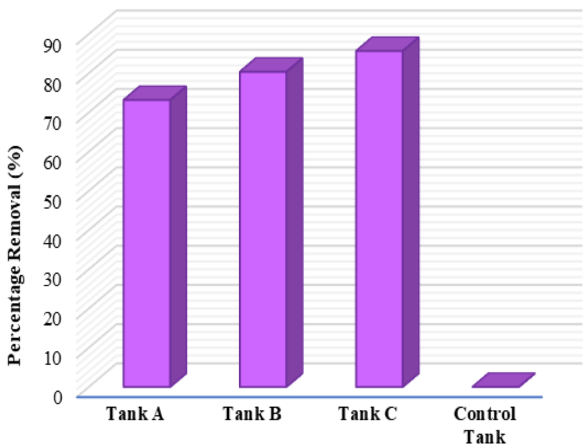

Fig. 3.12: Chart of Percentage Nitrate Removal in Phase II

Nitrate removal is best observed in Tank C as the number of lily canna was the highest and provided the highest density of roots for microbial activities to take place. The abundance of nitrifying bacteria present on the root surface in Tank C created a biofilm which contributed to degradation of microorganisms in the water sample into substances which can be taken up by the lily cannas.

3.3 Compliance with DOE Standards

The water sample from Ringlet Reservoir was treated using lily canna to remove pollutants such as TSS, turbidity and nitrate concentrations as discussed in this chapter. Quality of water is usually classified according to its usages. There are several standards that exists in Malaysia i.e. River Water Quality to ensure ecosystem sustainability, Effluent Quality to monitor treated effluent from the industrial sector such as factories, and The Drinking Water Quality to fulfil drinking water standards after being treated by a treatment plant.

The suitable standard which can be adapted for the water sample in this project is the River Water Quality Standard. Based on The Department of Environment, (2014), the river water quality standards are as follows:

Table 2: National River Water Quality Standards for Malaysia [26]

Parameter	Class				
	I	II	III	IV	V
TSS (mg/L)	25	50	150	300	300
Turbidity (NTU)	5	50	-	-	-
NO_3 (mg/L)	< 7	7	-	5	> 5

Comparing with the standards as stated, the TSS, turbidity and nitrate concentrations in this project meets the requirement as specified by the DOE.

Table 3: Summary of project results at the end of experimental period

Parameter	Phase I				Phase II				DOE
	A	B	C	Control	A	B	C	Control	
TSS (mg/L)	8	4	16	64[a]	30	32	38	14	Class II
Turbidity (NTU)	2	3	6	14	11	18	18	25	Class II
NO_3 (mg/L)	1.7	1.4	1.0	7.4[b]	1.5	1.1	0.8	5.6	Class I

** Note that 1 PtCo = 1 TCU*
[a] TSS concentration meets Class III DOE Standards
[b] Nitrate concentration meets Class III DOE Standards

4. Conclusion

This project delivers a comprehensive model for the removal of pollutants using ornamental plants. All the objectives set in this project has been successfully achieved. With the addition of lily canna into the water, the pollutants, namely Total Suspended Solids (Phase I), turbidity and nitrate concentrations has undergone significant reduction and enhancement of water quality has been observed. Overall, the final water quality meets the River Quality Standards as set by the Department of Environment (DOE) and the objective of improving water quality parameters have been fulfilled with the addition of lily canna plants, which also increases aesthetic values of the surrounding environment.

Acknowledgement

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