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Evaluation of water lettuce, giant salvinia and water hyacinth systems in phytoremediation of domestic wastewater

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ABSTRACT

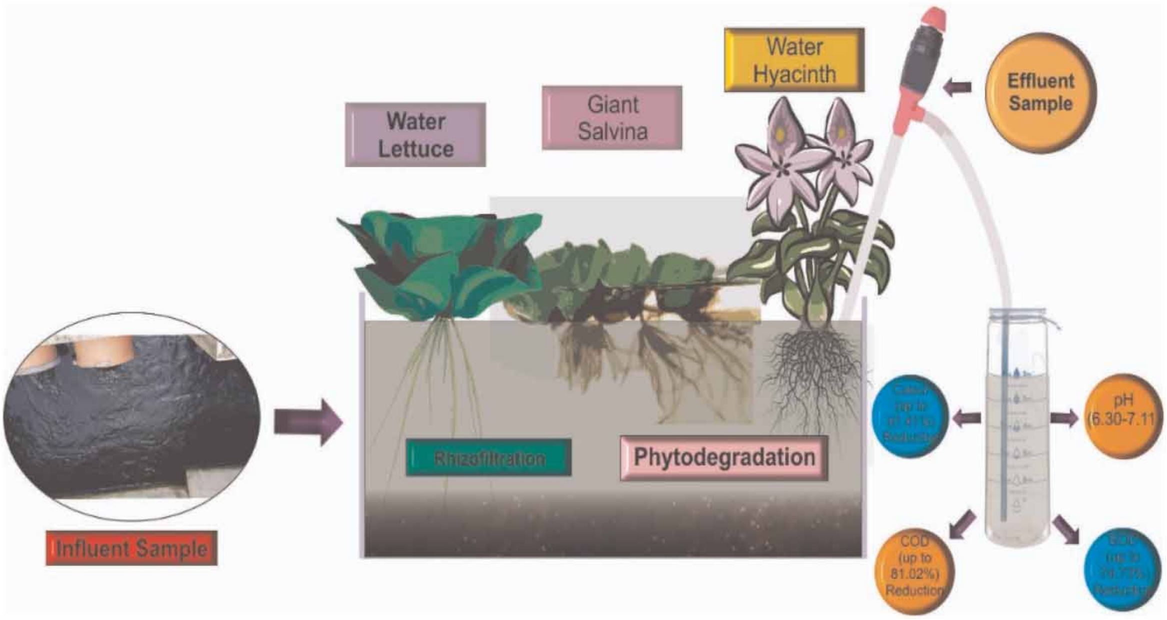
The objective of this research was to ascertain the best conditions for efficient applications of water lettuce, giant salvinia and water hyacinth in improving the quality of low strength domestic wastewater. Water quality assessment of the wastewater samples before (influent) and after treatment (effluent) with effect to retention times (6, 12 and 24 h) was analysed. The outcome of the study at 6 h retention showed that water lettuce (6.8–7.0 pH, 50.5% colour, 46.7% biochemical oxygen demand (BOD) and 37.8% chemical oxygen demand (COD)), giant salvinia (6.9–7.1 pH, 40.5% colour, 60% BOD and 43.2% COD) and water hyacinth (6.7–6.9 pH, 45.5% colour, 53% BOD and 35.1% COD) reduction values were achieved. At 12 h retention, water lettuce (6.6–7.0 pH, 57.2% colour, 77.1% BOD and 74.6% COD), giant salvinia (6.4–6.8 pH, 81.1% colour, 66.7% BOD and 72.2% COD) and water hyacinth (6.4–6.7 pH, 61.9% colour, 70% BOD and 61.1% COD) reduction values were achieved. Similarly, for 24 h retention, water lettuce (6.6–7.0 pH, 76.7% colour, 53.2% BOD and 70.3% COD), giant salvinia (6.6–7.0 pH, 91.4% colour, 74.7% BOD and 81.0% COD) and water hyacinth (6.4–6.9 pH, 74% colour, 58% BOD and 67.2% COD) reduction values were achieved. These findings indicated that the retention times of 12 and 24 h provided suitable conditions to break down the organic contaminants present in the shallow ponds.

Key words: domestic wastewater, organic contaminants, phytoremediation, retention time

HIGHLIGHTS

- Determine the ideal conditions for efficient applications of macrophytes in phytoremediation of treated domestic wastewater.
- The reduction rate of pollutants progressively increased, as the retention time and sampling period increased.
- The developed hydroponic ponds provided simple, cheap, and sustainable technology for tertiary treatment of wastewater within a short time.

GRAPHICAL ABSTRACT



INTRODUCTION

Diverse approaches have been introduced for amending pollution over the past 50 years. Government policies and communal views supported these approaches, which are more inclined towards biological treatment methods than the conventional methods (Ekperusi *et al.* 2019). However, biological methods, such as anammox technology, microbial fuel cells, anaerobic treatment and algal technology, have been employed in wastewater treatment. Nevertheless, the aforementioned biological techniques are known for high cost, complex mode of operation, long time requirement and high energy demand. For example, despite the efficiency of the activated sludge process in the reduction of water pollutants, high energy consumption ($0.3–0.6\ \mathrm{kW\,h\,m^{-3}}$) is a huge factor that hinders its application in biological wastewater treatment (Daverey *et al.* 2019). Consequently, energy has become a major strain on the net economic burden for most wastewater treatment plants (WWTPs) (Li *et al.* 2017). According to a study conducted in India, the average carbon footprint for large-scale sewage treatment plants was $0.78\ \mathrm{kg\ CO_2\ eq/m^3}$ (Singh *et al.* 2016). As a result, many countries across the globe are employing low-cost and eco-friendly green technology plants such as aquatic weed plants in phytoremediation of wastewater for a sustainable future (George & Gabriel 2017). Phytoremediation using hydroponic methods is cheap, simple to operate, requires little energy and it is a sustainable option for domestic wastewater treatment (Worku *et al.* 2018).

The recent study has reported the applications of different species of aquatic plants in phytoremediation of wastewater (Mustafa & Hayder 2021). Sayago (2019) investigated the potential of *Eichhornia crassipes* for wastewater treatment and the production of bioethanol. The results obtained showed that the application of *E. crassipes* in the treatment of the wastewater gave a satisfactory outcome, and the biomass obtained from the treatment process was useful in the production of biofuels. Correspondingly, Haidara *et al.* (2018) evaluated the performance of *Pistia stratiotes* and *E. crassipes* in bioremediation of fish pond wastewater at 21 day retention time. Water quality analysis was conducted at the interval of 7 days for 3 weeks. The average reduction values obtained from the *P. stratiotes* treatment system for temperature, pH, dissolved oxygen (DO) and nitrate were 27.07 ± 0.07 °C, 6.37 ± 0.27, 2.07 ± 0.09 mg/L and 0.9 ± 0.15 mg/L, respectively, while in the *E. crassipes* treatment systems, up to 7.0 ± 0 NTU turbidity, 0.6 ± 0.2 mg/L phosphate and 0.70 ± 0.15 mg/L ammonia reduction values were achieved. The authors concluded that the performance of the plants in nutrient uptake increased with respect to the retention time. Additionally, Ayaz *et al.* (2020) evaluated the efficiency of four aquatic plants in phytoremediation of sewage obtained from Hayatabad Industrial Estate (Peshawar, Pakistan) for 2 months. The outcome of the study revealed that heavy metals were removed in order of lead $>$ copper $>$

cadmium. Similarly, high cadmium removal was obtained in *P. stratiotes*, copper removal in *Lemna gibba* and lead by *E. crassipes*.

Nevertheless, it was observed that a great deal of time and maintenance was employed in the phytoremediation processes mentioned above. Although the plants were able to reduce the contaminants present in the wastewater, long-time monitoring and large space requirement in the case of constructed wetlands in phytoremediation processes make the technique tedious and limit its application in wastewater treatment. Accordingly, the need to develop simple operation techniques in the phytoremediation process to make it viable and attractive for wide applications in the field of wastewater management within the shortest time cannot be overemphasised. Hence, the purpose of this present research was to determine the ideal conditions for efficient applications of *P. stratiotes* (water lettuce), *Salvinia molesta* (giant salvinia) and *E. crassipes* (water hyacinth) in improving the quality of low-strength domestic wastewater using hydroponic cultivation methods. Water quality parameters, including pH, colour, chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) of the influent and effluent water samples with effects on retention time (6, 12 and 24 h), were analysed. Similarly, the effluent samples of each plant at the selected retention time were compared with the influent water samples. This was done to determine the ideal conditions for the plants to absorb and break down the residual organic pollutants present in the wastewater samples. However, the three plants selected in this research were based on information obtained from previous literature. *P. stratiotes* grows naturally or through anthropogenic activities in tropical or sub-tropical freshwater ecosystems. They were characterised by a high growth rate in wetlands and a high tolerance to a broad range of temperatures (Chapman *et al.* 2017). Similarly, *S. molesta* first originated in Brazil and it can withstand different environmental factors (Wahl *et al.* 2020). Meanwhile, *E. crassipes* is a member of the *Pontederiaceae* family known as a free-floating aquatic plant. In warm temperatures, it is believed to have a fast growth rate and has the ability to consume nutrients and dissolved substances from wastewater (Mitan 2019).

MATERIALS AND METHODS

Experimental setup

This study was conducted in a WWTP using pilot-scale hydroponic cultivation systems. The WWTP was located around Kajang, Selangor, Malaysia. Four rectangular tanks with a dimension of 670 mm × 420 mm × 220 mm (length × width × depth) were constructed for the cultivation of each selected plant. A vertical glass of 6 mm was attached as tray support and tank divider at the middle of the pond, dividing the influent and effluent flow of the water sample. Additionally, the water inlet and outlet pipe was controlled by a digital timer and the submersible pump and was located at 200 and 160 mm from the bottom of the pond, respectively. The control timer was connected to an electric source 40 m away from the cultivation system, and it controlled the inflow and outflow of the wastewater into the hydroponic system at the fixed retention time. The submersible pump was located at the discharge point of the secondary wastewater in the WWTP. A detachable tray sheet perforated with 20 holes of about 10–15 mm diameter was used to hold the plants vertically in place and also to protect the wastewater treatment system from excess sunlight and reptiles. The designs showing the dimensions of the constructed hydroponic ponds are presented in Figures 1 and 2.

Methodology

The selected plants: water lettuce, giant salvinia and water hyacinth were collected from Kajang, Selangor, Malaysia. The average annual temperature of the area is 27.2 °C. 80 g of freshwater lettuce, giant salvinia and water hyacinth were cultivated in each of the constructed hydroponic ponds filled with the treated secondary domestic wastewater from the WWTP. The unfiltered influent and effluent water samples were collected at an interval of 2 days for each retention time (6, 12 and 24 h) for 2 weeks. The water samples were transferred to the Universiti Tenaga Nasional (UNITEN) environmental laboratory for water quality assessment (pH, colour, BOD_5 and COD). The illustrated diagram of the cultivation system is presented in Figure 3.

Statistical analysis

The readings obtained from the water quality analysis were recorded in triplicate, and the average results were expressed as mean ± standard deviation. The percentage reduction efficiency was determined using Equation (1) reported by Valipour *et al.* (2015). Furthermore, the significance of difference between the influent and effluent samples was analysed using one-way analysis of variance (ANOVA) and *t*-test at 95% confidence level. Additionally, both the mean and standard deviations were calculated using the Microsoft® Excel (2016)

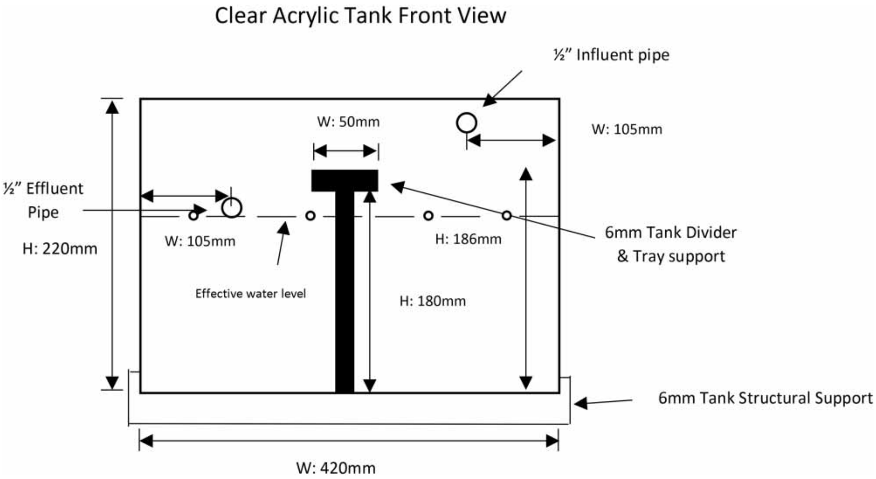


Figure 1 | Front view of the experimental tank.

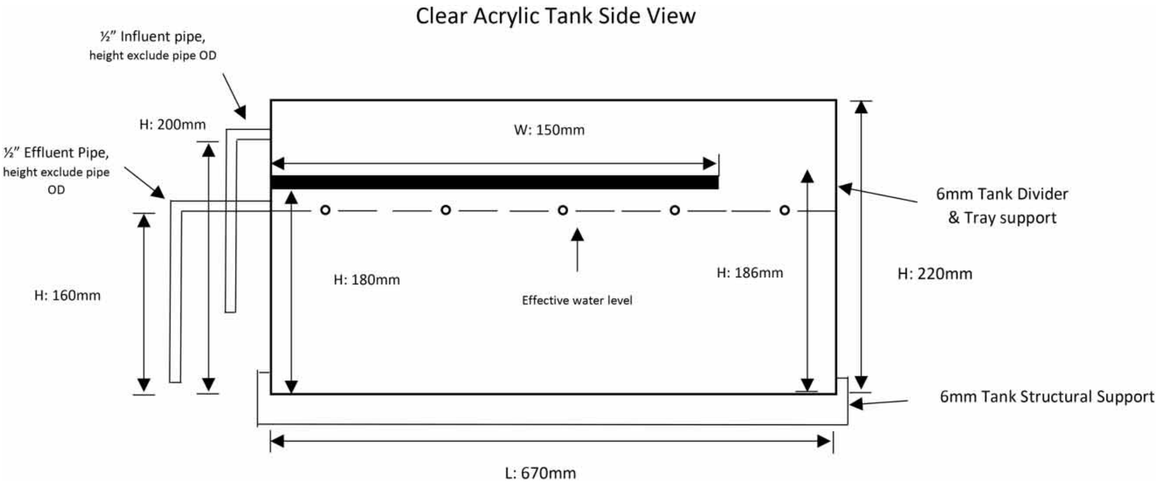


Figure 2 | Side view of the experimental tank.

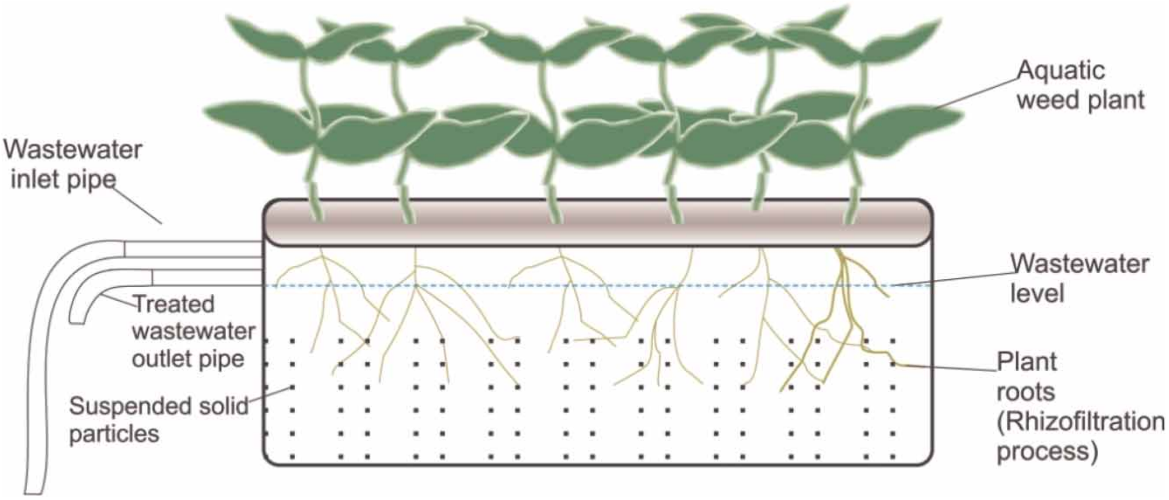


Figure 3 | Schematic diagram of the cultivation system.

statistical package:

$$\text{Reduction efficiency }(\%) = \frac{P_i - P_e}{P_i} \times 100 \qquad (1)$$

where P_i is the influent concentration and P_e is the effluent concentration.

RESULTS AND DISCUSSION

The results obtained from the phytoremediation treatment of secondary treated water samples using water lettuce, giant salvinia and water hyacinth systems at different retention times (6, 12 and 24 h) are presented in Table 1 and subsequent sections. The influent water samples were found to be variable all through the sampling period, as this was determined from the operation of the WWTP.

pH analysis

pH is among the relevant parameters of water quality. pH level signifies the degree of acidity or basicity of water. It also estimates the relative quantity of free hydrogen and hydroxyl ions in the water. This subsection presents the results of the pH analysis carried out on the influent and effluent wastewater samples for 14 day duration at a varying retention time of 6, 12 and 24 h.

As demonstrated in Figure 4, varying pH values were obtained in the influent samples throughout the sampling period, which fall within the range of 6.6–6.8. Additionally, a slight fluctuation of pH values in the effluent samples was recorded in comparison to the influent samples. Similarly, it was observed that the exposure of the test plants in the domestic wastewater samples adjusted the pH of the effluent samples from 6.7 to 7.1. Nevertheless, the ANOVA tests indicated that there was no statistically significant difference ($p > 0.05$) between the pH of the influent samples and water hyacinth effluent samples. At the same time, a statistically significant difference ($p < 0.05$) was detected between the influent samples and the other two (water lettuce and giant salvinia) effluent samples.

According to Figure 5, at the retention time of 12 h, the pH of the influent samples falls within 6.4 ± 0 to 6.9 ± 0. The cultivation of the test plants in the domestic wastewater samples adjusted the pH of the water samples (6.6–7.0) during the sampling period. Additionally, the one-way ANOVA scrutiny of discrepancy revealed a statistically

Table 1 | Summary of the phytoremediation results

	2nd day				**14th day**			
Retention time (h)	**Influent**	**Water lettuce**	**Giant salvinia**	**Water hyacinth**	**Influent**	**Water lettuce**	**Giant salvinia**	**Water hyacinth**
pH analysis								
6	6.7 ± 0	6.9 ± 0	6.9 ± 0	6.7 ± 0	6.7 ± 0.1	6.9 ± 0	7.1 ± 0	6.8 ± 0.1
12	6.6 ± 0	6.6 ± 0	6.5 ± 0	6.4 ± 0.1	6.6 ± 0.1	6.7 ± 0.1	6.5 ± 0.1	6.7 ± 0.1
24	6.6 ± 0	6.6 ± 0	6.8 ± 0	6.5 ± 0	7.1 ± 0.5	6.6 ± 0.1	6.7 ± 0	6.4 ± 0.1
Colour analysis (Pt-Co)								
6	376 ± 2.6	233.3 ± 1.5	300.6 ± 3.5	253.3 ± 3.1	222 ± 1	110 ± 0	132 ± 2	121 ± 1
12	249 ± 4.6	173.6 ± 3.2	87.6 ± 3.8	104 ± 2.1	451 ± 1	193 ± 2	85 ± 1	172 ± 1
24	226 ± 0	121 ± 1	79 ± 0	76 ± 1	445 ± 2	175 ± 2	67 ± 0	196 ± 2
BOD_5 analysis (mg/L)								
6	14.6 ± 0.1	11.6 ± 0.1	13.6 ± 0	11.9 ± 0	30 ± 0	16 ± 1	12 ± 0	14.1 ± 0
12	20 ± 1	4.59 ± 0	11.8 ± 0.1	9.2 ± 0	50 ± 1	24 ± 0	28 ± 0	22 ± 0
24	38.7 ± 0.9	33 ± 1	29 ± 1	35 ± 1	51.6 ± 0.1	40.4 ± 0	36.2 ± 0	39.4 ± 0.1
COD analysis (mg/L)								
6	74 ± 0	53 ± 0	67 ± 0	60 ± 0	74 ± 1	46 ± 0	42 ± 0	48 ± 1
12	55.3 ± 0.6	46.3 ± 0.6	30 ± 0	38 ± 0	84 ± 1	43 ± 1	38 ± 0	40 ± 1
24	136 ± 0.5	48 ± 0	45 ± 1	128 ± 1	84.3 ± 0.6	25 ± 1	16 ± 0	53 ± 1

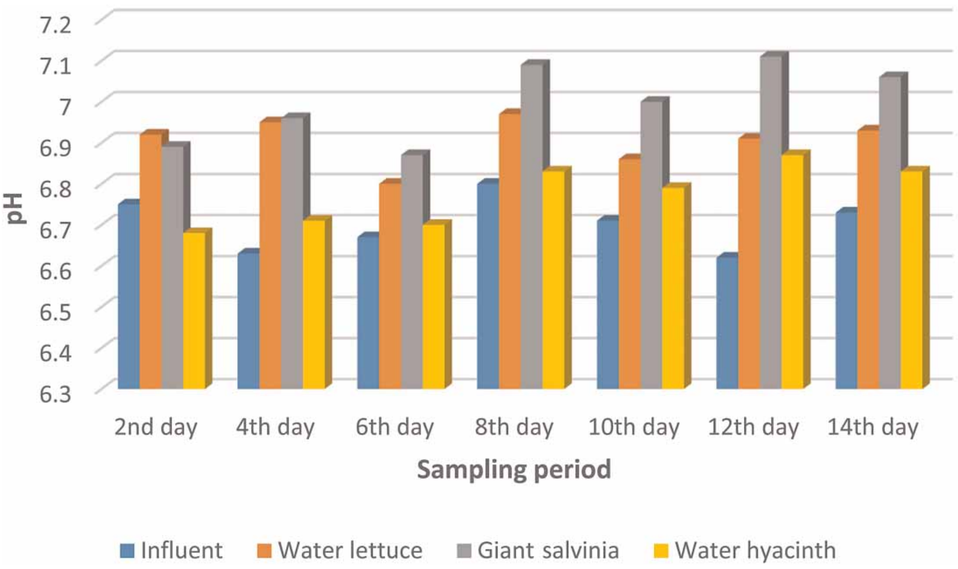


Figure 4 | Plot of pH against sampling period at 6 h retention time.

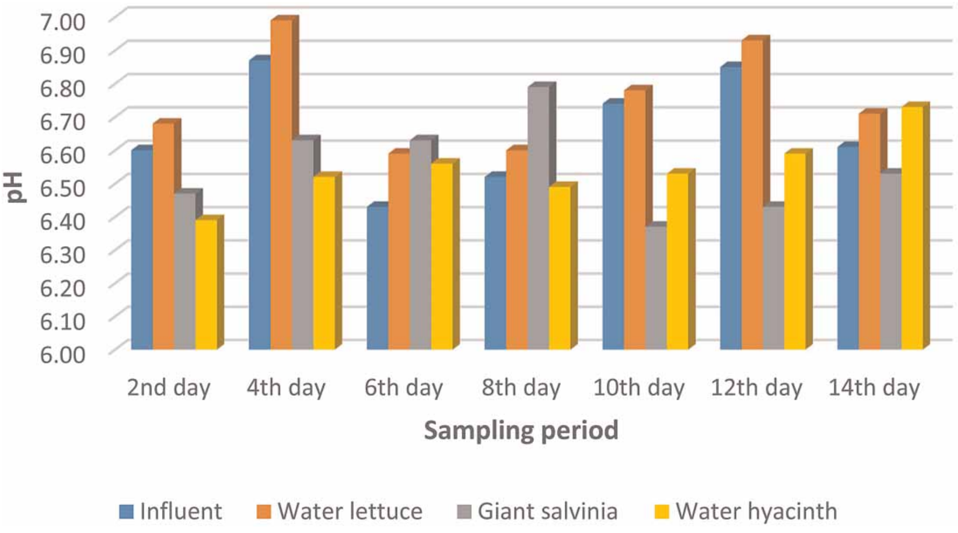


Figure 5 | Plot of pH against sampling period at 12 h retention time.

significant variance ($p < 0.05$) between the influent samples and water lettuce effluent samples. But the giant salvinia and water hyacinth effluent samples showed no significant difference ($p > 0.05$) in comparison with the influent samples.

From Figure 6, the pH of the influent samples ranged from 6.6 to 7.6. Similarly, all three test plants demonstrated a similar trend in the pH value, fluctuating between the values of 6.4 ± 0 and 7.0 ± 0. Additionally, water lettuce, giant salvinia and water hyacinth treatment systems recorded a pH value of 6.8 ± 0.2, 6.7 ± 0 and 6.6 ± 0, respectively, as against the pH value of the influent sample (7.4 ± 0.4) on the 12th day of the sampling period. The ANOVA test indicated a statistically significant change ($p < 0.05$) between the pH of the influent and the individual effluent samples.

In addition, the overall results of the pH analysis showed a stable pH in the range of 6.3–7.1, which falls within the range of 6.6–8.0 optimum pH values for microbial activities and nitrification process (Rezania *et al.* 2015). Therefore, it was presumed the stable pH obtained during the phytoremediation process provided a conducive environment for the microorganism and the selected plants to effectively degrade and absorb the pollutants. Therefore, this present study reaffirms that the pH of 6–9 is most suitable for aquatic plant performance in

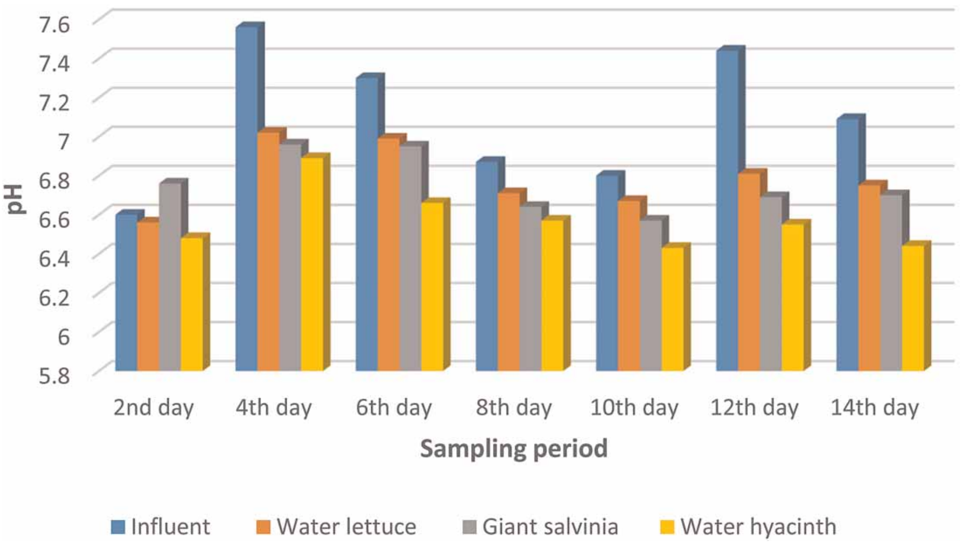


Figure 6 | Plot of pH against sampling period at 24 h retention time.

phytoremediation of domestic wastewater. Additionally, it was observed that the selected plants and most suitably: the 24 h retention time were the ideal combination to be used in the phytoremediation process of domestic wastewater, as the existence of the plants in wastewater depletes CO_2 during the period of photosynthetic activity. Furthermore, an increase in the DO consequently provides aerobic environments in wastewater, which favours the aerobic bacterial activity to break down BOD and COD in the wastewater (Priya & Selvan 2017). Similarly, the slight decrease of the pH, particularly in the 24 h treatment systems, may be attributed to the absorption of the pollutants by the plants. Besides, the findings obtained in this research coincides with the work of Mahmood *et al.* (2005) and Priya & Selvan (2017). They reported that *E. crassipes* decreased the alkaline pH to neutral, which may be attributed to the simultaneous release of H^+ ions with the uptake of metal ions or the absorption of nutrients. Additionally, these findings are closely related to the work of Haidara *et al.* (2018), in which 100 g of *P. stratiotes* and *E. crassipes* gave a pH reduction value of 6.4 ± 0.1 and 6.5 ± 0.2, respectively, in phytoremediation of aquaculture wastewater at 21 day detention time.

Colour analysis

The average results for the colour analysis of the influent and effluent wastewater samples are presented in the graphs of Figures 7–9.

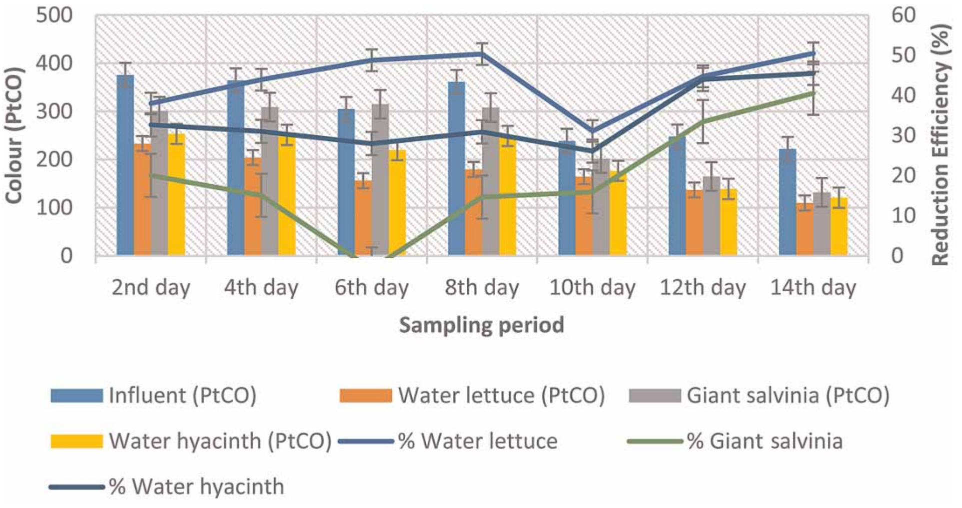


Figure 7 | Plot of colour concentration against sampling period at 6 h retention time.

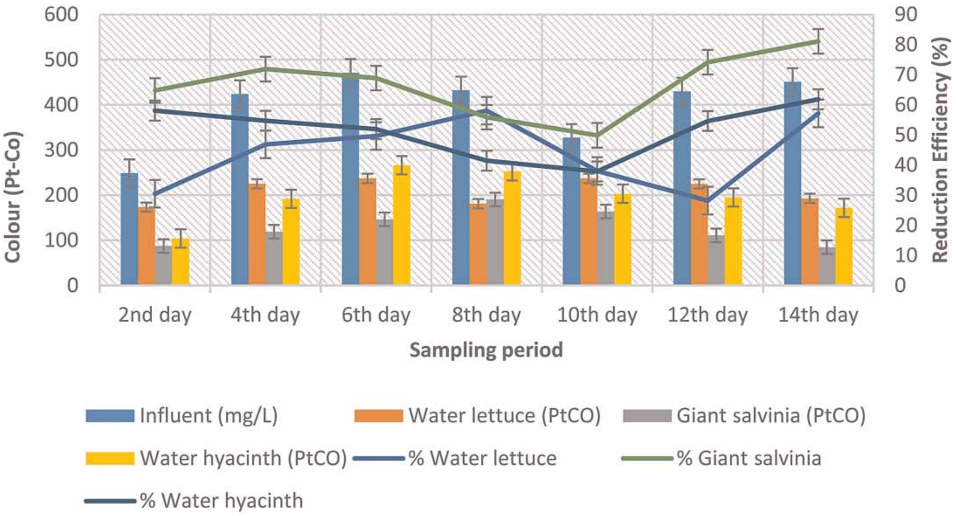


Figure 8 | Plot of colour concentration against sampling period at 12 h retention time.

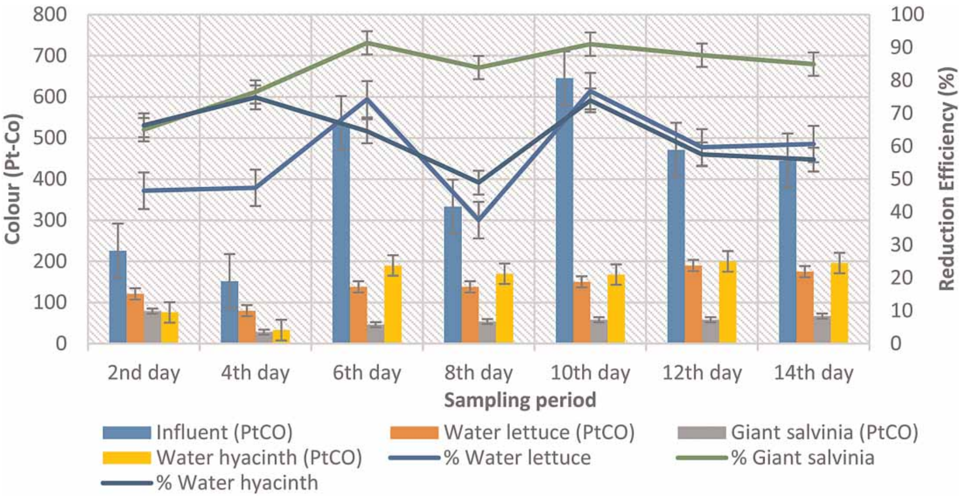


Figure 9 | Plot of colour concentration against sampling period at 24 h retention time.

According to Figure 7, at 6 h retention time, the initial colour concentration of the influent samples from the STP varied throughout the sampling period and ranged from 222 ± 1 to 376 ± 2.6 Pt-Co. The initial colour value of 376 ± 2.6 Pt-Co was obtained in the influent sample on the 2nd day of the study period, which was improved to 233.3 ± 1.5, 300.6 ± 3.5 and 253.3 ± 3.1 Pt-Co by water lettuce, giant salvinia and water hyacinth, respectively. Similarly, the highest reduction efficiency of 50.5% (water lettuce), 40.5% (giant salvinia) and 45.5% (water hyacinth) was obtained on the 14th day of the sampling study. The overall results observed from the graph showed that water lettuce performed better than giant salvinia and water hyacinth systems in improving the colour concentration of the influent wastewater at a short retention time of 6 h. Also, it was observed that the ANOVA test indicated a statistically significant change ($p < 0.05$) between the influent and the individual effluents samples.

From Figure 8, it is observed that the influent colour concentration discharged from the WWTP ranged from 249 ± 4.6 to 471.3 ± 1.5 Pt-Co. A progressive increase was continuously observed in the improvement of the influent samples across the sampling days with slight fluctuations on the 10th and 12th days of the sampling period. Furthermore, on the final day, the initial average colour concentration of the influent sample was 451 ± 1 Pt-Co, which was lowered to 193 ± 2, 85 ± 1 and 172 ± 1 Pt-Co by water lettuce, giant salvinia and water hyacinth, respectively. These changes showed a reduction efficiency of 57.2, 81.1 and 61.9% for water lettuce, giant salvinia and water hyacinth, respectively. Thus, these outcomes confirmed that giant salvinia was more effective in lowering the colour concentrations of the influent samples at 12 h retention time compared to water lettuce and water hyacinth. In addition, the colour reduction performance of the influent and effluent wastewater samples was found to be statistically significant ($p < 0.05$).

Based on the graph of Figure 9, at 24 h retention, it is observed that the removal pattern of the colour decreased drastically during the 14 day sampling period when compared with the influent sample. The reduction percentage values fluctuated between 65 and 91.4% from the beginning to the end of the sampling period. However, the overall results demonstrated an irregular pattern of colour concentration reduction by the test plants. Also, giant salvinia demonstrated the highest reduction efficiency of colour concentration with 91.4% on the 6th day of the sampling study. The one-way ANOVA test for colour reduction performance between the influent samples and the individual treatment systems was found to be statistically significant ($p < 0.05$).

In addition, it is evident that the three selected plants positively impacted on the colour concentration of the influent samples at different (6, 12 and 24 h) retention times. After the 14 day cultivation process, the overall average colour value for water lettuce, giant salvinia and water hyacinth effluent samples at a retention time of 6 h was recorded as 169.3, 247.37 and 201.4 Pt-Co, respectively, while the overall average colour reduction value for water lettuce, giant salvinia and water hyacinth at a retention time of 12 h was found to be 210, 129 and 197.9 Pt-Co, respectively, and for 24 h retention time was found to be 142, 129 and 344 Pt-Co for water lettuce, giant salvinia and water hyacinth, respectively. The outcome of this study indicated that giant salvinia treatment systems at a retention time of 12 and 24 h condition was more suitable for improving the colour concentration of the domestic wastewater. According to the results presented, the introduction of the selected plants improved the physical appearance of the influent wastewater samples from grey-black to a colourless water sample. This improvement in the colour change can be attributed to the ability of the selected plant roots to settle, floc, filter and entrap the solid suspended particles present in the influent samples within the 2-day interval at different retention times. The granules of the solid particles were observed to sediment at the bottom of the hydroponic treatment ponds. Furthermore, the giant salvinia effluent samples were found to be within the class IIA Malaysian water quality standard (DOE 2005).

BOD_5 analysis

Scientists can estimate the amount of organic matter present in wastewater through biochemical oxygen demand (BOD_5) analysis. BOD_5 analysis is used to measure the quantity of oxygen required for the decomposition of organic particles in water by aerobic microorganisms (Prambudy *et al.* 2019). The results of BOD_5 analysis obtained from this study are presented in Figures 10–12.

From Figure 10, it was observed that the BOD_5 of the influent was variable throughout the sampling period, as this was determined from the operation of the WWTP. Similarly, a BOD_5 value of 14.6 mg/L was obtained for the influent sample on the 2nd day of the experiment, but the exposure of water lettuce, giant salvinia and water

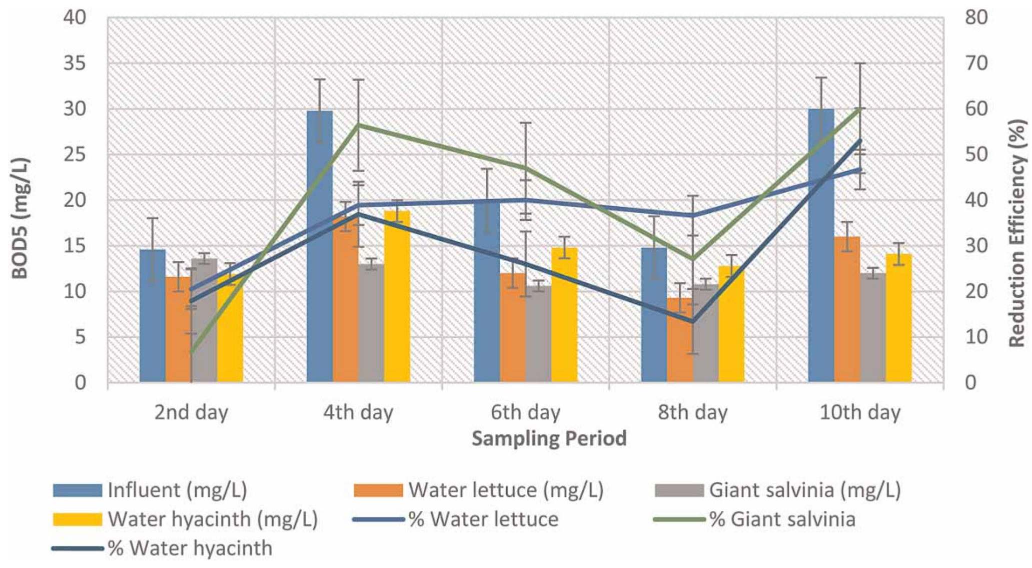


Figure 10 | Plot of BOD_5 concentration against sampling period at 6 h retention time.

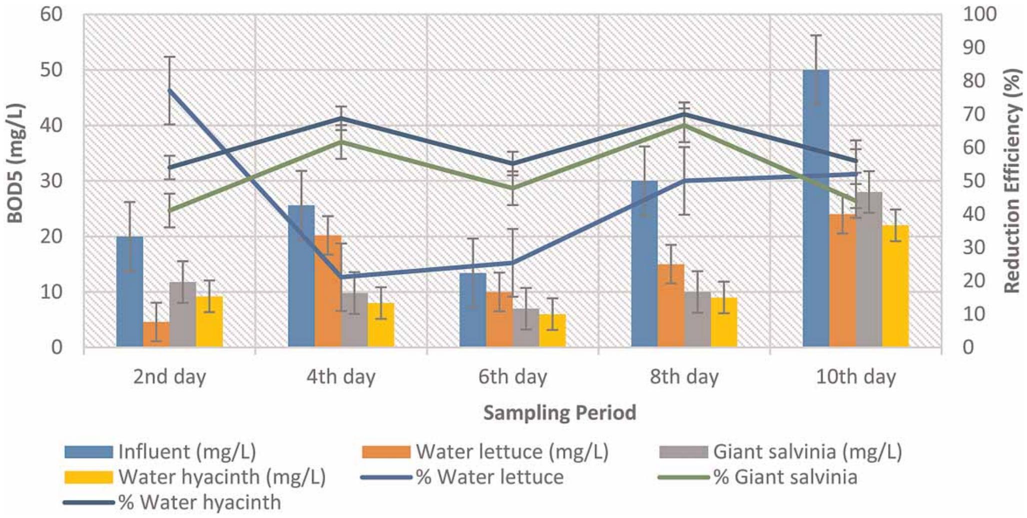


Figure 11 | Plot of BOD_5 concentration against sampling period at 12 h retention time.

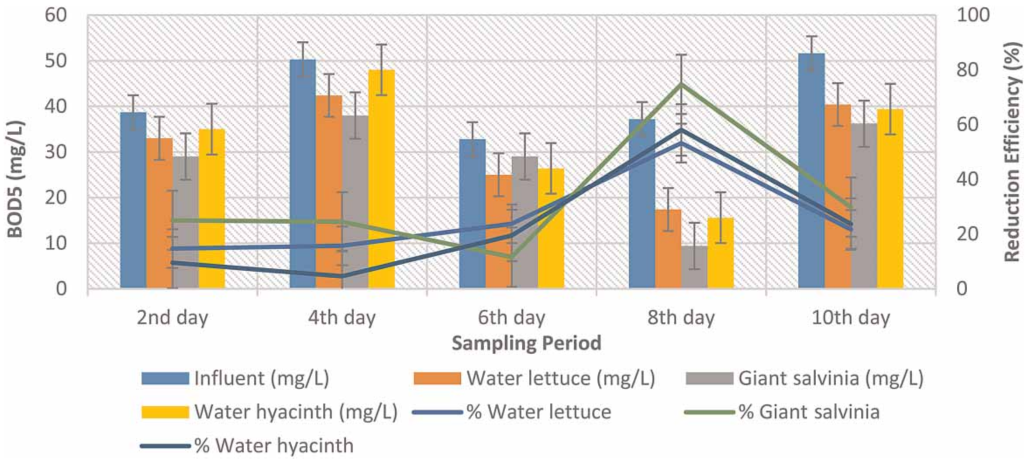


Figure 12 | Plot of BOD_5 concentration against sampling period at 24 h retention time.

hyacinth in the influent water samples decreased the concentration to 11.6 mg/L (20.5%), 13.6 mg/L (6.8%) and 11.9 mg/L (17.9%), respectively. Furthermore, among the three treatment systems, giant salvinia showed better tendency to reduce the BOD level to the standard limit within a short retention time of 6 h compared to water lettuce and water hyacinth aquatic plants. The performance between the influent and the individual effluent samples was found to be statistically significant ($p < 0.05$).

According to the graph of Figure 11, the results obtained demonstrated that a BOD_5 value of 20 mg/L was obtained for the influent sample on the 2nd day of the experiment, but the exposure of water lettuce, giant salvinia and water hyacinth in the wastewater samples decreased the BOD_5 concentration to 4.6, 11.79 and 9.2 mg/L, respectively. Similarly, these changes led to a removal efficiency of 77.1, 41.1 and 54% for water lettuce, giant salvinia and water hyacinth, respectively. Additionally, a gradual decline of the removal efficiency was observed in the water lettuce effluent samples on the 4th and 6th days of the sampling period in which 21.1 and 25.4% were recorded as against the 71% obtained on the 2nd day. Furthermore, these findings revealed that the three test plants have great tendencies to reduce the BOD level of the influent water samples to the standard limit within a short retention time of 12 h**.** The performance between the influent and the individual effluent samples was found to be statistically significant ($p < 0.05$).

From the results (Figure 12), it is observed that the BOD_5 values were within the range of 18.6–51.6 mg/L. According to the outcome of the analysis, on the 4th day of the experiment, the test plants reduced the initial BOD_5 value of 50.3 to 42.4 mg/L (water lettuce), 38 mg/L (giant salvinia) and 48 mg/L (water hyacinth).

Furthermore, these changes led to a reduction efficiency of 15.7, 24.5 and 4.6% by water lettuce, giant salvinia and water hyacinth, respectively. The highest reduction efficiency of 74.7% was obtained for giant salvinia, followed by water hyacinth (58%) and water lettuce (53.2%) treatment systems. The ANOVA test indicated that there was a statistically significant difference ($p < 0.05$) between the influent and performance of the test plants in reducing the BOD_5.

Additionally, it was observed that the exposure of the test plant samples in the wastewater led to an increase in DO, which indicated the reduction in BOD_5 level. Similarly, Saha *et al.* (2017) reported that an increase in DO of water through photosynthetic activity lead to an aerobic bacterial activity, which reduced the BOD and COD concentrations in polluted water. Furthermore, the stable pH of 6–8 observed all through the phytoremediation provided a conducive environment for the reduction of BOD_5 concentration of the influent samples. However, among the three treatment systems, the 12 h retention time is the ideal condition for the steady reduction of the BOD_5 concentrations. Similarly, among the three test plants, giant salvinia showed better tendency to reduce the BOD level to the standard limit within a short retention time compared to water lettuce and water hyacinth aquatic weed plants. These findings proved that the three test plants are potential bioagents for absorbing and degrading contaminants from wastewater treatment. Besides, DO is essential for aquatic organisms, and it enters the water through diffusion from the atmosphere as well as the by-product of the photosynthesis process by the aquatic plants and algae. DO of less than 2 mg/L implies poor water quality and could adversely affect aquatic organisms (Hazmi & Hanafiah 2018).

COD analysis

The quantity of oxygen required to chemically break down the organic substances present in water is known as the COD. COD is a parameter used to assess the degree of contamination in wastewater samples based on chemical characteristics (Prambudy *et al.* 2019). The outcomes of the COD analysis are presented in Figures 13–15.

From Figure 13, the results demonstrated that the COD values were lowered in all the samples as a result of the cultivation of the three test plants in the influent wastewater samples. Similarly, it was observed that the initial COD value recorded on the 2nd day of the sampling period was slightly decreased from 74 ± 0 to 53 ± 0 mg/L (water lettuce), 67 ± 0 mg/L (giant salvinia) and 60 ± 0 mg/L (water hyacinth). These led to a reduction efficiency of 28.3% (water lettuce), 23% (giant salvinia) and 18.9% (water hyacinth). The maximum reduction efficiency of 37.8% (water lettuce), 44.7% (giant salvinia) and 35.1% (water hyacinth) was recorded during sampling periods. Furthermore, the one-way ANOVA test showed a statistically significant change ($p < 0.05$) between the influent and effluent wastewater samples, except for giant salvinia effluents in which no statistically significant change ($p > 0.05$) was observed.

From the graph of Figure 14, it was obvious from the results that the test plants improved the COD concentration of the influent samples throughout the 14 day sampling period. Similarly, gradual improvement was observed on the 4th day of the experiment, as the three test plants reduced the COD concentrations from

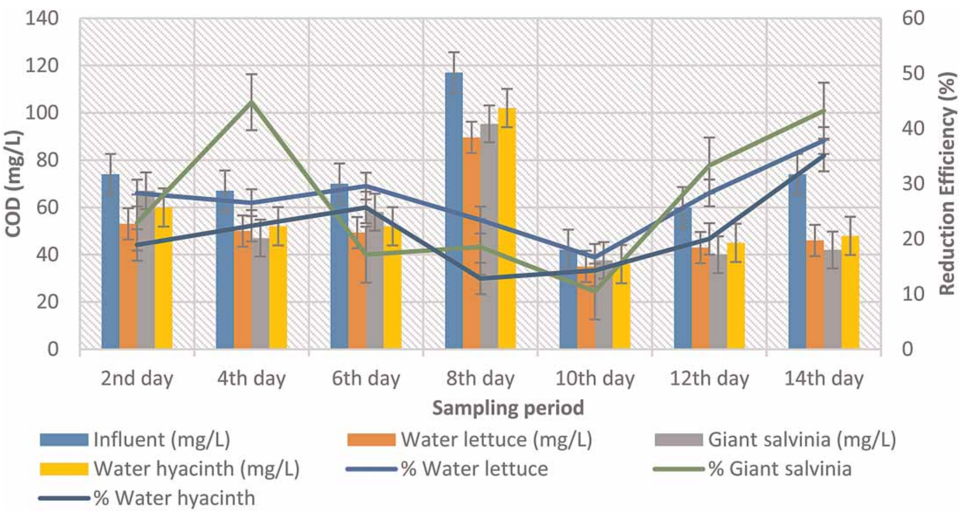


Figure 13 | Plot of COD concentration against sampling period at 6 h retention time.

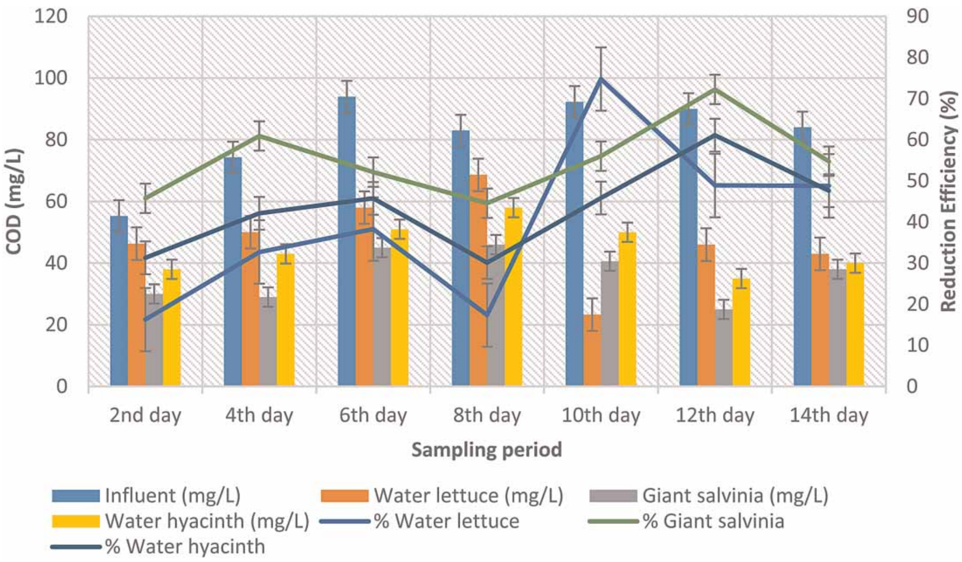


Figure 14 | Plot of COD concentration against sampling period at 12 h retention time.

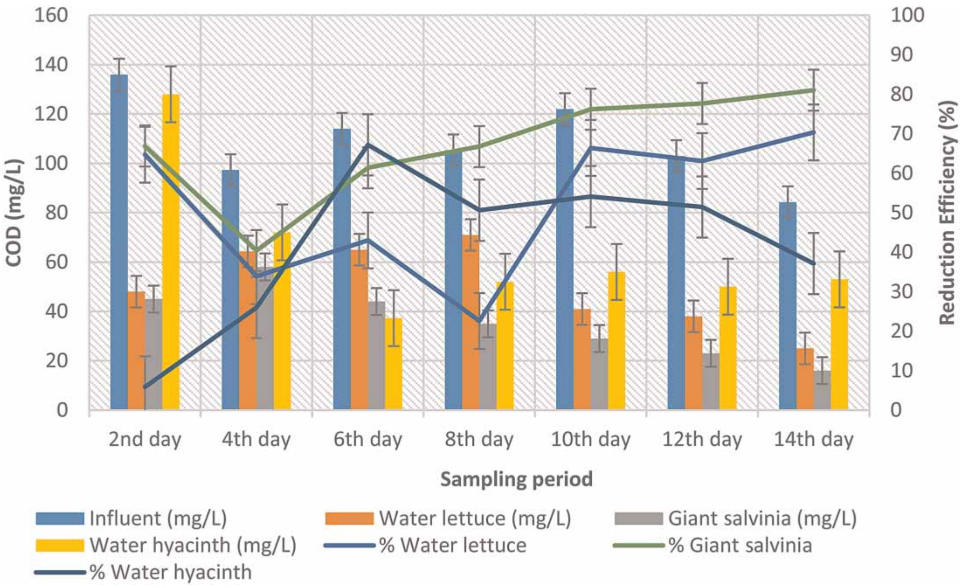


Figure 15 | Plot of COD concentration against sampling period at 24 h retention time.

74.3 ± 0.6 mg/L of the influent samples to 50 ± 0 mg/L by water lettuce, 29 ± 0 mg/L by giant salvinia and 43 ± 1 mg/L by water lettuce. Meanwhile, the COD reduction trends continue to fluctuate at a slow rate across the sampling period. The highest reduction efficiencies of 72.2 and 61.1% were observed for giant salvinia and water hyacinths effluent samples, respectively. In contrast, the highest reduction efficiency for water lettuce was found to be 74.8% on the 10th day of the sampling. Based on the results presented, it can be deduced that the test plants decreased the COD concentration at a slow rate with water lettuce plants displaying the best result on the 10th day within the 12 h retention time. A statistically significant difference ($p < 0.05$) was recorded between the influent and individual effluent samples.

From Figure 15, it was evident from the graphs that the cultivation of the three test plants in the wastewater improved the COD concentration of the influent samples. Additionally, it was found that the COD concentration values of the influent wastewater samples were within the range of 84.3–136 mg/L. The treatment of the influent water samples by the test plants began from the 2nd day of the experiment, and the removal efficiency was recorded as 64.7 and 66.9% for water lettuce and giant salvinia effluent samples, respectively. The highest

COD reduction efficiency for water lettuce, giant salvinia and water hyacinth was observed to be 70.3, 81 and 67%, respectively. Furthermore, the ANOVA test indicated a statistically significant ($p < 0.05$) change between the influent and the individual effluent samples.

In addition, the overall average COD value of the effluent samples at the retention time of 6 h was recorded to be 53.7 mg/L (water lettuce), 58.4 mg/L (giant salvinia) and 58.7 mg/L (water hyacinth) as against the overall average COD value of 71.3 mg/L obtained from the influent sample, while the overall average COD value for water lettuce, giant salvinia and water hyacinth at 12 h retention time was found to be 49.9, 36.2 and 45 mg/L, respectively, as against the overall average COD value of the influent sample of 81.8 mg/L. Similarly, the overall average COD value for water lettuce, giant salvinia and water hyacinth effluent samples at the retention time of 24 h was found to be 50.3, 35.7 and 64 mg/L as against the overall average COD value of the influent sample of 108.8 mg/L. These results indicated that at 24 h retention time, giant salvinia plants have better properties in decreasing the COD concentrations of the influent samples, whereas the water hyacinth plants were more effective in reducing the COD concentrations of the influent samples at 12 h retention time. Moreover, the initial COD values of the influent wastewater samples were found to be within the range of class IV (100) and class V (>100) of the Water Quality Standards for Malaysia, but after the phytoremediation process, the initial COD level of the influent samples was improved to class III (25–50) (DOE 2005). The results obtained in this present study conforms to the work of Lu *et al.* (2018), who stated that up to 61.7 and 68.2% of COD reduction was achieved by the treatment of polluted river water with *P. stratiotes* and *E. crassipes* plants, respectively.

In the cultivation system, it is summarised that the adsorption was enabled due to the ability of the aquatic plant roots to increase their surface area and hydraulic flow between the mat and the bottom of the water body is formed, thus, resulting in a significant removal of contaminants from the wastewater treatment system. The roots acted as a filter and habitat for the growth and development of microorganisms. Additionally, pollutants are removed by three main processes, namely adsorption, sedimentation and biodegradation. Similarly, functions such as adsorption of suspended solid, nutrient uptake, extracellular enzyme synthesis, sequestration, turbulence reduction, surface area for biofilm and oxygen diffusion are all performed by plants in phytoremediation of wastewater (Pavlineri *et al.* 2017).

Furthermore, root exudates aid in the retention of microbes on the roots by providing them with nutrients (Ashraf *et al.* 2018). Additionally, roots deliver oxygen to rhizospheric bacteria for the purpose of aerobic breakdown of organic matter. The roots and attached biofilms perform different physical and biochemical processes for the removal of pollutants from the contaminated water (Zhang *et al.* 2016). Trapping in the biofilm of the roots is an essential mechanism for particulate matter removal. Moreover, the roots allow microbial colonies to assimilate the carbon compounds, which enhanced the reduction of BOD and COD. In other words, most organic pollutants are degraded by microorganisms present on the roots, while some of the organic pollutants are taken by the plants. Therefore, organic pollutants can either be accumulated in the biomass of the aquatic plants or degraded by bacteria present in the plants (Hussain *et al.* 2019). It is noteworthy to mention that much of the organic materials may have settled out in the system since the influent was unfiltered.

Management of the harvested aquatic plants

Macrophytes used in phytoremediation of wastewater are usually characterised by high biomass accumulation and growth rates. Macrophyte species exhibiting these traits outside of their natural area are regarded as invasive, having the ability for rapid colonisation (Fletcher *et al.* 2020). Therefore, there is an important link between the use of aquatic plants in phytoremediation and strategies for the control of invasive plants (Fletcher *et al.* 2020). It is more suitable to utilise these aquatic plants as part of an integrated strategic approach to prevent the spread of the plants while effectively degrading the suspended sediment, removing nutrients and metals and harvesting the biomass for economic benefit (Yan *et al.* 2016). However, environmental managers considering the applications of aquatic plants for phytoremediation of wastewater purpose must conduct an exploratory research to evaluate the benchmark balance of nutrient input/output and plant removal capacity, as well as the need for upstream best practices as part of an integrated management strategy. Thus, in this study management of the aquatic plants was carried out through the manual method (removal by hand). This is because the cultivation of the aquatic plants was conducted on a small scale. Although, the hand removal method is laborious and time-intensive, it allows targeted removal of macrophytes and minimises the disturbance (Quilliam *et al.* 2015). Furthermore, the harvested aquatic plants (biomass) were in turn processed for use as feedstock for the generation of biofuels.

CONCLUSION

It is evident from this study that the selected aquatic plants (water lettuce, giant salvinia and water hyacinth) were capable of remediating the domestic wastewater samples. The retention times of 12 and 24 h were the most suitable ideal conditions for the plants to lower the colour, BOD and COD concentrations of the influent. Additionally, the removal of the pollutants progressively increased, as the retention time and sampling period increased. Furthermore, this study indicated that the roots of the plants acted as filters and possibly provided a favourable surface for microbial colonies to assimilate the carbon compounds, which led to the breakdown of the organic contaminants.

Finally, the hydroponic ponds provided a cheap, sustainable and green technology for phytoremediation of wastewater within a short time. Therefore, this technology can be constructed in WWTPs as tertiary treatment systems and for the cultivation of aquatic plants for the generation of biomass.

FUTURE RESEARCH

Future studies should focus on the surface area requirements, the effect of sedimentation processes on contaminant removals and the study of nitrogen and phosphorus removals in phytoremediation of wastewater. Additionally, a circular economy study on phytoremediation of domestic wastewater using the selected plants in this research is another area that requires further study.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Ashraf, S., Afzal, M., Naveed, M. & Shahid, M. 2018 Endophytic bacteria enhance remediation of tannery effluent in constructed wetlands vegetated with *Leptochloa fusca*. *International Journal of Phytoremediation* **20**(2), 121–128. https://doi.org/10.1080/15226514.2017.1337072.

Ayaz, T., Khan, S., Khan, A. Z., Lei, M. & Alam, M. 2020 Remediation of industrial wastewater using four hydrophyte species: a comparison of individual (pot experiments) and mix plants (constructed wetland). *Journal of Environmental Management* **255**, 109833. https://doi.org/10.1016/j.jenvman.2019.109833.

Chapman, D., Coetzee, J., Hill, M., Hussner, A., Netherland, M., Pescott, O., Stiers, I., van Valkenburg, J. L. & Tanner, R. 2017 *Pistia stratiotes* L. *Bulletin OEPP/EPPO Bulletin* **47**(3), 1–7. https://doi.org/10.1111/epp.12429.

Daverey, A., Pandey, D., Verma, P., Verma, S., Shah, V., Dutta, K. & Arunachalam, K. 2019 Recent advances in energy efficient biological treatment of municipal wastewater. *Bioresource Technology Reports* **7**, 10052. https://doi.org/10.1016/j.biteb.2019.100252.

DOE, Department of Environment 2005 *Environmental Quality Report, 2002-2005, Malaysia*. Ministry of Science, Technology and Environment.

Ekperusi, A. O., Sikoki, F. D. & Nwachukwu, E. O. 2019 Application of common duckweed (*Lemna minor*) in phytoremediation of chemicals in the environment: state and future perspective. *Chemosphere* **223**, 285–309. https://doi.org/10.1016/j.chemosphere.2019.02.025.

Fletcher, J., Willby, N., Oliver, D. M. & Quilliam, R. S. 2020 *Phytoremediation Using Aquatic Plants* (Shmaefsky, B., ed.). Springer International Publishing. https://doi.org/10.1007/978-3-030-00099-8.

George, G. T. & Gabriel, J. J. 2017 Phytoremediation of heavy metals from municipal waste water by *Salvinia molesta* Mitchell. *The Saudi Journal of Life Sciences* **2**(3), 108–115. https://doi.org/10.21276/haya.

Haidara, A. M., Magami, I. M. & Sanda, A. 2018 Bioremediation of aquacultural effluents using hydrophytes. *Bioprocess Engineering* **2**(4), 33–37. https://doi.org/10.11648/j.be.20180204.11.

Hazmi, N. I. A. & Hanafiah, M. M. 2018 Phytoremediation of livestock wastewater using *Azolla filiculoides* and *Lemna minor*. *Environment & Ecosystem Science* **2**(1), 13–16. https://doi.org/10.26480/ees.01.2018.13.16.

Hussain, F., Tahseen, R., Arslan, M., Iqbal, S. & Afzal, M. 2019 Removal of hexadecane by hydroponic root mats in partnership with alkane-degrading bacteria: bacterial augmentation enhances system's performance. *International Journal of Environmental Science and Technology* **16**, 4611–4620. https://doi.org/10.1007/s13762-018-2165-1.

Li, W., Li, L. & Qiu, G. 2017 Energy consumption and economic cost of typical wastewater treatment systems in Shenzhen, China. *Journal of Cleaner Production* **163**, S374–S378. https://doi.org/10.1016/j.jclepro.2015.12.109.

Lu, B., Xu, Z., Li, J. & Chai, X. 2018 Removal of water nutrients by different aquatic plant species: an alternative way to remediate polluted rural rivers. *Ecological Engineering* **110**, 18–26. https://doi.org/10.1016/j.ecoleng.2017.09.016.

Mahmood, Q., Zheng, P., Siddiqi, M. R., Islam, E. U., Azim, M. R. & Hayat, Y. 2005 Anatomical studies on water hyacinth (*Eichhornia crassipes* (Mart.) Solms) under the influence of textile wastewater. *Journal of Zhejiang University: Science B* **6**(10), 991–998. https://doi.org/10.1631/jzus.2005.B0991.

Mitan, N. M. M. 2019 Water hyacinth: potential and threat. *Materials Today: Proceedings* **19**, 1408–1412. https://doi.org/10.1016/j.matpr.2019.11.160.

Mustafa, H. & Hayder, G. 2021 Recent studies on applications of aquatic weed plants in phytoremediation of wastewater: a review article. *Ain Shams Engineering Journal* **1**(12), 355–366. https://doi.org/10.1016/j.asej.2020.05.009.

Pavlineri, N., Skoulikidis, N. & Tsihrintzis, V. 2017 Constructed floating wetlands : a review of research, design, operation and management aspects, and data meta-analysis. *Chemical Engineering Journal Journal* **308**, 1120–1132. https://doi.org/10.1016/j.cej.2016.09.140.

Prambudy, H., Supriyatin, T. & Setiawan, F. 2019 The testing of chemical oxygen demand (COD) and biological oxygen demand (BOD) of river water in Cipager Cirebon. *Journal of Physics: Conference Series* **1360**(1). https://doi.org/10.1088/1742-6596/1360/1/012010.

Priya, S. & Selvan, S. 2017 Water hyacinth (*Eichhornia crassipes*) – an efficient and economic adsorbent for textile effluent treatment – a review. *Arabian Journal of Chemistry* **10**, S3548–S3558. https://doi.org/10.1016/j.arabjc.2014.03.002.

Quilliam, R. S., Niekerk, M. A., Van, Chadwick, D. R., Cross, P., Hanley, N., Jones, D. L., Vinten, A. J. A., Willby, N. & Oliver, D. M. 2015 Can macrophyte harvesting from eutrophic water close the loop on nutrient loss from agricultural land? *Journal of Environmental Management* **152**, 210–217. https://doi.org/10.1016/j.jenvman.2015.01.046.

Rezania, S., Din, M. F. M., Taib, S. M., Dahalan, F. A., Songip, A. R., Singh, L. & Kamyab, H. 2015 The efficient role of aquatic plant (water hyacinth) in treating domestic wastewater in continuous system. *International Journal of Phytoremediation* **18**(7), 679–685. https://doi.org/10.1080/15226514.2015.1130018.

Saha, P., Shinde, O. & Sarkar, S. 2017 Phytoremediation of industrial mines wastewater using water hyacinth. *International Journal of Phytoremediation* **19**(1), 87–96. https://doi.org/10.1080/15226514.2016.1216078.

Sayago, U. F. C. 2019 Design of a sustainable development process between phytoremediation and production of bioethanol with *Eichhornia crassipes*. *Environmental Monitoring and Assesment* **191**(221), 1–8. https://doi.org/10.1007/s10661-019-7328-0.

Singh, P., Kansal, A. & Carliell-Marquet, C. 2016 Energy and carbon footprints of sewage treatment methods. *Journal of Environmental Management* **165**, 22–30. https://doi.org/10.1016/j.jenvman.2015.09.017.

Valipour, A., Raman, V. K. & Ahn, Y. H. 2015 Effectiveness of domestic wastewater treatment using a bio-hedge water hyacinth wetland system. *Water* **7**(1), 329–347. https://doi.org/10.3390/w7010329.

Wahl, C. F., Diaz, R. & Ortiz-Zayas, J. 2020 Assessing *Salvinia molesta* impact on environmental conditions in an urban lake: case study of Lago Las Curias, Puerto Rico. *Aquatic Invasions* **15**(4), 562–577. https://doi.org/10.3391/ai.2020.15.4.02.

Worku, A., Tefera, N., Kloos, H. & Benor, S. 2018 Bioremediation of brewery wastewater using hydroponics planted with vetiver grass in Addis Ababa, Ethiopia. *Bioresources and Bioprocessing* **5**(39), 1–12. https://doi.org/10.1186/s40643-018-0225-5.

Yan, S., Song, W., Guo, J., Yan, S., Song, W. & Guo, J. 2016 Advances in management and utilization of invasive water hyacinth (*Eichhornia crassipes*) in aquatic ecosystems – a review. *Critical Reviews in Biotechnology* **8551**, 1–11. https://doi.org/10.3109/07388551.2015.1132406.

Zhang, L., Zhao, J., Cui, N., Dai, Y., Kong, L., Wu, J. & Cheng, S. 2016 Enhancing the water purification efficiency of a floating treatment wetland using a biofilm carrier. *Environmental Science and Pollution Research* **23**, 7437–7443. https://doi.org/10.1007/s11356-015-5873-9.

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