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Phytoremediation of Municipal Wastewater using Aquatic Macrophytes

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ABSTRACT

Under present investigation, the efficiency of two different aquatic macrophytes was tested for the treatment of municipal wastewater collected from the sewage treatment plant (STP), Universiti Teknologi MARA (UiTM) Pulau Pinang. The experiments were operated by placing the raw wastewater into six similar storage containers having dimensions of 0.37 m (L) x 0.29 m (W) x 0.3 m (D). The containers were then divided into three groups, where each group has its duplicates. Four containers were placed with the locally available aquatic macrophytes for the treatment of wastewater; two containers with Centella asiatica and the other two containers with Eichhornia crassipes. The last two containers acted as the control sample. Initial concentrations of the raw wastewater parameters were determined. To evaluate the treatment efficiency of each macrophyte, pH, temperature, BOD_5*, COD and* NH_3*-N of the wastewater taken from the outlet (effluent) of the containers were tested for the duration of 10 days. The average reduction of effluent value of each parameter using Centella asiatica were 52.0% for* BOD_5*, 46.4% for COD and 73.0% for* NH_3*-N. For Eichhornia crassipes, the average reduction efficiency for selected parameters were 55.0% for* BOD_5*, 35.9% for COD and 58.8% for* NH_3*-N. There were no significant changes on the pH values and the temperature remained unchanged throughout the experiment. All parameters tested were within the permissible standard allowed based on Standard B taken from the Environmental Quality Act (EQA), 1974. Phytoremediation model was used to predict the treatment potential of the existing municipal wastewater using the aquatic macrophytes. It was observed that the model was appropriate to describe the phytoremediation potential of the aquatic macrophytes. It was suggested that by extending the duration of treatment, the model can be applied for this study. The current study indicated that Centella asiatica and Eichhornia crassipes can be utilized for the phytoremediation of municipal wastewater.*

Keywords: *aquatic macrophytes; Centella asiatica; Eichhornia crassipes; phytoremediation; wastewater*

1. INTRODUCTION

Over the past few years, global concerns toward the environment problem have been raised due to the hazardous pollutants that are contained in wastewater. In many developing countries, most of the pollution sources affecting the quality of the surface and ground water

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are from municipal and industrial wastewaters. Even though there are many technologies and treatment system that are used to treat the wastewater, changes in the pollution or breakdown of equipment can cause wastewater to be released unintentionally into the river [1]. The conventional approaches to remediate wastewater are expensive and require high energy causing the need to develop a more sustainable technology [2]. The main objective of wastewater treatment is to allow wastewater to be disposed into the environment without danger towards human health and the environment itself.

A conventional wastewater treatment consists of physical, chemical, and biological processes and operations to remove solids, organic matter and nutrients from wastewater. The methods used nowadays are too expensive and the treatment plants require a high energy to operate. Due to these problems, using aquatic plants in wastewater treatment can be seen as an environmental friendly option. Phytoremediation is the use of living green plants such as aquatic macrophytes to remediate contaminated water. (vague reference of It)Is it→ The treatment process is / The aquatic macrophytes are reproduced via a vegetative reproduction that allows the plants to quickly concord large area in short period of time [4]. Aquatic macrophytes that were explored and identified from polluted water and also tested for the phytoremediation of wastewater includes *Eichhornia crassipes* [1,2,3,4,5], *Centella asiatica* [6], *Pistia stratiotes* [4], *Lemna minor* [3,4] and *Salvinia molesta* [7,8]. Aquatic macrophytes namely, *Eichhornia crassipes* and *Centella asiatica* used in this study could easily be found in Malaysia because of the warm climate all year around. Apart from that, the plants live abundantly in lakes, rivers and man-made ponds. The treatment of wastewater by aquatic macrophytes has been initiated for quite some time. Nevertheless, the effectiveness of the different types of aquatic macrophytes to reduce the wastewater quality indicators such as biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and ammoniacal-nitrogen (NH_3-N) should be further explored. Generally, aquatic macrophytes treat wastewater by organic matter uptaken from the wastewater. It is of interest to determine the lowest treatment quality could be achieved if the removal by aquatic macrophytes is influenced by certain conditions. This reflects on the range of application of aquatic plants for wastewater treatment.

A mathematical model was developed for the prediction of organics compound removal from the wastewater of pulp and paper industry employing phytoremediation by *Eichhornia crassipes* [11]. Based on the investigation by Kumar et al., the proposed model is useful in predicting the trend of phytoremediation potential of *Eichhornia crassipes* for pulp and paper industry effluent and other similar industries at any time interval. Therefore, the purpose of this study is to evaluate the reduction performance of BOD_5, COD and NH_3-N by *Eichhornia crassipes* and *Centella asiatica.* Using the phytoremediation model proposed by Kumar et. al for industrial wastewater, the study will also highlight the prediction of phytoremediation of municipal wastewater using the aquatic macrophytes.

2. METHODOLOGY

2.1. Municipal Wastewater

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Preliminary characterization of municipal wastewater influent and effluent were performed for the measurement of pH, temperature, BOD_5, COD and NH_3-N. The municipal wastewater for the study was collected from the sewage treatment plant (STP), Universiti Teknologi MARA (UiTM) Pulau Pinang (5.3824° N, 100.4171° E). The STP was designed based on population equivalent of 10000. The STP received wastewater from the administration building, hostels and food court. The effluent is discharged into existing drains adjacent to the plant. The influent sample was collected during the peak flow, between 7.30 am to 9.00 am. The effluent sample for STP was taken 24 hours after the influent was collected. The samples were taken over four weeks where three days of sampling were conducted.

2.2 Selection of Aquatic Macrophytes

Centella asiatica and *Eichhornia crassipes* were collected from Sungai Kelang Ubi, Bukit Mertajam, Pulau Pinang. These aquatic macrophytes were placed in a tank containing tap water, for two-week acclimatization period, before relocating the plants into the wastewater treatment system [9].

2.3 Experimental Set-up

The aquatic macrophytes, which were placed in tap water for two weeks, were washed with no tissue being removed. To minimize the variations of the macrophytes tested, it is important that the plants have the same background, looked green and fresh, have approximately same size and have approximately the same number of leaves to avoid big surface differences [9]. Approximately 200 – 300 grams of aquatic macrophytes were placed into 4 liters of wastewater influent. There were six experimental runs conducted on the wastewater influent treated by aquatic macrophytes. The experiment was performed for the duration of 10 days depending on the adaptability of the aquatic macrophytes during the treatment. The control set-up consisted of wastewater without aquatic macrophytes. The volume of wastewater in each tank was kept constant and the change in volume due to evapotranspiration was compensated by the addition of distilled water. The experiments were placed near the laboratory where the aquatic macrophytes were exposed to moderate sunlight. The samples taken from the tank were analyzed for the pH value, temperature, BOD_5, COD and NH_3-N. The reduction of each parameter by both aquatic macrophytes was recorded throughout the study.

2.4 Analytical Procedure

BOD_5, COD and NH_3-N were analyzed according to Standard Methods for the Examination of Water and Wastewater [10].

2.5 Statistical Analysis

The data were presented as mean values of duplicates. Statistical analysis using the one-way ANOVA by Excel 2010 (Microsoft Office) was measured to assess significant differences between the two aquatic macrophytes. The comparisons of mean using the least significant different test were calculated for P-values. A value of $P < 0.05$ was considered significant.

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2.6 Phytoremediation Model

The phytoremediaton model proposed by Kumar et al. was developed to predict the phytoremediation potential by *Eichhornia crassipes* in treating industrial wastewater [11]. It was assumed that with increasing time, the concentration and/or efficacy of the pollutants decreases by the aquatic macrophytes that can scavenge inorganic and some organic compounds from wastewater. Based on the assumptions above, the phytoremediation model represented in equation (1) was used to predict the phytoremediation potential of *Eichhornia crassipes.* The model applied some important physio-chemical parameters namely, pH, electrical conductivity (EC), BOD_5, COD, total suspended solids (TSS), total dissolved solids (TDS) and calcium. In this study, the model was applied to evaluate whether the model was appropriate to predict the phytoremediation of municipal wasterwater using *Centella asiatica* and *Eichhornia crassipes* based on parameters BOD_5, COD and NH_3-N.

For BOD_5, COD and NH_3-N, the difference between experimental and predicted data is evaluated. The differences was calculated using equation (1) where P is the phytoremediation potential of *Eichhornia crassipes* at time t from initial day of the experiment. The model is valid for $t > 0$ days. The value μ of depends upon the curve of difference according to the time lapse which can be calculated from equation (2). Then by putting the value of μ in the equation (3), the activity can be predicted.

$$P = P_0 \exp(\mu t) \tag{1}$$

where:

P = phytoremediation potential of the water hyacinth at time from initial day of the experiment.

t = time interval starting from the intial day of the experiment

μ = a value depends upon the curve of difference

$$\mu = \frac{\sum_1^N \mu_i}{N} \tag{2}$$

The equation (3) is used to calculate the summation of μ_i:

$$\mu_i = \frac{\left\{ln\frac{P_0}{P_i}\right\}}{t_i} \tag{3}$$

3. RESULTS AND DISCUSSION

3.1 Characteristics of Wastewater from Sewage Treatment Plant

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The characteristics of the influent and effluent of municipal wastewater were determined using the selected parameters which include pH, temperature, BOD_5, COD and NH_3-N. The characteristics of wastewater from the STP are as shown in Table 1 where the average values were calculated based on the 3 days sampling for four weeks. The STP effluent was within the permissible amount allowed based on Standard B taken from the Environmental Quality Act (EQA), 1974.

Table 1: Characteristics of wastewater from sewage treatment plant (STP), Universiti Teknologi MARA Pulau Pinang Branch

Parameters	Unit	Influent	Effluent	EQA Standard (B)
pH	-	6.69	6.57	5.5 – 9.0
Temperature	°C	26.6	26.5	40
BOD_5	mg/L	306.9	68.0	50
COD	mg/L	750	200	200
NH_3-N	mg/L	5	2	20

3.2 BOD_5

The reduction of BOD_5 by both aquatic macrophytes is shown in Figure 1(a). The BOD_5 effluent concentrations at the end of the tenth day were 39.7 mg/L for *Centella asiatica* and 34.7 mg/L for *Eichhornia crassipes*. It was observed that main reduction of BOD_5 by *Eichhornia crassipes* occured on the first 3 days of the experiment, after which the reduction was at a slower rate. This may be caused by the plant uptake is much higher during the first 3 days. Shah et al. reported similar reduction trend where rapid removal of BOD_5 by *Eichhornia crassipes* and *Pistia stratiotes* (water lettuce) was observed for the first 3 days. This was similar with *Centella asiatica*, where the reduction of BOD_5 mainly took place during this period. It was observed that both aquatic macrophytes achieved the concentration of BOD_5 within the permissable amount allowed (<50 mg/L). The reduction efficiencies for both aquatic macrophytes displayed similar performance, resulting 52 – 55 percentage reduction of BOD_5 as depicted in Figure 1(b).

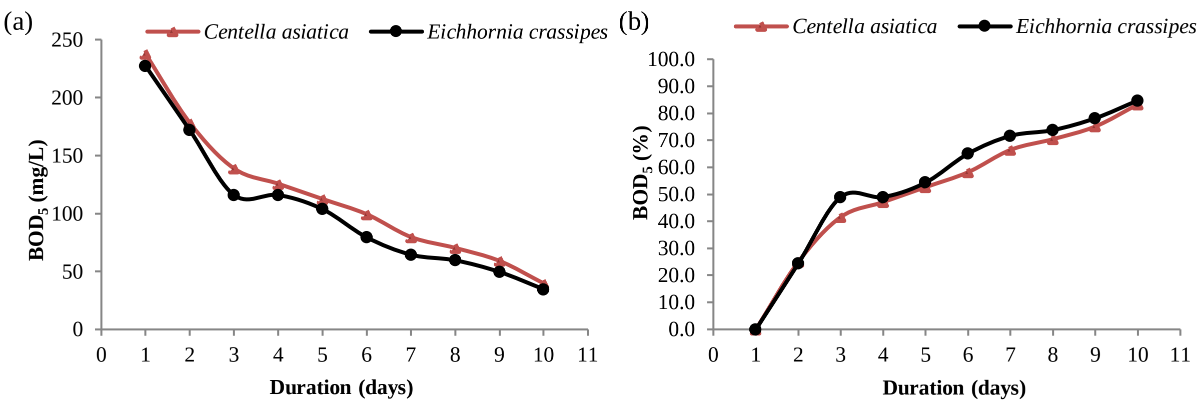

Figure 1: (a) Reduction of BOD_5 and (b) Percentage removal of BOD_5 using *Centella asiatica* and *Eichhornia crassipes*

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3.3 COD

Figure 2 illustrate the reduction and percentage removal of COD using *Centella asiatica* and *Eichhornia crassipes*. *Centella asiatica* was capable to decrease COD from its initial value to final value below the EQA standard (< 200 mg/L). Similarly for *Eichhornia crassipes*, it was observed that the reduction of COD from intial value, 700 mg/L to final value of 100 mg/L as shown in Figure 2(a). In terms of performance efficiency, Figure 2(b) shows that *Eichhornia crassipes* achieved 85.7% COD reduction compare to *Centella asiatica* (71.4%). From the results portray in Figure 2(a), it can be seen that *Centella asiatica* was able to uptake COD rapidly until the 3th day. Meanwhile, *Eichhornia crassipes* where rapid removal was detected from the 6th until the 10th day. Results confirmed that the growth of macrophytes showed high performance to remove COD mainly because of well-developed root system. Shah et al. reported that in their study, three aquatic macrophytes (*Lemna minor*, *Eichhornia crassipes* and *Pistia stratiotes*) showed similar trends where 30 – 40% decrease in the parameters occurred within the 10 days of the experiment.

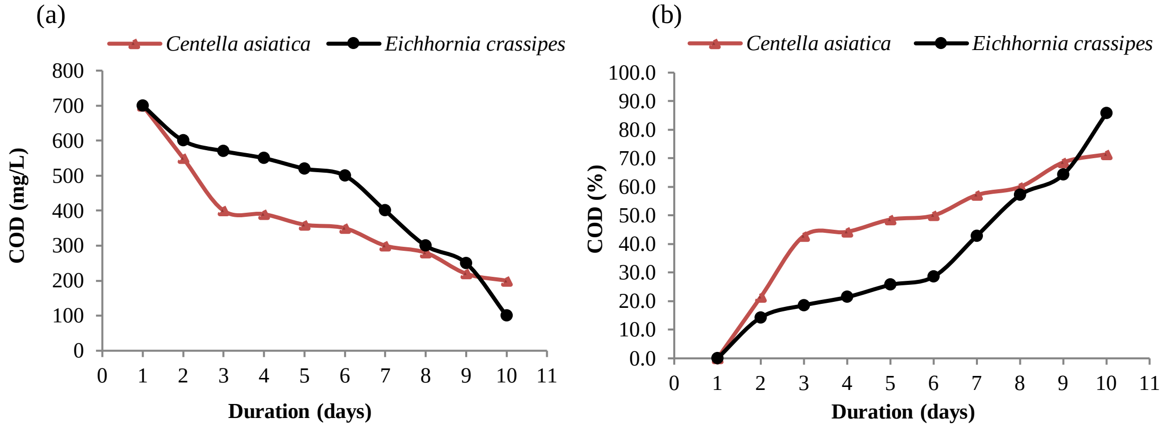

Figure 2: Reduction of COD and (b) Percentage removal of COD using *Centella asiatica* and *Eichhornia crassipes*

3.4 NH_3-N

The reduction trend and the percentage removal of NH_3-N by both aquatic macrophytes is shown in Figure 3. In the *Centella asiatica* system, the reduction of NH_3-N ranging between 5.0 mg/L to 0.5 mg/L (73.0% average reduction) whereas the reduction in *Eichhornia crassipes* system ranges from 5.0 mg/L to 1 mg/L (47.0% average reduction). From Figure 3(a), the presence of *Centella asiatica* and *Eichhornia crassipes* significantly reduced the NH_3-N from their initial levels. A sharp decline of NH_3-N was found throughout the period of 7 days. After 7 days, *Centella asiatica* completely removed NH_3-N while *Eichhornia crassipes* rapidly reduced NH_3-N the first 6 days in the system (57.1%). However, other than the macrophyte uptake, N reduction can occur by NH_3 volatilization which are favoured by high pH, nitrification under aerobic condition and denitirification under anaerobic condition and formation of organic films [3]. Therefore, the NH_3-N reduction by *Centella asiatica* maybe influenced by the pH in the system. *Centella asiatica* showed highest level of NH_3-N

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reduction as compared to *Eichhornia crassipes. The result* of the present study showed that both aquatic macrophytes were found capable of removing NH_3-N (P > 0.05).

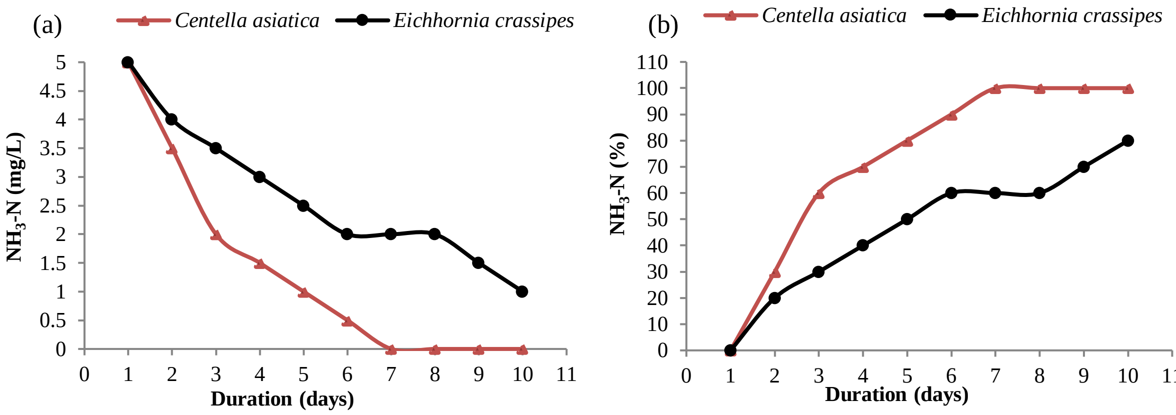

Figure 3: Reduction of NH_3-N and (b) Percentage removal of NH_3-N using *Centella asiatica* and *Eichhornia crassipes*

3.5 pH and Temperature

The results are shown in Table 2 for pH values and temperature of the phytoremediation system. The pH values and temperature in the phytoremediation system showed insignificant difference between the aquatic macrophytes (P>0.05). The pH values for both aquatic macrophytes system were maintained ranging from 6.02 to 7.36. Similarly, the temperature taken from both system showed constant temperature ranging 26.4°C to 26.8°C.

Table 2: Temperature and pH values collected from the phytoremediation treatment system containing *Centella asiatica* and *Eichhornia crassipes*

Days	*Centella asiatica*		*Eichhornia crassipes*	
	Temperature	pH	Temperature	pH
1	26.6	6.02	26.7	6.03
2	26.7	6.03	26.6	6.35
3	26.6	7.33	26.7	7.36
4	26.4	6.59	26.3	6.63
5	26.4	6.25	26.4	6.02
6	26.6	6.79	26.5	6.15
7	26.8	6.42	26.8	6.43
8	26.5	6.39	26.5	6.39
9	26.7	6.49	26.8	6.50
10	26.8	6.50	26.7	6.53

3.6 Statistical Analysis

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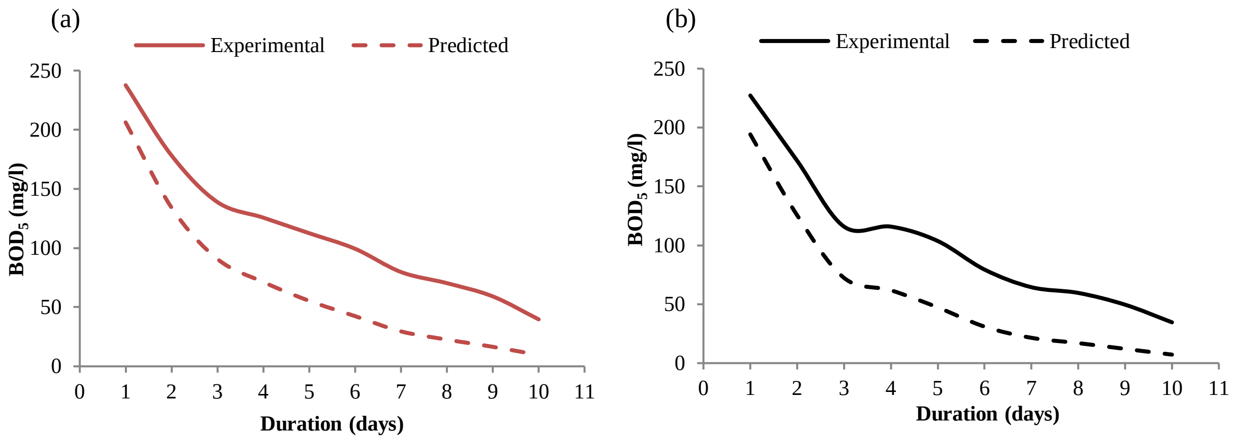
The analysis of variance (ANOVA) test was done for the reduction percentage differences of the effluent parameters between *Centella asiatica* and *Eichhornia crassipes*. Table 3 shows the statistical analysis for the performance of *Centella asiatica* and *Eichhornia crassipes* treatment system. The ANOVA analysis showed that no significant difference ($P > 0.05$) between *Centella asiatica* and *Eichhornia crassipes* as the both plants have similar capability in reducing BOD_5, COD and NH_3-N.

Table 3: ANOVA table showing the performance of aquatic macrophytes in term of average percentage reduction of BOD_5, COD and NH_3-N

Parameters	df	SS	MS	F	P
pH					
Between Macrophytes	1	0.0028	0.0028	0.010531	> 0.05
Error	18	4.9228	0.273489	-	-
Total	19	4.92568	-	-	-
Temperature					
Between Macrophytes	1	0.0005	0.0005	0.020045	> 0.05
Error	18	0.4490	0.024944	-	-
Total	19	0.4495	-	-	-
BOD_5					
Between Macrophytes	1	50.9	50.9	0.15	> 0.05
Error	18	5488.1	343.0	-	-
Total	19	5539.0	-	-	-
COD					
Between Macrophytes	1	558.8	558.8	0.96	> 0.05
Error	18	10439.6	580.0	-	-
Total	19	10998.4	-	-	-
NH_3-N					
Between Macrophytes	1	1015.3	1015.31	0.96	> 0.05
Error	18	19063.1	1059.0	-	-
Total	19	20078.4	-	-	-

3.7 Evaluating the Phytoremediation Model

The evaluation of the experimental and predicted reduction trend displayed in Figure 4, 5 and 6 suggests that the model is agreeable in predicting the phytoremediation. All parameters exhibited exponential decrease in *P* of *Centella asiatica* and *Eichhornia crassipes* for the duration of 10 days. Although there were differences between the experimental and predicted values, the increase in phytoremediation duration will minimize the variation between the experimental and predicted values. This was supported by Kumar et. al where the increase of phytoremediation duration by the aquatic macrophytes attained the equilibrium level of absorption and/or degradation of pollutants present in the wastewater. This suggests that by extending the duration of phytoremediation, the model is appropriate to describe the phytoremediation potential of the aquatic macrophytes in municipal wastewater. It is recommended to validate the model by increasing the duration and interval [11]. Figure 7, 8 and 9 shows the correlations between the experimental and predicted values where the graph



denotes the appropriateness of the model. The correlations between experimental and predicted values of BOD_5, COD and NH_3-N displayed strong correlations where R^2 values ranged from 0.9324 to 0.9865. Therefore, Figure 7, 8 and 9 indicates a good agreement between the experimental and predicted values.

Figure 4: Comparison between the predicted and experimental values of BOD_5 by (a) *Centella asiatica* and (b) *Eichhornia crassipes*

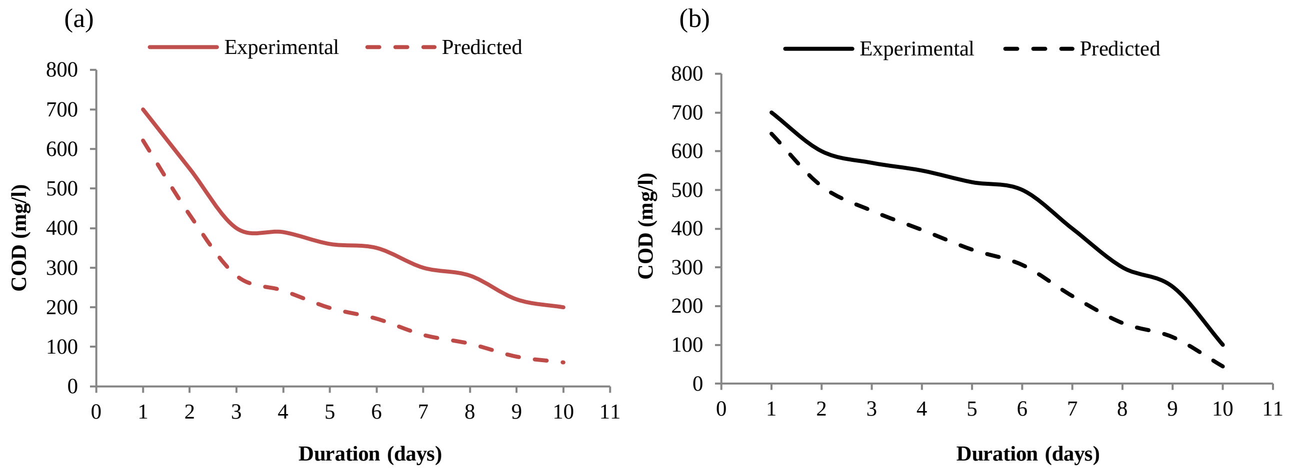


Figure 5: Comparison between the predicted and experimental values of COD by (a) *Centella asiatica* and (b)

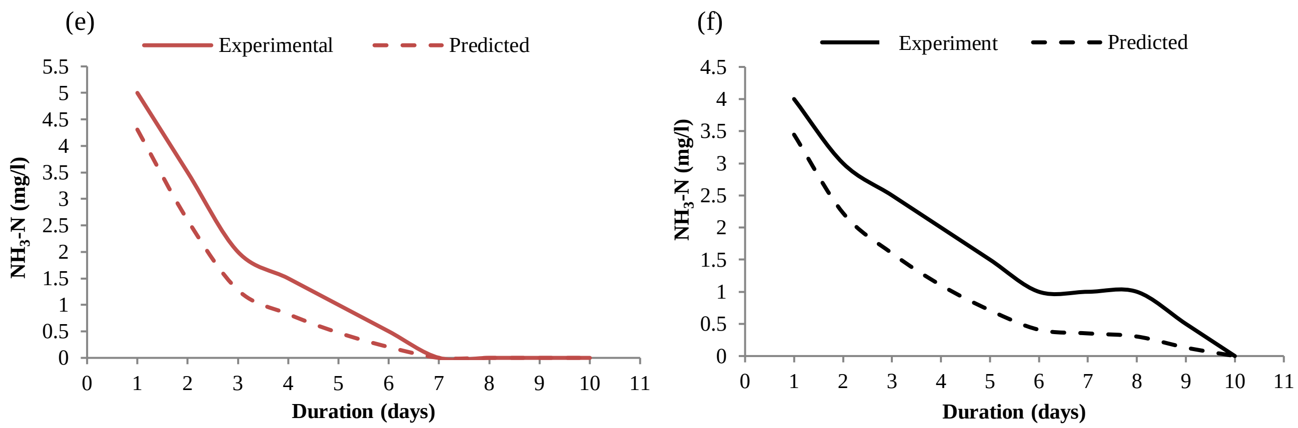


Figure 6: Comparison between the predicted and experimental values of NH_3-N by (a) *Centella asiatica* and (b) *Eichhornia crassipes*

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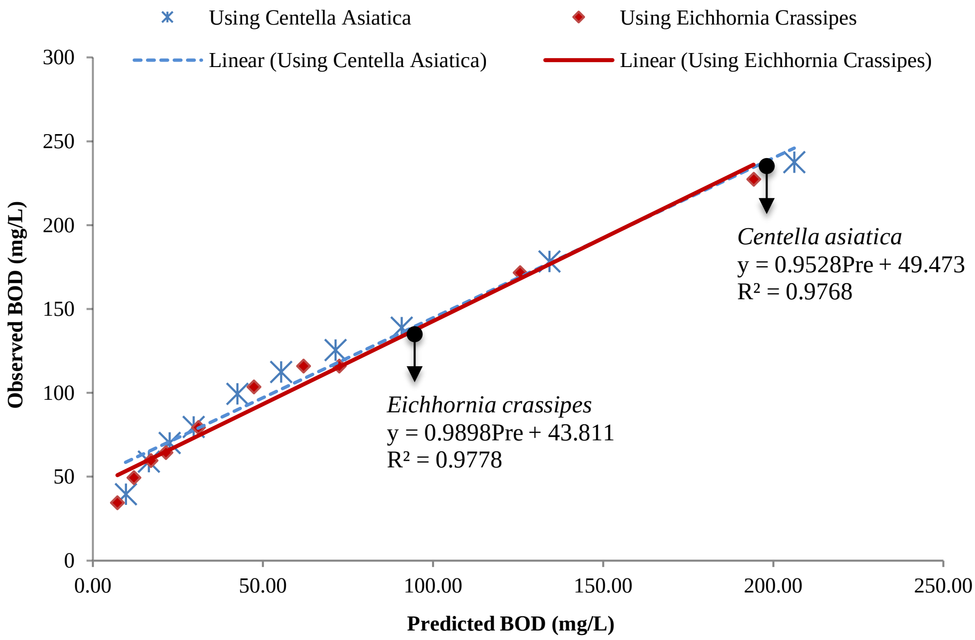

Figure 7: Correlation between the predicted and experimental values of BOD_5 by *Centella asiatica* and *Eichhornia crassipes*

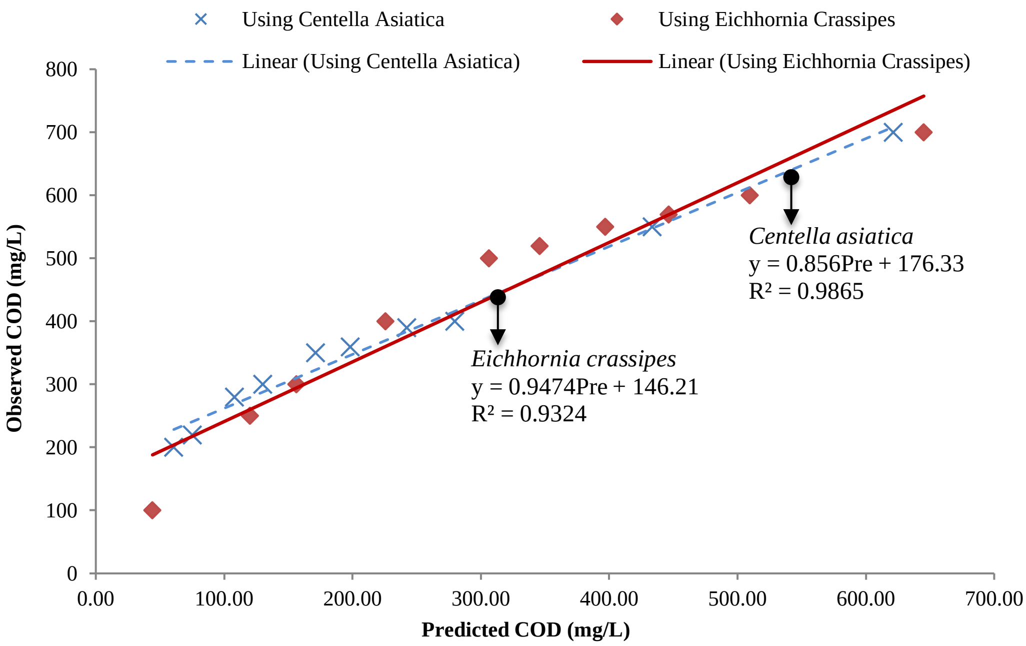

Figure 8: Correlation between the predicted and experimental values of COD by *Centella asiatica* and *Eichhornia crassipes*

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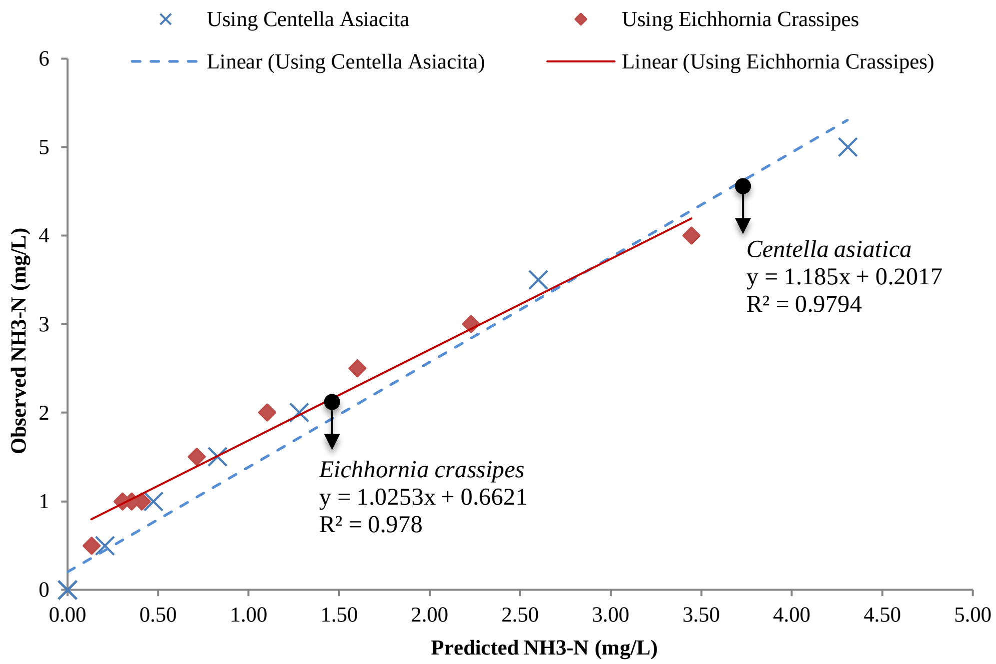

Figure 9: Correlation between the predicted and experimental values of NH_3-N by *Centella asiatica* and *Eichhornia crassipes*

4. CONCLUSION

The results of the present study showed that *Centella asiatica* and *Eichhornia crassipes* were effective in reducing the concentration of BOD_5, COD and NH_3-N. The average reduction of effluent value of each parameter using *Centella asiatica* were 52.0% for BOD_5, 46.4% for COD and 73.0% for NH_3-N. For *Eichhornia crassipes*, the average reduction efficiency for selected parameters were 55.0% for BOD_5, 35.9% for COD and 58.8% for NH_3-N. In addition, *Centella asiatica* and *Eichhornia crassipes* successfully reduced BOD_5, COD and NH_3-N within the permissible amount allowed to be discharge into the waters. The reduction efficiency was affected by the sorption of organics and inorganics from the wastewater which atrributed to attainment of equilibrium up to the carrying capacity of aquatic macrophytes. The phytoremedial potential by the aquatic macrophytes was also affected by the duration of treatment, where the concentration and/or efficacy of the pollutants has not yet shown any significant changes. As for the appropriateness of the phytoremediation model, the model can be applied to predict the phytoremediation potential of *Centella asiatica* and *Eichhornia crassipes* in municipal wastewater.

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