EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 13(2) 2020 124-137
DOI 10.14456/ea.2020.35
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Performance of Water Hyacinth *(Eichhornia crassipes)* in the Treatment of Residential and Surimi wastewater

Chawisa Wattanapanich, Napat Durongpongtorn , and
Naiyanan Ariyakanon*

Department of Environmental Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

*Corresponding author: anaiyanan@yahoo.com

Received: February 6, 2020; Revised: February 24, 2020; Accepted: March 6, 2020

Abstract

The phytoremediation of residential and surimi wastewater by water hyacinth, *Eichhornia crassipes* (Mart.) Solms, was investigated at a wastewater concentration of 10–50% (v/v). The pH, biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), total kjeldahl nitrogen (TKN), and total phosphorus (TP) levels of each wastewater before and after phytoremediation were determined on day 0, 3, 6, 9, 12, and 15. The relative growth rate (dry weight) of the plant biomass increased from day 0–15 and depended on the wastewater concentration. The maximum growth of water hyacinth grown in 50% (v/v) residential or surimi wastewater over 15 day was 42.4 ± 1.5% and 41.7 ± 1.9%, respectively. After treatment with water hyacinth, most of the wastewater parameters were significantly decreased in according with a logarithm model (R^2 greater than 0.84) at every tested concentration of both residential and surimi wastewater. The greatest removal efficiency of BOD, COD, TSS, TKN, and TP in 10% (v/v) residential wastewater was 90.1 ± 3.7%, 85.1 ± 4.2%, 85.5 ± 2.9%, 61.4 ± 1.9%, and 85.3 + 2.9%, respectively, while for 10% (v/v) surimi wastewater was 90.6 ± 4.7%, 83.7 ± 3.9%, 87.5 ± 4.1%, 62.3 ± 2.8%, and 82.1 ± 2.3%, respectively. Thus, phytoremediation with water hyacinth is an effective and alternative method for treatment of contaminants in wastewater.

Keywords: Water hyacinth; Residential wastewater; Surimi wastewater; Phytoremediation

1. Introduction

Wastewater discharged by domestic residences, industry, and agriculture are the main sources of water pollution in Thailand. In 2018, the population (ca. 66 million people) in Thailand generated 9.7 million m^3 of wastewater/day, while the 95 available treatment plants had an operational capacity of only 2.6 million m^3/day, some 27% of the total wastewater (Pollution Control Department, 2019). With the high cost of wastewater treatment systems, it cannot cover all areas of this country.

In large cities, including the capital as Bangkok and urban communities, the construction of large buildings, such as hotels, condominiums, hospitals, department stores, dormitories, and office buildings, are rapidly increasing. These buildings are required to install a wastewater treatment system and treat wastewater in accordance with the standards. This is especially true for residential wastewater that originates from dwellings, households, and communities, where the biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS) are found in high concentrations (Adewumi and Ogbiye, 2009). Without suitable treatment, this wastewater will cause many environmental problems when released into downstream ecosystems.

Surimi is one of the important industries that produce seafood products in Thailand. Surimi wastewater is continuously released during the washing step of surimi preparation from fresh fish to remove water soluble materials, including proteins. The surimi wastewater is creamish-white with a strong fishy odor, and is deficient in dissolved oxygen (DO) with very high BOD values (Wasave and Kulkarni, 2004). Accordingly, the direct discharge of surimi wastewater may generate negative impacts on the environment (Huang and Morrissey, 1998). Although the solid waste from surimi processing is usually converted to animal feed or fishmeal, the liquid waste is generally discarded back into the plant's waste stream.

Therefore, it is essential to develop efficient treatment systems for both residential and surimi wastewater. Phytoremediation is a likely suitable alternative method that uses plants to clean the polluted water. Phytoremediation has gained a lot of interest as a green technology in wastewater treatment due to its low cost and environmental-friendly nature (Paz-Alberto and Sigua, 2013). The selection of aquatic plants for use in phytoremediation is the important factor for a successful phytoremediation process. It is essential to choose aquatic plants that have a high uptake capacity for the desired pollutants, adaptable to the specific wastewater condition, fast growth rate, and easy to control (Rezania *et al*., 2015).

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms, is a free-floating perennial aquatic plant, with a rapid growth, ability to adapt to a wide range of environmental conditions, and a large nutrient uptake capacity. Accordingly, water hyacinth is considered as a suitable aquatic macrophyte for phytoremediation (Rezania *et al*., 2015). Indeed, water hyacinth has been shown to have the potential to treat various contaminants present in wastewater, such as pesticides, zinc oxide nanoparticles, heavy metals/metalloids, and nutrients (Anudechakul *et al*., 2015, Boonkrue and Ariyakanon 2017, Saha *et al*., 2017). The dense fibrous root system of water hyacinth provides an extensive surface area for absorption and adsorption of various pollutants. Water hyacinth has rapid growth, high biomass production, therefore increasing filtering capacity of contaminants from wastewater (Fox *et al.,* 2008). For industrial wastewater treatment, water hyacinth showed a high efficiency in reducing the turbidity (92.5%), COD (83.7%), TSS (91.8%), total dissolved solids (62.3%), nitrates (67.5%), ammonia (71.6%), and total phosphates (90.2%), as well as cadmium (97.5%), nickel (95.1%), mercury (99.9%), and lead (83.4%) (Fazal *et al*, 2015). Domestic wastewater treatment by water hyacinth resulted in a significant reduction in the COD (79%), BOD (86%), TSS (73%), total nitrogen (77%), TP (45%) (Valipour *et al*., 2015).

Water hyacinth has a high tolerance to pollution, nutrient absorption capacity, and abundance in Thailand, and so this plant was selected for use in this study. The objective of this research was to evaluate the phytoremediation efficiency of water hyacinth for treatment of residential and surimi wastewater. The water quality before and after treatment was analyzed, including in comparison with the acceptable limits for residential and industrial effluent standards in Thailand. All of parameters (pH, BOD, COD, TSS, TKN) except TP were considered for regulation limit in Thailand. TP was also analyzed because high level of TP related to eutrophication.

2. Materials and Methods

2.1 Plant sampling

Water hyacinth samples were collected from the Nakhon Chisri River in Nakhon Pathom Province, Thailand, and taken in 50 x 75 cm polyethylene bags to the laboratory. Plants were confirmed for species identification by reference to the Thai Forest Herbarium. The plants were disinfected by immersion in 0.01% (v/v) Clorox bleach for 2 min to eliminate adhering algae and insect larva, rinsed with excess distilled water for 5 min and then thoroughly cleaned under gentle running water. These cultures of water hyacinth were maintained in two tanks of 60 × 90 × 20 cm polyvinyl chloride (PVC) aquaria containing Hoagland's No. 2 nutrient solution (Anudechakul *et al.* 2015) under natural sunlight for 3 weeks for adaptation. Then, new budding plants were selected and separated from the original plants. New healthy plants with 4–5 leaves and of 45 ± 2 g wet weight were selected for use.

2.2 Wastewater sampling

Residential wastewater was collected from the septic tank of 809 units of condominium in Phaya Thai District, Bangkok. Surimi wastewater was collected from a surimi plant located in the Bang Chalong, Bang Phli District, Samut Prakan Province, where the main products were prepared from minced fish. This surimi industry produced wastewater at about 1000–1200 m^3/day. The wastewater samples were taken in 20-L PVC containers to the laboratory, stored at 4 ^oC and analyzed within 1 week, except the pH and five-day BOD (BOD_5) values were determined within 24 h.

2.3 Experimental design

The experimental design was based upon a complete randomized block design with five treatments and three replications. The treatments were comprised of:

(i) water hyacinth with tap water
(ii) 10%, 20%, 30%, 40%, and 50% (v/v) residential wastewater
(iii) 10%, 20%, 30%, 40%, and 50% (v/v) surimi wastewater
(iv) water hyacinth cultured in 10%, 20%, 30%, 40%, and 50% (v/v) residential wastewater
(v) water hyacinth cultured in 10%, 20%, 30%, 40% and 50% surimi wastewater

The experimental units were identical glass vessels of 3 L capacity, a surface area of 360 cm^2 and a depth of 15 cm. Each vessel contained 2 L of wastewater. All the vessels were placed in a greenhouse to obtain natural sunlight, with a temperature range of 26–33 ^oC during the 15-days culture period.

2.4 Wastewater water analysis

The physicochemical parameters (pH, BOD_5, COD, TSS, TKN, and TP) of the residential and surimi wastewater before and after phytoremediation were evaluated at 0, 3, 6, 9, 12, and 15 day after treatment. The pH of each treatment was measured using a pH meter (Denver, USA, digital pH meter, model UB-10). Determination of the BOD_5, COD, TSS, TKN, and TP followed the standard methods for the examination of water and wastewater by American Public Health Association (APHA), American Water Work Association and Water Environment Federation (Rice *et al.*, 2017). The water level in the vessels was maintained at the initial level by the addition of tap water to control for that lost by evaporation or phototranspiration.

2.5 Plant sampling and determination

The plants were collected from each vessel at 0, 3, 6, 12, and 15 day, respectively collecting all the plants from a single culture vessel on each date, with different replicate culture vessels in each treatment being harvested on different dates. The harvested plants were carefully washed using tap water followed by distilled water to remove any residual chemicals on the surface of the plant, drained on a sieve and dabbed dry before weighing the whole plant to obtain the wet weight. After drying to a constant mass in an oven at 65 ^oC (48 h), they were carefully weighed to obtain the dry weight (DW).

Relative growth rate (RGW_{DW}) and removal efficiency

The relative growth rates (RGR_{DW}) were calculated from the DW biomass measurements according to Rees et al. (2010) using Eq. (1);

$$RGR = \frac{[\ln(W2)-\ln(W1)]}{t2-t1} \quad (1)$$

where W1 and W2 are the plant weights at times t1 and t2, respectively. The efficiency of water hyacinth to treat the wastewater was calculated as the percentage of removal for each parameter following Eq. (2);

$$\text{Removal efficiency} = \underline{[C_i-C_e]}/C_i \times 100 \quad (2)$$

where C_i and C_e are the influent and effluent concentrations, respectively.

2.7 Statistical analysis

All statistical analysis was performed using the SPSS Statistics version 22.0 for windows (SPSS Inc., USA) software. The significance of any differences between means, including the $RGR_{DW,}$ and removal efficiency, were determined using the Turkey range test, where P values < 0.05 were accepted as significant.

3. Results and Discussion

3.1 Physicochemical properties of wastewater before phytoremediation

The parameters of the residential and surimi wastewaters were determined before phytoremediation. The pH of the residential and surimi wastewaters was 7.19 ± 0.13 and 6.8 ± 0.11, respectively, which were within the Pollution Control Department standard and Ministry of Industry standard limit range. The TKN of the residential and surimi wastewaters was 18.8 ± 0.62 and 22.4 ± 0.96 mg/L, respectively, which was lower than the acceptable limit (Table 1). However, The BOD_5, COD, and TSS levels of both the residential and surimi wastewaters exceeded the respective standards. The TP level in the surimi wastewater was 3.18-fold higher than in the residential wastewater, which reflected the extensive washing that was used to remove water soluble substances resulting in (large volumes of) wastewater that contained a high concentration of organic materials. Therefore, the BOD_5, COD, TSS, and TP in the surimi wastewater were high. Likewise, the residential wastewater from the Covenant University community, Nigeria, contained high BOD_5 (275 mg/L), COD (452 mg/L), and total solids (428 mg/L) levels (Adewumi and Ogbiye. 2009), with similar BOD_5 and COD values to the results in this experiment.

Table 1. Physicochemical properties of the residential and surimi wastewater before treatment in comparison to the Thai effluent standard, and the analysis method

Para meter	**Residential wastewater**	**Residential effluent standard***	**Surimi waste water**	**Industrial effluent standard ****	**Analysis method**
pH	7.19 ± 0.13	5–9	6.8 ± 0.11	5.5–9.0	pH Meter
BOD_5 (mg/L)	268 ± 12	20	329 ± 14	20	Azide modification
COD (mg/L)	522 ± 28	-	525 ± 22	120	Potassium dichromate digestion
TSS (mg/L)	326 ± 13	30	91.5 ± 3.7	50	Glass fiber filter disc
TKN (mg/L)	18.8 ± 0.62	35	22.4 ± 0.96	100	Kjeldahl
TP (mg/L)	11.9 ± 0.37	-	37.8 ± 1.19	-	Ascorbic acid colorimetric

* Effluent Standards for wastewater from condominium > 500 units, Pollution Control Department, Ministry of Natural Resources and Environment (2005).

** Effluent Standards for industrial wastewater, Ministry of Industry (2017).

3.2 Effects of wastewater on the growth of water hyacinth

The optimum growth of water hyacinth is a key factor for phytoremediation. The environmental conditions, such as pH, temperature, and salinity of the water, affect the overall size of the plant (Lissy and Madhu, 2010). The RGR_{DW} of water hyacinth grown in the tap water (control), and in the residential or surimi wastewaters at 10–50% (v/v) were compared after a 15-days culture period. When cultured in tap water only, the biomass of water hyacinth slightly increased over the 15-days period with a RGR_{DW} of 0.010 ± 0.008 mg/g.day (Table 2). The biomass of water hyacinth grown in the residential or surimi wastewater significantly increased at each wastewater concentration over this 15-day period. It may be that the residential and surimi wastewaters had a high enough content of TKN, TP, and essential elements to support the growth of water hyacinth within 15 days.

Moreover, no visible morphological changes in the plants were seen, indicating that water hyacinth was broadly tolerant to the residential and surimi wastewater at these concentrations. Nitrogen and phosphorus rich water can induce a high growth of water hyacinth, and the maximum growth of water hyacinth has been reported to occur at 28 mg/L of TKN and 7.7 mg/L of TP Mohan *et al*. 2016). In this study, the RGR_{DW} values of water hyacinth grown in residential or surimi wastewater at 30%, 40%, and 50% (v/v) were significantly greater than those at 10% and 20% (v/v) of either wastewater. However, in a preliminary study, water hyacinth cultured in 60–100% (v/v) wastewater died within 3–4 day (data not shown). Therefore, 50% (v/v) was the maximum concentration of these residential and surimi wastewater samples that the water hyacinth could tolerant and growth.

The maximum growth of water hyacinth over the 15 day was observed in the 50% (v/v) residential and surimi wastewaters at 42.4 ± 1.5 % and 41.7 ± 1.9%, respectively. This result is in according with the study by Rezania *et al*. (2013), who studied the efficiency of water hyacinth to remove COD, TKN, and TP and found that the biomass of water hyacinth increased 40% during 2 weeks in a closed system. Likewise, Ayyasamy *et al*. (2009) reported that the biomass of water hyacinth grown in water containing nitrate increased about 37% over 10 days.

3.3 Wastewater treatment efficiency of water hyacinth

The wastewater parameters in the treatments with and without water hyacinth were determined after 0, 3, 6, 9, 12, and 15 days. The pH fluctuation in the residential wastewater treated with plants was less than that in the surimi wastewater (Figure 1).

Table 2. The RGR_{DW} of water hyacinth at different concentrations of the residential and surimi wastewaters

Concentration [% (v/v)]	RGR_{DW} (mg/g.day)	
	Residential wastewater	Surimi wastewater
10%	0.025 ± 0.0013^b	0.024 ± 0.0012^b
20%	0.026 ± 0.0017^b	0.025 ± 0.0014^b
30%	0.029 ± 0.0015^c	0.029 ± 0.0011^c
40%	0.031 ± 0.0012^c	0.030 ± 0.0015^c
50%	0.032 ± 0.0014^c	0.031 ± 0.0012^c
0% (Control)	0.010 ± 0.0008^a	

RGR_{DW} represent the relative growth rate by plant dry weight biomass. Data are shown as the mean ± 1 S.D., derived from three repeats. Means within a column with a different lower case superscript letter ($^{a–c}$) are significantly different ($P < 0.05$) according to the Turkey test.

However, the pH in all treatments was below the regulation limit (5.5–9.0). Shah *et al.,* (2014) reported that a pH range of 6–9 was appropriate for using macrophytes for wastewater treatment, while the optimum pH range for water hyacinth growth was reported to be 5.8–7.5 (Gupta *et al*., 2012). In this study, the pH at 12 and 15 days in all treatments with plants decreased (Figure 1), because during the plants uptake of nutrients, such as nitrogen, deprotonation occurs which releases H^+ ions into the water medium and so increases the acidity in the water (Gupta *et al*., 2012).

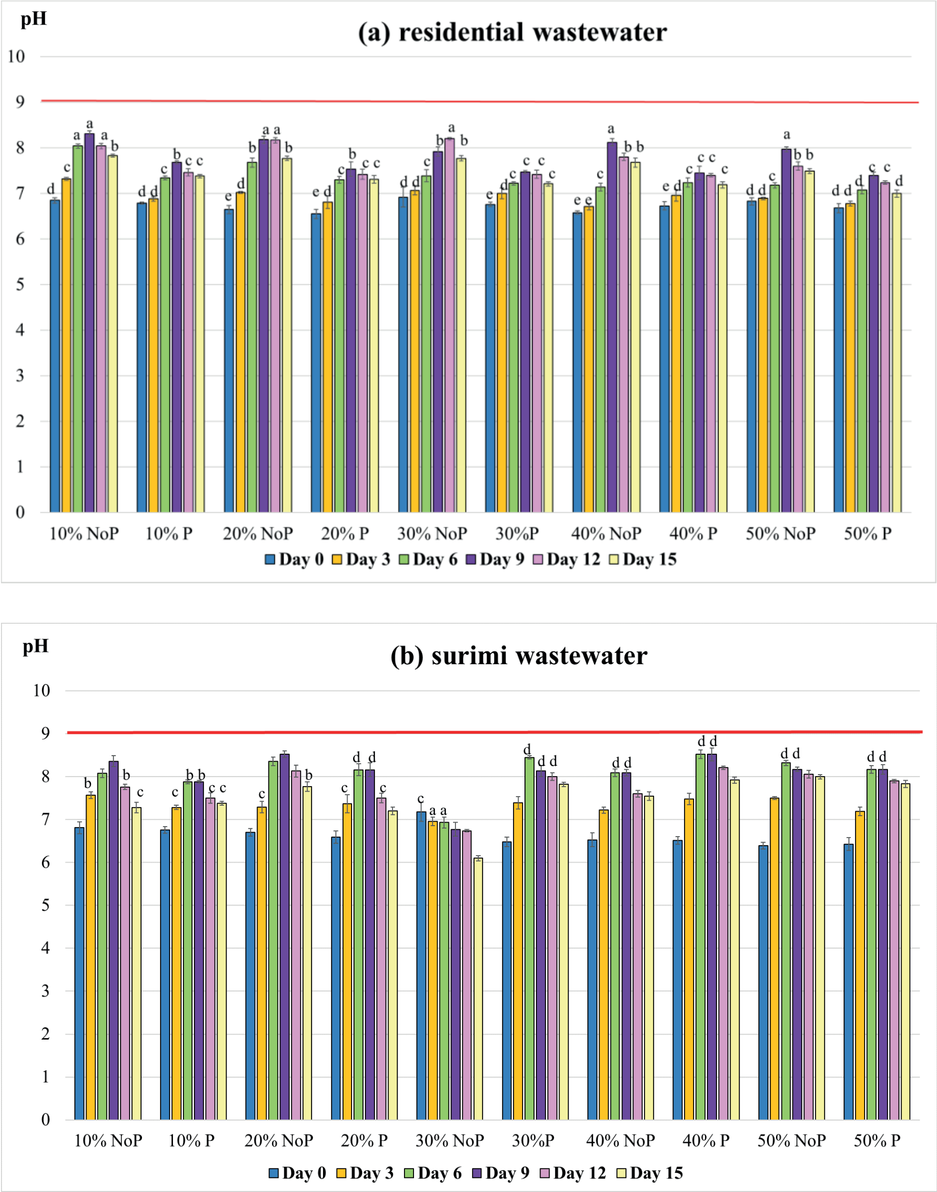


Figure 1. The pH change in different initial concentrations of (a) residential and (b) surimi wastewaters during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates. The red bar indicated the highest pH level of effluent standard for wastewater.

The BOD, COD, TSS, TKN, and TP in the treatment without water hyacinth slowly decreased from 0–15 days, and this could be represented as a linear model (R^2 greater than 0.8 at every concentration) in both the residential and surimi wastewaters (Figures 2–6). In the wastewater treatment with water hyacinths, most of the parameters were significantly decreased and could be represented as logarithm model (R^2 greater than 0.84 at every concentration) in both the residential and surimi wastewaters. That means water hyacinth accelerated the reduction of the BOD, COD, TSS, TKN, and TP in the respective wastewaters. Water hyacinth has an extensive root system and root surface area for uptake and remove of water contaminants, which occurs by adsorption of cations onto the negatively charged root surfaces (Rezania *et al.*, 2016). The mechanisms of contaminant removal in this study include aerobic microbiological conversion, sorption, sedimentation, volatilization and chemical transformations (Victor *et al.*, 2016).

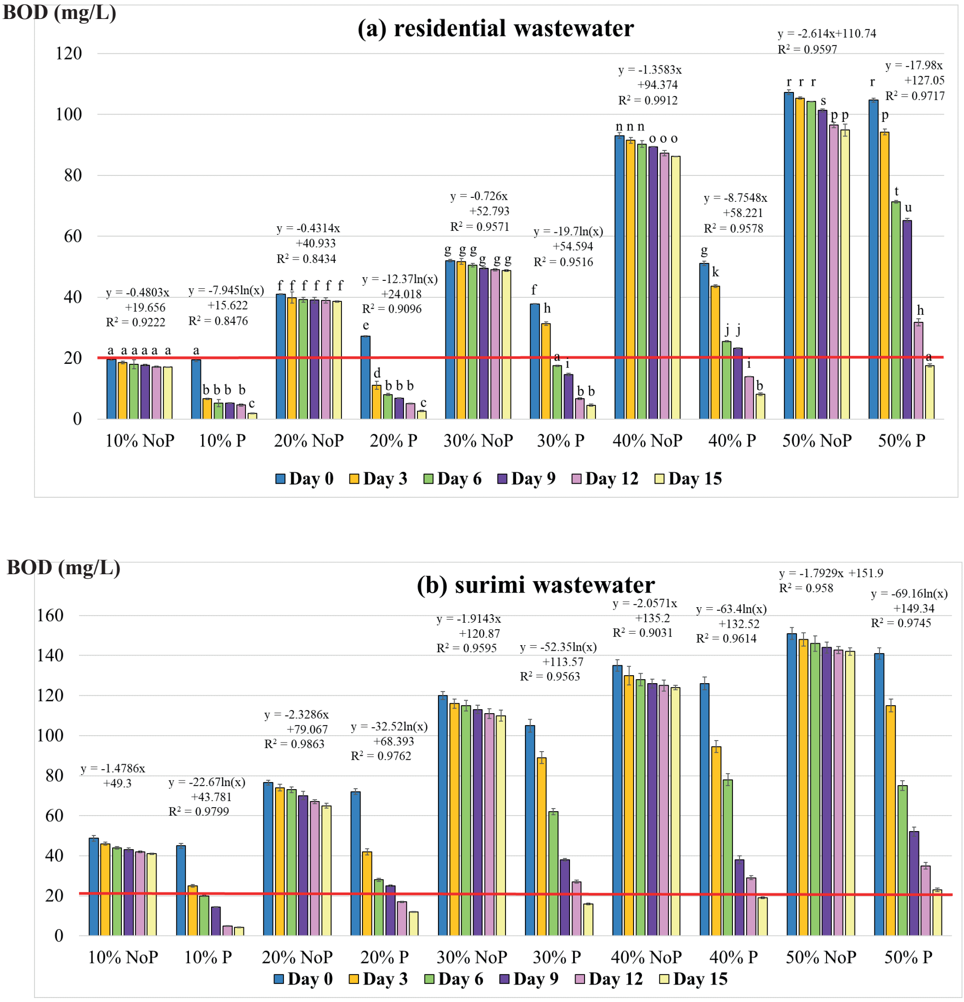


Figure 2. The BOD reduction level in different initial concentrations of (a) residential and (b) surimi wastewaters during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates. The red bar indicated the highest BOD of effluent standard for wastewater.

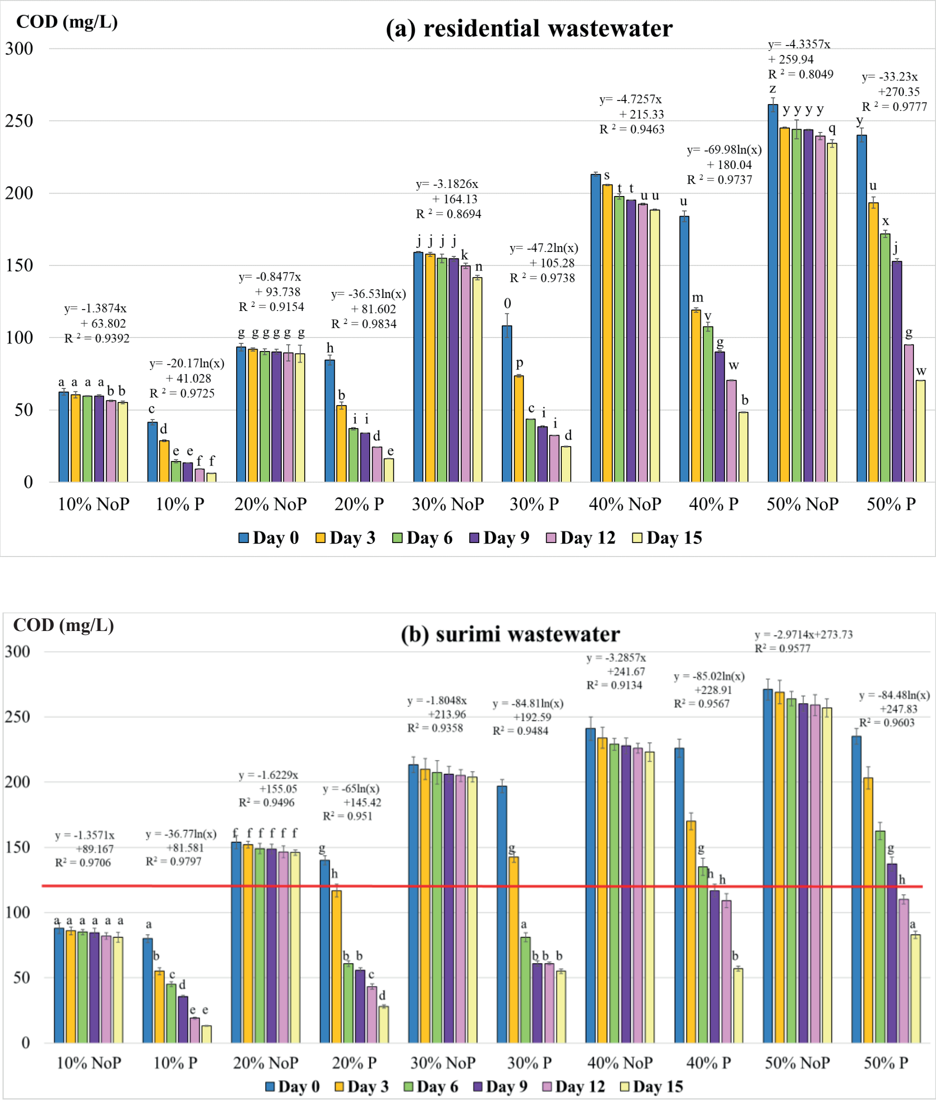
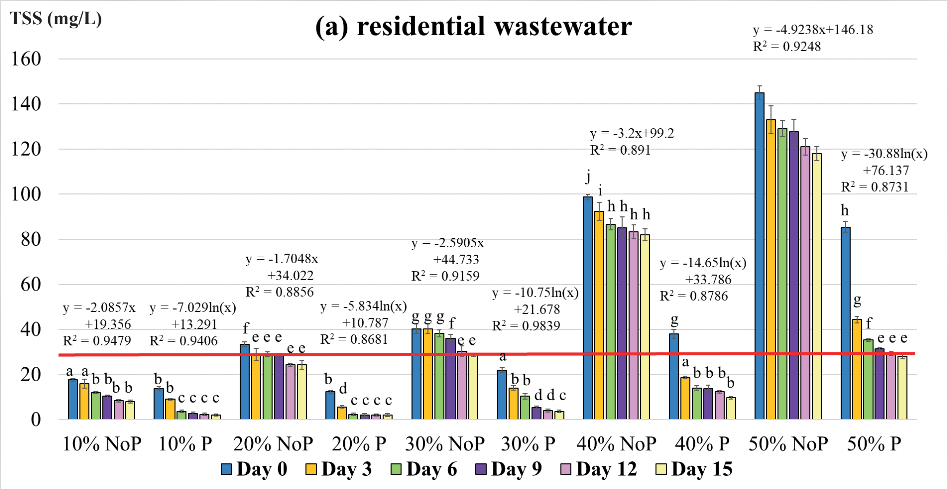


Figure 3. The COD reduction level in different initial concentrations of (a) residential and (b) surimi wastewater during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates. The red bar indicated the highest COD of effluent standard for industrial wastewater. There is no regulation for COD level in residentialwastewater.



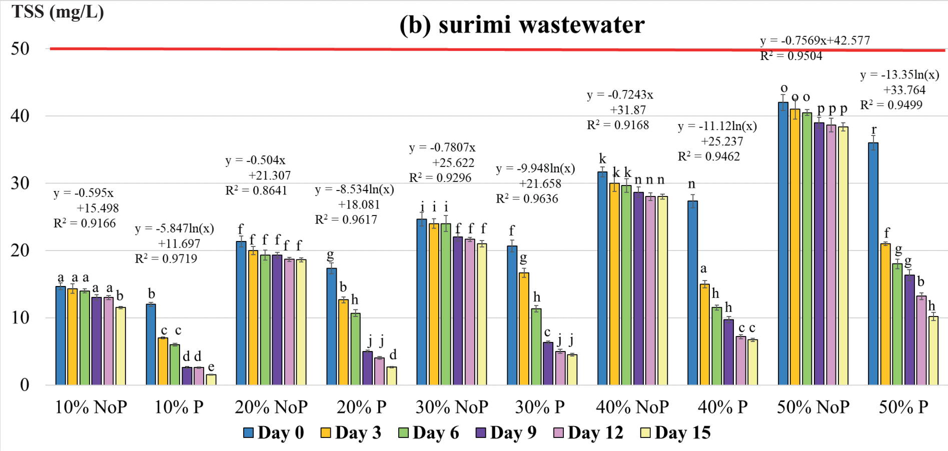


Figure 4. The TSS reduction level in different initial concentrations of (a) residential and (b) surimi wastewater during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates. The red bar indicated the highest TSS of effluent standard for residential wastewater (30 mg/L) and for industrial wastewater (50 mg/L).

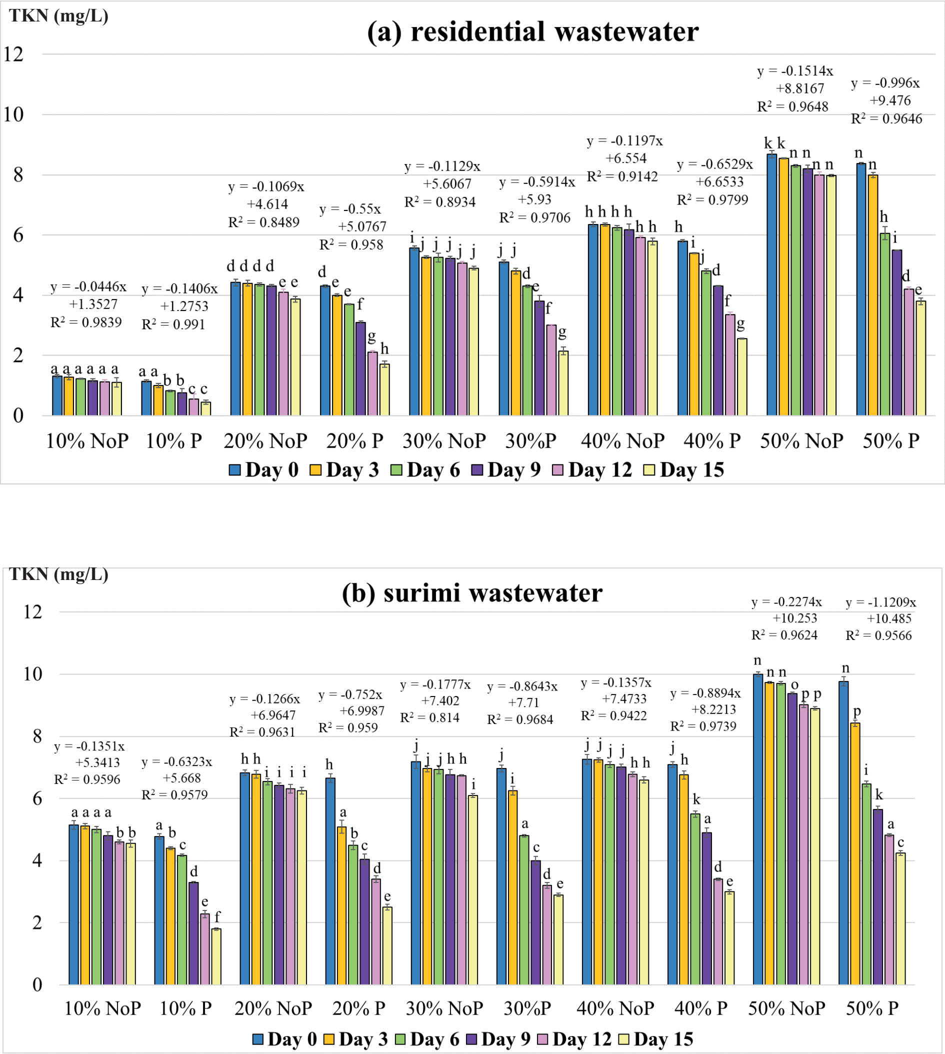
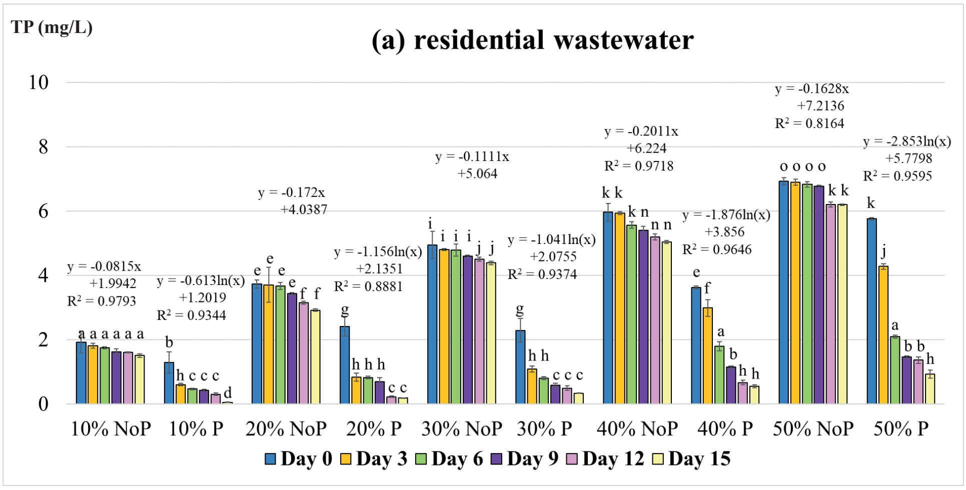


Figure 5. The TKN reduction level in different initial concentrations of (a) residential and (b) surimi wastewater during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates.



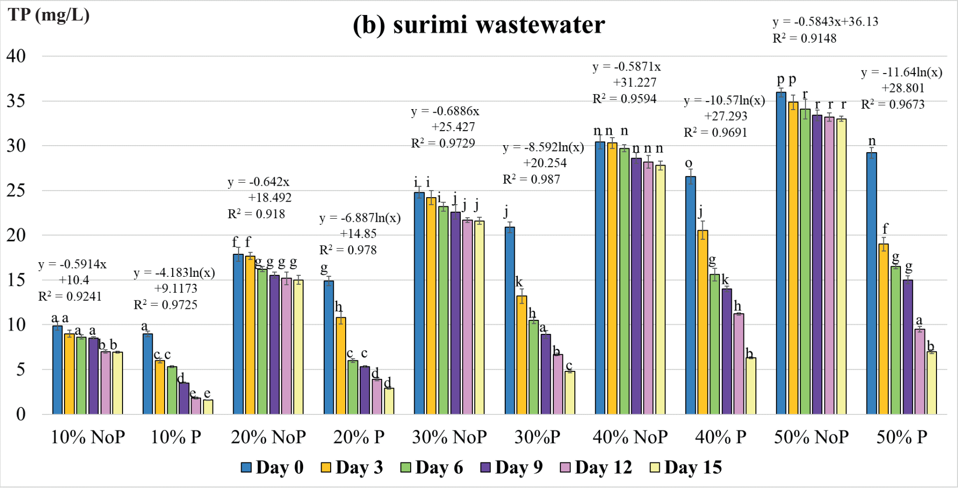


Figure 6. The TP reduction level in different initial concentrations of (a) residential and (b) surimi wastewater during treatment with (P) and without (NoP) water hyacinth for 15 day. Data are shown as the mean ± 1SD, derived from three replicates.

The maximum BOD removal level from the 10% (v/v) residential and surimi wastewaters were 90.1 ± 3.7% and 90.6 ± 4.7%, respectively. At 50% (v/v) wastewater, the BOD in the residential wastewater was reduced to below the standard limit by 15 days, but the BOD in surimi wastewater still higher than the standard limit, which was because of the high initial organic loading. The highest COD removal level in the 10% (v/v) residential and surimi wastewaters was 85.1 ± 4.2% and 83.7 ± 3.9%, respectively. At 50% (v/v) wastewater, the COD level in the surimi wastewater decreased to below the standard limit by 12 days, but there is no regulation for COD levels in residential wastewater.

According to Reddy (1981), the presence of plants decreased the dissolved CO_2 in the wastewater during periods of high photosynthetic activity, which increased the DO level of the water, creating aerobic conditions in wastewater that favor aerobic bacterial activity to reduce the BOD and COD. Water hyacinth and algae were previously reported to reduce the BOD in sewage wastewater by 96.9% (Tripathi and Shukla, 1991). For phytoremediation, the decreased COD level is due to the degradation (oxidation) of organic carbon to CO_2 and water (Ng and Chan, 2017). Zimmels *et al*. (2006) reported the feasibility of water hyacinth in treating domestic sewage that contained a COD level of 270–550 mg/L.

The maximum removal of TSS from the 10% (v/v) residential and surimi wastewaters was 85.5 ± 2.9% and 87.5 ± 4.1%, respectively. At 50% (v/v) residential wastewater, the TSS decreased to less than the standard limit by 12 day, while in the surimi wastewater the TSS was lower than the acceptable limit in every treatment. Trivedy and Pattanshetty (2002) reported that water hyacinth was highly efficient in eliminating TSS, TKN, and TP in shallow depth systems, in according with the shallow tanks used in this study.

The highest TKN removal from the 10% (w/v) residential and surimi wastewaters was 61.4 ± 1.9% and 62.3 ± 2.8%, respectively, while for TP it was 85.3 ± 2.9% and 82.1 ± 2.3%, respectively. Water hyacinth has previously been reported to remove 50.04% TP from industrial wastewater (Victor *et al*., 2016), and also to remove 80% COD, 75% TN, and 75% TP from domestic wastewater at 14 day (Rezania *et al*., 2013). Qin *et al*. (2016) reported that water hyacinth showed a higher nitrogen removal efficiency than water lettuce due to its larger total root surface area (0.97–1.10 m^2/g fresh weight), active absorption area (0.31–0.36 m^2/g fresh weight), and leaf area, as well as a higher root activity, root biomass, and net photosynthetic rate (20.28 μmol CO_2/m^2S). A floating mat of water hyacinth forms a root-biofilm network that maximizes the contact between the wastewater medium and the root zone for microbial activity to degrade and assimilate pollutants, and to serve as a filtration and entrapment media (Misha and Maiti, 2017).

Table 3. Maximum removal efficiency (%) of water hyacinth in residential and surimi waste water

Conc.	BOD		COD		TSS		TKN		TP	
	Res	Su	Res	Su	Res	Su	Res	Su	Res	Su
10%	90.1^{a} ± 3.7	90.6^{a} ± 4.7	85.1^{b} ± 4.2	83.7^{b} ± 3.9	85.5^{b} ± 2.9	87.5^{a} ± 4.1	61.4^{g} ± 1.9	62.3^{g} ± 2.8	85.3^{b} ± 2.9	82.1^{c} ± 2.3
20%	89.7^{a} ± 4.2	88.9^{a} ± 4.9	80.6^{c} ± 2.6	80.2^{c} ± 4.4	83.7^{b} ± 3.1	84.6^{b} ± 2.7	60.2^{g} ± 2.4	62.1^{g} ± 3.2	82.1^{c} ± 3.5	80.5^{c} ± 2.2
30%	88.0^{a} ± 2.9	87.6^{a} ± 4.1	77.3^{d} ± 2.7	78.8^{d} ± 3.5	83.3^{b} ± 3.4	78.2^{d} ± 3.2	57.9^{h} ± 2.1	58.3^{h} ± 2.5	75.3^{d} ± 4.2	78.3^{d} ± 3.4
40%	84.1^{b} ± 3.5	86.4^{b} ± 2.8	73.7^{e} ± 1.9	74.7^{e} ± 2.3	74.5^{e} ± 2.5	75.4^{e} ± 3.5	56.8^{i} ± 2.3	57.6^{i} ± 2.4	74.5^{e} ± 2.3	76.2^{d} ± 2.5
50%	83.3^{b} ± 2.7	85.7^{b} ± 3.2	70.6^{f} ± 2.1	67.8^{f} ± 2.6	67.2^{f} ± 2.3	71.6^{e} ± 2.7	55.6^{i} ± 1.7	56.4^{i} ± 3.1	73.8^{e} ± 2.6	75.0^{d} ± 3.2

Conc=Concentration, Res=Residential, Su=Surimi
Data are shown as the mean ± 1 S.D., derived from three repeats. Means with a different lower case superscript letter($^{a-i}$) are significantly different ($P < 0.05$) according to the Turkey test.

Based on the results of this study, it can be suggested that the highest capacity of water hyacinth for treating the wastewater over 15 days was at 50% (v/v) and 40% (v/v) for the residential and surimi wastewaters, respectively. After this, the plants should be harvested and the treated water can be released to the natural water medium. In this study, healthy young water hyacinth plants were used because the roots of young plants have a higher capacity to uptake contaminants and release oxygen for microbial support than older plants (Valipour *et al*. 2015), which is an important process for phytoremediation. The results clearly indicated that water hyacinth can be a promising candidate for removing contaminants from wastewater.

4. Conclusion

Water hyacinth has the potential for reducing the concentration of BOD, COD, TSS, TKN, and TP in both residential and surimi wastewaters. The wastewater parameters after treatment by water hyacinth cultivation for 15 days were below the regulation limit of the Pollution Control Department of Thailand, except for the BOD in the surimi wastewater at a 50% (v/v) concentration. However, plants grew well in both the residential and surimi wastewater at 10–50% (v/v) without any evident morphological changes or necrosis. The results showed that water hyacinth was tolerant and could be applied to treat these wastewaters at low to medium concentrations. With increasing population levels, and so increasing volumes of both residential and industrial wastewater adding to the environmental and energy crisis, phytoremediation using water hyacinth could be an effective and good alternative method to treat wastewater after primary treatment. It is important to develop this work to a pilot scale and find out the best management strategy for controlling the growth of this species before implementation for residential and industrial purposes in Thailand.

References

Anudechakul C, Vangnai AS, Ariyakanon N. Removal of Chlorpyrifos by Water Hyacinth *(Eichhornia crassipes)* and the Role of a Plant-Associated Bacterium. International Journal of Phytoremediation 2015; 17(7): 678-685.

Adewumi I, Ogbiye AS. Using water hyacinth *(Eichhornia crassipes)* to treat wastewater of a residential institution. Toxicological and Environmental Chemistry 2009; 91(5): 891-903.

Ayyasamy PM, Sundaram R, Sathishkumar M, Swaminathan K, Viswanathan S, Lakshmanperumalsamy P, Lee S. Nitrate removal from synthetic medium and groundwater with aquatic macrophytes. Desalination 2009; 242(1-3): 286-296

Boonkrue A, Ariyakanon N. Effects of ZnO nanoparticle on plant growth, plant stress, Zn bioaccumulation in water hyacinth *(Eichhornia crassipes)*. Proceeding of the 4th Environment Asia International Conference. Thailand 2017.

Fox LJ, Struik PC, Appleton BL, Rule JH. Nitrogen phytoremediation by water hyacinth *(Eichhornia crassipes* (Mart.) Solms). Water, Air, and Soil Pollution 2008; 194: 199-207.

Gupta P, Roy S, Mahindrakar AR. Treatment of water using water hyacinth, water lettuce and vetiver grass-a review. Research Environment 2012; 2: 202-215.

Huang L, Morrissey MT. Fouling of membranes during microfiltration of surimi wash water: Roles of pore blocking and surface cake formation. Journal of Membrane Science 1998; 144: 113-123.

Lissy AMPN, Madhu BG. Removal of heavy metals from waste water using water hyacinth. Proceedings of the International Conference on Advances in Civil Engineering 2010; 42-47.

Ministry of Industry. Industrial Effluent Standards. Thailand. 2017. https://www.jetro.go.jp/ext_images/thailand/pdf/MOIEffluentStandards2560.pdf. (accessed on January 14, 2020).

Misha S, Maiti A. The efficiency of *Eichhornia crassipes* in the removal of organic and inorganic pollutants from wastewater: a review. Environmental Science and Pollution Research 2017; 7921-7937.

Mohan A, Bhatt SM, Girdhar M, Goyal G, Ansari AA, Rehman H. Current technical perspective and application of aquatic weeds in phytoremediation. In: Phytoremediation. Springer International Publishing 2016; 269-289.

Ng YS, Chan DJC. Wastewater phytoremediation by *Salvinia molesta.* Journal of Water Process Engineering 2017; 15: 107-115.

Paz-Alberto AM, Sigua GC. Phytoremediation: A green technology to remove environmental pollutants. American Journal of Climate Change 2013; 2: 71-86.

Pollution Control Department. Ministry of Natural Resources and Environment. Water quality standards: Effluent standards for wastewater from condominium > 500 units. Thailand. 2005. http://www.pcd.go.th/info_serv/reg_std_water04.html#s3 (access on January 14, 2020).

Pollution Control Department. Booklet on Thailand State of Pollution 2018. Ministry of Natural Resources and Environment. 2019.

Qin H, Zhang Z, Liu M, Wang Y, Wen X, Zhang Y, Yan S. Site test of phytoremediation of an open pond contaminated with domestic sewage using water hyacinth and water lettuce. Ecological Engineering 2016; 95: 753-762.

Reddy KR. Diel variations in physico-chemical parameters of water in selected aquatic systems. Hydrobiologia 1981; 85: 201-207.

Rees M, Osborne CP, Woodward I, Hulme SP, Turnbull LA, Taylor S. Partitioning the Components of Relative Growth Rate: How Important Is Plant Size Variation?. The American Naturalist 2010; 176(6): 152-161.

Rezania S, Din MFD, Pornraj M, Sairan FM, Kamaruddin SF. Nutrient uptake and wastewater purification with Water Hyacinth and its effect on plant growth in batch system. Journal of Environmental Treatment Techniques 2013; 1(2): 81-85.

Rezania S, Ponraj M, Talaiekhozani A, Mohamad SE, Din MFM, Taib SM, Sabbagh F and Sairan FM. Perspectives of phytoremediation using water hyacinth for removal of heavy metals, organic and inorganic pollutants in wastewater. Journal of Environmental Management 2015; 163: 125-133.

Rezania S, Taibb SM, Din MFM, Dahalan FA, Kamyab H. Comprehensive review on phytotechnology: Heavy metals removal by diverse aquatic plants species from wastewater. Journal of Hazardous Materials 2016; 318: 587-599.

Rice EW, Baird RB, Eaton AD. Standard methods for the examination of water and wastewater. 23rd edition. American Public Health Association, American Water Works Association and Water Environment Federation. 2017.

Saha P, Shinde O, Sarkar S. Phytoremediation of industrial mines wastewater using water hyacinth. International Journal of Phytoremediation 2017; 19(1): 89-96.

Shah M, Hashmi HN, Ali A, Ghumman AR. Performance assessment of aquatic macrophytes for treatment of municipal wastewater. Journal of Environmental Health, Science and Engineering 2014; 12: 106-118.

Trivedy RK, Pattanshetty SM. Treatment of dairy waste by using water hyacinth. Water Science & Technology 2002; 45 (12): 329–334.

Tripathi BD, Sukla SC. Biological treatment of wastewater by selected aquatic plants. Environmental Pollution 1991; 69: 69-78.

Valipour A, Raman VK, Ahn Y. Effectiveness of domestic wastewater treatment using a bio-hedge water hyacinth wetland system 2015; 7: 329-347.

Victor KK, Seka Y, Norbert KK, Sanogo TA, Celestin AB. Phytoremediation of wastewaters toxicity using water hyacinth *(Eichhornia crassipes)* and water lettuce *(Pistia stratiotes)*. International Journal of Phytoremediation 2016; 18(10): 949-955.

Wasave SM, Kulkarni GN. Surimi wastewater characteristics and its toxicity to the fingerlings of tilapia, *Oreochromis mossambicus.* Pollution Research 2004; 23: 125-130

Zimmels Y, Kirzhner F, Malkovskaja. Application of *Eichhornia crassipes* and *Pistia stratiotes* for treatment of urban sewage in Israel. Journal of Environmental and Management 2006; 81: 420-428.