Phytoremediation of Lead(II) Using Aquatic plants

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ABSTRACT

Phytoremediation is considered to be a possible method for the removal of pollutants present in wastewater and recognized as a better green remediation technology. Three types of aquatic plants, i.e. water lettuce (*Pistia stratiotes* Linn.), hydrilla (*Hydrilla verticillata*) and duckweed (*Lemna perpusilla* Torr.), were investigated for the adsorption efficiency of lead(II) ions from synthetic wastewater. The results showed that hydrilla and duckweed at 5 ppm and 10 ppm concentrations were dipped plants for 2 days, which can absorb 100%, but the hydrilla at 10 ppm can withstand the adsorption of lead(II) in the plant longer than duckweed for 4 days. In addition, the water lettuce at 5 ppm was dipped the plant for 2 days duration can absorb 97.886%. According to the hydrilla contained all parts of the plant under water, which may be able to absorb heavy metals contaminated in water and duckweed is small plant, short roots, and able to cover the area of the water well, whereas the water lettuce has a large long root, and has the ability to spread covering a small area. Therefore, the lead(II) adsorption efficiencies are as the followings: hydrilla > duckweed > water lettuce, respectively.

Keyword: Synthetic wastewater; Lead(II); Water lettuce; Hydrilla; Duckweed

INTRODUCTION

Natural water resources are essential for all living things, including humans, and inevitably used in daily human activities such as consumption, industry, irrigation, agriculture and transportation, etc. However, considered as a solvent, water is contaminated with many minerals such as chlorides and hardness, resulting in saltiness and turbidity, especially in groundwater. In addition, high amounts of heavy metals, i.e. iron and manganese, are found in waters in Thailand. For this reason, water must be passed to improve water quality before using in order to eliminate or reduce these impurities to meet the quality standards set by many

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standardizing organizations, including the Ministry of Natural Resources and Environment, Thailand. Water pollution is one of the most important problems all over the world. Therefore, in order to control the quality of the natural water sources and prevent their pollution following the standards, an introduction of new technologies to control and treat wastewater before releasing into the water sources. The international authorities established acceptable standards for lead contamination in water as well as Thailand set the standards for effluent quality from industrial estates, which is not more than 0.2 mg/L (Roya & Ali, 2017).

Heavy metal contamination in the environment by heavy metals has increased sharply since the beginning of the 20th century, as a result of industrial revolution and excessive population growth, posing major environmental and human health problems worldwide (Abdelhafez & Li, 2016). It is alarming both in the developed and developing countries and a critical issue threatening ecology (Rezania, Taib, Din, Dahalan, & Kamyab, 2016). Several contaminated sources include emissions from waste incinerators, car exhaustions, organic and inorganic industries, and the use of agricultural amendments such as sludge or composts, pesticides and mineral fertilizers, which the degree of contamination of the water depends on time and activity that contributes to the contaminated areas. Then, it is obviously important to remove toxic metals from these contaminated areas in order to control the hazardous effects, owning to spreading and leaching to nearby agricultural soil and groundwater (Abou-Shanab et al., 2011).

Various industries of Thailand currently contribute to the progress and drive Thai economy and society. Most industries have used heavy metals as a component in production processes, especially lead(II) that is a heavy metal, generally used in electrical or electronic, automotive, battery, and plastic industries, including the manufacture of paints and inks etc. Meanwhile, there is a chance of contamination and residues of lead in water sources, and then released into the environment from those industries causing water pollution problems in Thailand. Lead is a substance that remains naturally decomposed and can be found in both organic and inorganic compounds. If it is accumulated in large quantities or exposed over a long period of time, chronic effects in both human and animal organisms can affect the blood system, causing anemia, kidney function, liver, heart, nerve and muscle disorders, tumor, gastrointestinal tract and affect intelligence levels, especially in children (Roya & Ali, 2017).

Nowadays, there are various methods for treating heavy metals from water sources, such as chemical precipitation and sedimentation, electrochemical treatment, activated carbon, and biological treatment. However, some methods have limitations in therapy and there are many problems in the treatment. For examples, chemical precipitation method and wastewater treatment by electrochemical processes have the limitation on the concentration of heavy metals which cannot be treated in the range of 1-100 mg/L and biological treatment by using microorganisms as adsorbents has also encountered problems such as the inability to separate heavy metals from microorganisms and so on (Roya & Ali, 2017). Furthermore, adsorption is one of the most popular methods that many researchers have been interested and tried to develop low-cost sorbents to replace expensive sorbents for increasing the efficiency of treatment.

Recently, phytoremediation has emerged as a cost-effective technique to remediate the metal contaminated water and soil. Phytoremediation is the process of using plants to eliminate the toxicity of polluted and residual pollutants in the environment and is an environmentally friendly method that can treat pollutants both in both organic and inorganic substances in soil, water and air (Alaboudi, 2018; He & Yang, 2007; Pratas, Favas, D'Souza, Varun, & Paul, 2013; Pratas, Favas, Paulo, Rodrigues, & Prasad, 2012). Generally, the process of plants will move, store, or cause toxic substances that are harmful to living organism. It is a method that can be used in widely contaminated areas with low costs. It can be said or so-called a green technology that treats low-risk toxins and causes less negative impacts than other methods. Therefore, phytoremediation is one of the best alternative methods owning to naturally economical and ecologically practical innovation. Besides, there are plentiful plants having this regular capacity to uptake the toxic contaminants and natural contaminations (Jeevanantham et al., 2019).

In the past, plants and aquatic plants were investigated for their efficiencies of absorbing heavy metals (Rahman & Hasegawa, 2011 and Nouri et al., 2009). These found that different plants in their abilities to accumulate heavy metals. To our knowledge, there have been no Thai local aquatic plants being investigated for lead (II) ion adsorption. Hence, we studied the different types of the local aquatic plants found in Thailand for their adsorption efficiencies of lead(II) in synthetic wastewater using lettuce (*Pistia stratiotes* Linn.) , hydrilla (*Hydrilla verticillata*) and duckweed (*Lemna perpusilla* Torr.) . For our work, the appropriate concentrations and durations for the adsorption of lead(II) ions in synthetic wastewater were studied. This information can be used for choosing local aquatic plants to reduce the costs of wastewater treatment in order to maximize benefits.

MATERIALS AND METHODS

1. Preparation of synthetic wastewater

A high purity analytical grade of Pb(II) standard solution was used as the source of Pb(II) stock solutions. All the required solutions were prepared with analytical reagents and distilled water. A stock standard solution from studied metal was used to contaminate the water with Pb(II) ions at different concentrations of 5, 10 and 15 ppm.

2. Preparation of absorbents

Selection of 3 types of aquatic plants, i.e. water lettuce, hydrilla and duckweed with mature ages about 3-4 weeks old, which were not too old and soft. The water lettuce was chosen to have a suitable root length about 10-15 cm, which its stalk size was not too large. The hydrilla was selected with the length of trunk from the top to the appropriate length of about 10-20 cm and the duckweed leaf color was light green without yellow leaves. After that, all the plants were washed and cleaned with deionized (dI) water and followed by bringing them to be conditioned in the water for 3 days before experimenting.

3. Experimental design

Thirty 2.5-liter plastic boxes were prepared for 2 experimental sets: control sets with individual plant immersed in water without lead(II) synthetic water (3 boxes) and experimental sets with plant-based treatments. Each type was immersed in lead(II) synthetic wastewater at concentrations of 5, 10 and 15 ppm, that the experiment was triplicated (27 boxes). Every box contained 2 liters of synthetic wastewater with each aquatic plant weight of 15 g.

4. Sampling of synthetic wastewater

After immersing all 3 types of aquatic plants in the control set and the experimental sets at concentrations of 5, 10 and 15 ppm for 10 days, samples of synthetic wastewater were collected using a 100 mL syringe. Then, the samples were put into a clean plastic water sample jar and completely closed with the freud and lid. The number of days for collecting the samples was the 1st, 2nd, 3rd, 4th, 5th, 7th and 10th days, totally 7 days, during 08.00-10.00 am. After collected until the trial period being completed, the water samples were analyzed for the lead(II) adsorption efficiency by Atomic Absorption Spectroscopy (AAS) technique.

5. Adsorption efficiency testing method

Before using the synthetic water samples to be analyzed with the AAS technique, the sample solution concentration was adjusted from the previous collection, which was filtered using filter paper to remove dirt. Then, an amount of 12.5 mL was adjusted using 2% nitric acid to obtain 50 mL. Finally, we prepared the lead(II) standard solution at concentrations of 0, 1, 2, 3 and 4 ppm to draw a standard curve and measured the prepared sample solution for lead(II) content using AAS.

RESULTS AND DISCUSSION

1. Influence of water plant growth

The results of the comparison of the growth of aquatic plants by calculating the biomass weight of aquatic plants in 3 types with both control and experiment sets at 5 ppm concentration for a period of 10 days as shown in Table 1.

Table 1. Comparison of biomass weight of aquatic plants before and after the experiment

Biomass weight	Duckweed		Hydrilla		Water lettuce	
	Control set	Experiment set [a]	Control set	Experiment set [a]	Control set	Experiment set [a]
Biomass weight before experiment (g)	15.920 ±0.125	15.320 ±0.133	15.650 ±0.042	15.140 ±0.172	15.380 ±0.069	15.420 ±0.152
Biomass weight after experiment (g)	17.210 ±0.096	10.270 ±0.158	14.930 ±0.079	9.640 ±0.229	12.080 ±0.058	5.550 ±0.095

Changing biomass weight (g)	+1.290 ±0.089	-5.050 ±0.168	-0.720 ±0.064	-5.500 ±0.051	-2.300 ±0.075	9.870 ±0.147
% changing biomass weight	+8.103 ±0.156	-32.963 ±0.185	-4.600 ±0.082	-36.327 ±0.098	-14.954 ±0.073	-64.007 ±0.256

a = average

The results showed that each plant had different growth; for the control set, water lettuce was the only one type having good growth and has a biomass increase at +8.103% as illustrated in Table 1. In addition, it was apparently found that the plant had darker green leaves and slightly yellowish under the leaves, a larger clump extension and a longer root compared to those before the experiment. Unfortunately, the control set of the hydrilla and duckweed did not grow and found that the biomass decreased slightly at -4.600% and -14.954%, respectively. Additionally, both plants had faded green leaves, some stunted shapes, yellow leaves and dead root. When compared with the experiments of all three plants, they did not grow at all. Their biomass weights of all the aquatic plants were clearly decreased as shown in Figure 1, which those of water lettuce, hydrilla and duckweed were reduced at -32.963%, -36.327% and -64.007%, respectively. However, all aquatic plants had grown consistently well over the first few days but began to show yellow and root rot and then died after 6 days. The leaves had apparently fallen out of the roots of the leaves after the 7th day, especially the duckweed in the experimental set because the duckweed has a very small leaf size, resulting in less weight than other aquatic plants. Their leaves were very thin and short-lived and were also sensitive to toxins when stimulated. The characteristics of the aquatic plants used in wastewater treatment for 10 days, as shown in Figure 2.

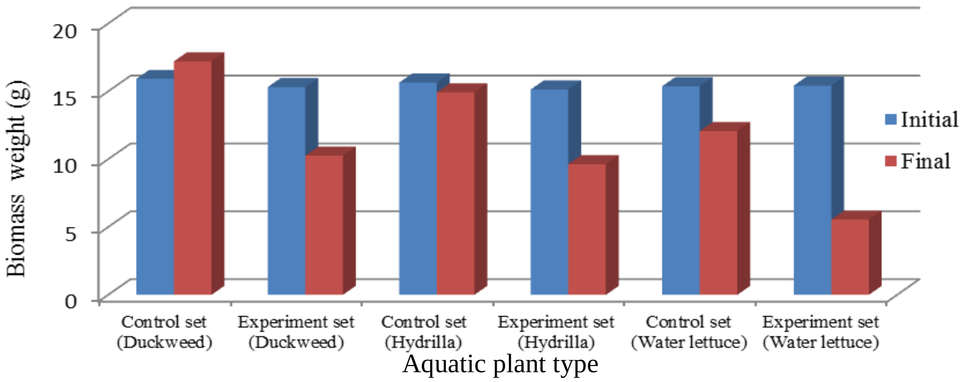

Figure 1 Comparison of the biomass weights of all three aquatic plants for a period of 10 days

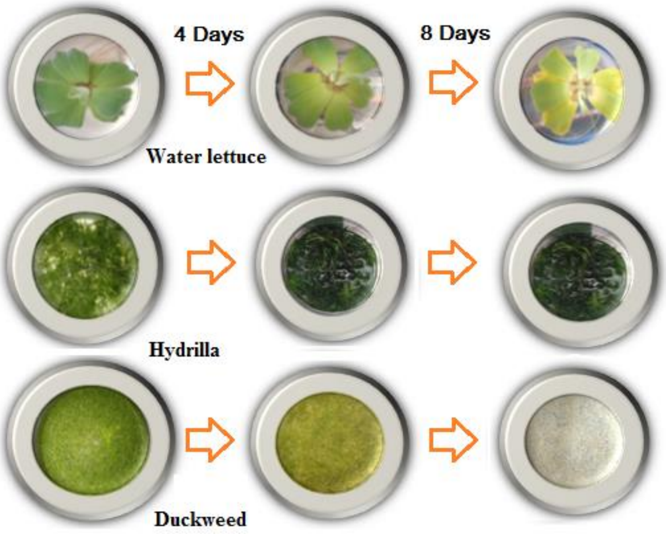

Figure 2 Characteristics of the aquatic plants used in wastewater treatment for 10 days

2. Influence of concentration and duration

The influences of concentration and duration were achieved by collecting these three types of aquatic plant, which the specimens were immersed with both control and experiment sets at different concentrations. The water samples were collected for the 7th day. Then, the metal adsorption efficiency was examined using the AAS technique. The results of the experiment are illustrated in Table 2.

Table 2 Analysis of the influences of the concentration and duration of aquatic plants

Aquatic plant type	Concentration (ppm)	Lead(II) adsorption efficiency (%) [a]						
		1st	2nd	3rd	4th	5th	7th	10th
Duckweed	5	54.103 ±0.040	97.886 ±0.048	96.505 ±0.440	96.376 ±0.030	87.156 ±0.037	68.457 ±0.039	59.010 ±0.038
	10	5.777 ±0.047	22.897 ±0.030	26.820 ±0.542	29.683 ±0.022	35.384 ±0.028	31.841 ±0.046	22.212 ±0.042
	15	6.202 ±0.058	11.569 ±0.059	21.838 ±0.723	22.345 ±0.117	22.850 ±0.077	21.069 ±0.045	12.630 ±0.039
Hydrilla	5	79.812 ±0.065	100.000 ±0.000	100 ±0.000	100.000 ±0.000	94.597 ±0.048	65.286 ±0.042	35.393 ±0.048
	10	95.211 ±0.018	100.000 ±0.000	100 ±0.000	100.000 ±0.000	75.458 ±0.022	57.094 ±0.030	34.293 ±0.053
	15	50.850 ±0.038	60.787 ±0.025	57.919 ±0.531	54.096 ±0.026	48.312 ±0.026	29.524 ±0.080	26.767 ±0.064
Water lettuce	5	66.690 ±0.766	100.000 ±0.000	100 ±0.000	100.000 ±0.000	63.604 ±0.057	33.581 ±0.011	22.322 ±0.084
	10	87.469 ±0.075	100.000 ±0.000	92.054 ±0.569	85.982 ±0.021	60.628 ±0.006	44.829 ±0.001	13.717 ±0.102
	15	4.353 ±0.054	15.013 ±0.052	33.565 ±0.741	28.565 ±0.144	18.985 ±0.231	9.659 ±0.198	5.031 ±0.152

a = Average from 3 trials

When considering only the lead(II) adsorption efficiency of water lettuce at different concentrations, the concentration of 5 ppm for the 2nd day showed the highest adsorption efficiency at 97.886%. However, the adsorption efficiency of the water lettuce was reduced slightly when left for the 3rd day onwards as shown in the Figure 3, indicating that the plant was exposed to lead(II) ions which were accumulated in the water lettuce to return to water solution. In addition, the experiment was conducted by increasing the concentrations at 10 and 15 ppm to compare the adsorption efficiency of the aquatic plants at the highest concentration. Both concentrations at 10 and 15 ppm showed that the adsorption efficiencies were 35.384% and 24.850%, respectively for the period for 5 days. After that, the adsorption efficiency tended to decrease indicating that the lettuce was able to absorb lead(II) ions at a maximum of 5 ppm for the 2nd day and saturated and returned lead(II) ions to wastewater.

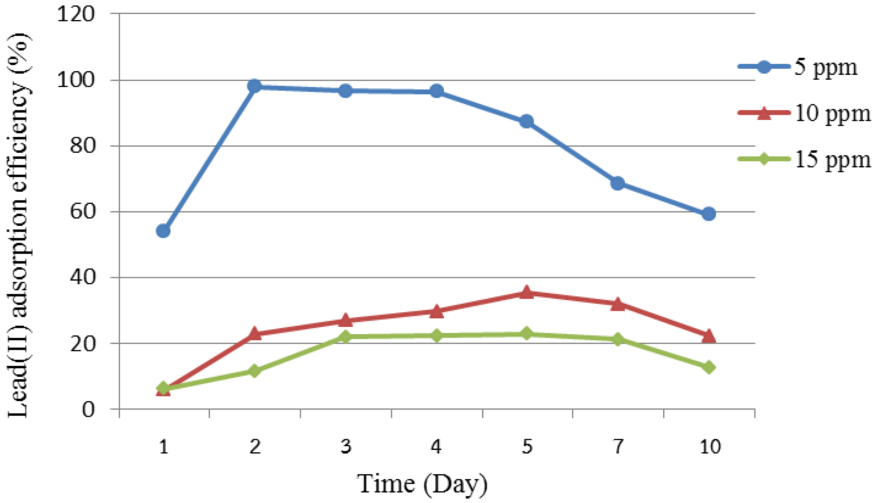

Figure 3 Comparison of the adsorption efficiency of lead(II) synthetic wastewater with water lettuce

The lead(II) adsorption efficiency of hydrilla and duckweed showed similar results as shown in Figures 3 and 4, respectively. In the case of the examination of the efficiency of adsorption of hydrilla at 5 and 10 ppm for a period of 1-4 days showed the highest adsorption efficiency in the range of 80-100% as shown in Table 2 and Figure 4. Therefore, the adsorption efficiency was stable during this period indicating the ability to absorb the lead(II) ions of the plant very well and showing the durability in the adsorption of lead(II) ions. This point showed that the hydrilla was saturated. In addition, the concentration at 15 ppm showed the adsorption efficiency at 60.787% for 2 days. After that, the adsorption efficiency tends to decrease gradually, which is caused by the release of lead(II) from the plant that has been absorbed until saturated and thus can detect the amount of lead(II) in wastewater being increased.

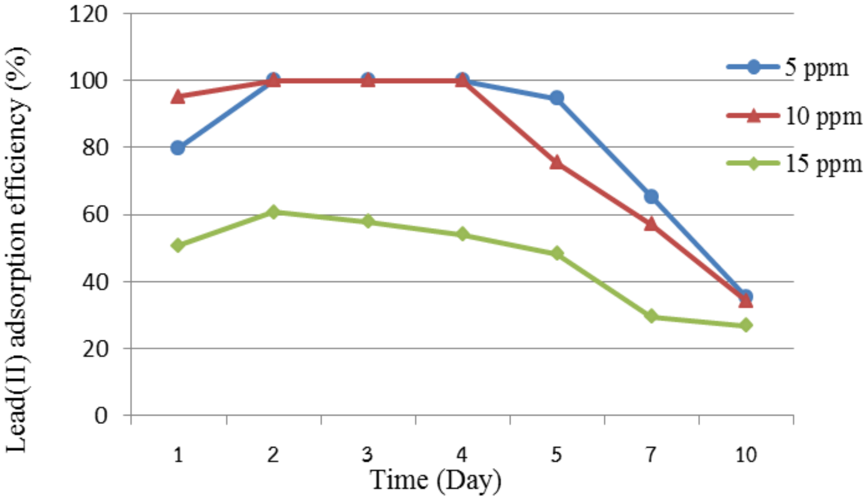

Figure 4 Comparison of the adsorption efficiency of lead(II) synthetic wastewater with hydrilla

The duckweed is another aquatic plant that was examined for the lead(II) adsorption efficiency. The results at concentrations of 5 and 10 ppm for 2 days showed the highest adsorption efficiency at 100% as shown in Figure 5. In the case of concentration at 5 ppm, the duckweed showed the saturation and showed the ability to absorb lead(II) of the plant for up to 4 days; after that, the adsorption efficiency began to decrease gradually. While the adsorption efficiency at the concentration of 10 ppm was found to gradually decrease after saturation on the 2nd day, indicating that duckweed could not tolerate the adsorption of lead(II) ions, which is different from the case of concentration at 5 ppm. In addition, the concentration of 15 ppm showed that the adsorption efficiency was at 33.565% for the 3rd day and the adsorption efficiency tended decreased gradually as well.

In this study, the concentrations of lead(II) ions in which synthetic wastewater after the aquatic plants immersed within 10 days were compared with those before they immersed. However, it may be possible that suspended particles or sediment of lead remain in the experiment container but it has a low concentration (Rajappa, Manjappa, & Puttaiah, 2010). Besides, lead shows fairly low concentrations in water samples due to its restricted mobility from the natural sources (Lu, He, Graetz, Stoffella, & Yang, 2011).

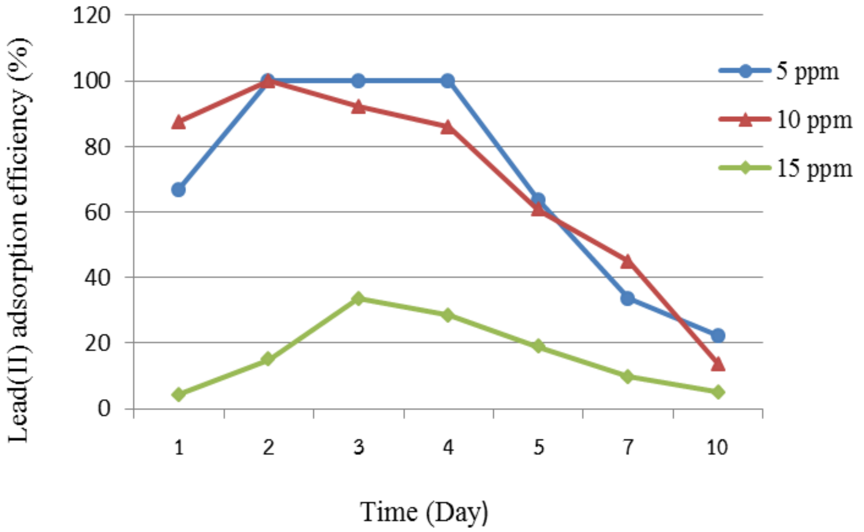

Figure 5 Comparison of the adsorption efficiency of lead(II) synthetic wastewater with duckweed

3. Comparison of adsorption efficiency of aquatic plants

Comparison of the lead(II) adsorption efficiency of all three aquatic plants at the same concentration at 5 ppm found that all three types of aquatic plants had similar adsorption behavior of lead(II) ions. The concentration of 5 ppm found that all plants showed the highest adsorption efficiency when immersed in the wastewater for 2 days. The results showed that only two types of the hydrilla and duckweed exhibited the highest adsorption efficiency of lead(II) at 100%, followed by water lettuce at 97.886%. In addition, all plants were able to withstand the adsorption of lead(II) ions until the 4th day of the experiment, then the adsorption behavior gradually decreased as shown in Figure 6 and Table 2. Moreover, the experiment was conducted by increasing the concentrations at 10 and 15 ppm. The results showed that the hydrilla and duckweed at 10 ppm concentrations still showed the highest adsorption efficiency at 100%. Interestingly, only the hydrilla showed the ability to absorb lead(II) for up to 4 days, while the duckweed showed that the adsorption efficiency decreased slightly after 2 days, indicating that both of hydrilla and duckweed had the highest adsorption efficiency of lead(II) at a concentration of 10 ppm.

Furthermore, it was found that all three types of aquatic plants at concentration of 15 ppm showed significant decrease in adsorption efficiency for water lettuce, hydrilla and duckweed as 22.850%, 60.787% and 33.565%, respectively. Therefore, the lead(II) efficiency of the adsorption of aquatic plants can be sorted as follows: hydrilla > duckweed > water lettuce. This is because the hydrilla contains all parts of the plant under the water, which may be able to absorb heavy metals contaminated in the water well. The duckweed is a small plant with short roots but has good dispersion ability, covering the area of the water in a wide area. While the water lettuce has long roots and large size, indicating the ability to spread, this covered less area than duckweed, resulting in less adsorption efficiency. Therefore, it can be concluded that the adsorption efficiency of lead metal does not only depend on concentration and duration but also rely on the physical characteristics of each plant and species of aquatic plants.

However, the adsorption efficiency of aquatic plants for 10 days showed that the physical characteristics of all aquatic plants exhibited a burning yellow leaf clearly at a period of 7 days. Leaves and roots were removed from the stem and slowly rotted to death, indicating that the three aquatic plants could not absorb the lead(II) ions anymore. Therefore, plants exposed to heavy metals at high concentrations results in severe damage to various metabolic activities leading consequently to the death of plants. The exposure of excess levels of metals to plants inhibits physiologically active enzymes, inactivates photosystems, and destructs mineral metabolism (Janas et al., 2010). As mentioned above, the biomass of selected plants for phytoremediation technology is very important to ensure high removal rate of toxic heavy metals. All aquatic plants were chosen in this study based on their high biomass, fast growth rate and their ability to remove heavy metals from contaminated water.

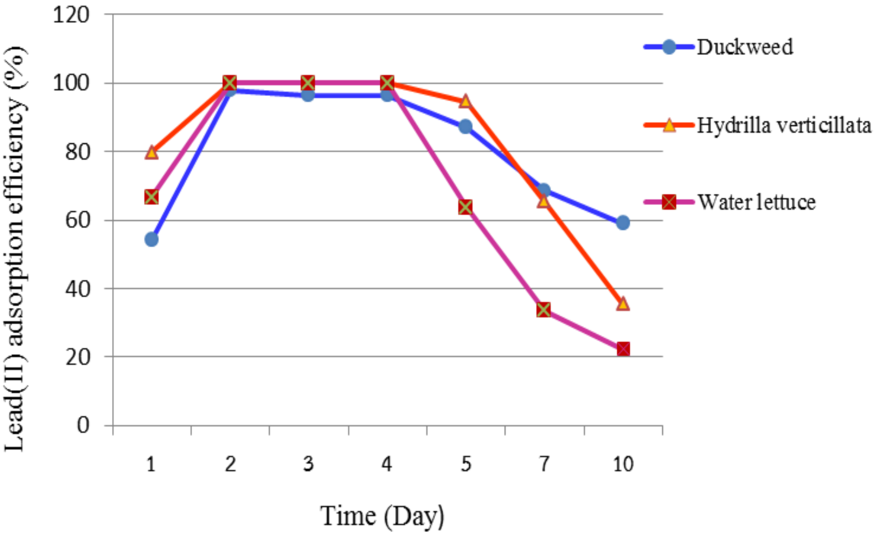

Figure 6 Comparison of adsorption efficiency of lead synthetic wastewater (II) with aquatic plants at a concentration of 5 ppm

Comparison of the adsorption efficiency of lead(II) with aquatic plants used in this work and other researchers found that it is consistent with other metals and plants, meaning that aquatic plants and other family plants can effectively absorb a variety of heavy metals. For example, (Krutthoob & Wachirawongsakorn, 2015) studied efficiency removal of lead and cadmium contaminated water by vetiver grass (*Montoya*), water hyacinth and hydrilla. Lead and cadmium in water were determined and inspected the tolerance of all plants week by week throughout 8 weeks. The results showed that water hyacinth was significantly higher lead treatment efficiency than vetivergrass and hydrilla for every concentration. Moreover, the results showed that water hyacinth could not tolerate cadmium toxicity and dead at the 6th week of experiment period. Punyauppa-path, nantasaeng, & Punyauppa-path (2015) studied arsenic treatment in water with three native plant species: water lettuce, azolla and hydrilla. On arsenic reduction ability test at initial concentration 100 µg/L, the three aquatic plants showed their ability to reduce the concentration of arsenic in water in the range of 60-80%, which was in the different efficiency in varying period of time. In 7 experimental days, Azolla was the first aquatic plant, which had the highest efficiency (74.47%), while water lettuce and hydrilla showed their reduction efficiency at 71.48 and 51.85%, respectively. The arsenic reduction efficiency of three aquatic plants in 7 experimental days could be sorted as following efficiencies of Hydrilla > Azolla > Water lettuce. Jumpa (2007) examined the potential of *Ceratophyllum demersum* Linn. in adsorbing of copper, zinc and lead under 3 conditions, i.e. the concentration of drinking water, the concentration of wastewater from household and agriculture, and the concentration of wastewater from industry. The results showed that *Ceratophyllum demersum* Linn. could adsorbed all 3 heavy metals well within the first 32 hours. Its adsorption values of copper, zinc and lead under the concentration of drinking water were 87.0887, 28.3333 and 375.2654 mg/kg (dry weight), respectively; those under the concentration of wastewater from household and agriculture were 134.5899, 48.2372 and 2,834.1719 mg/kg; and those under the concentration of wastewater from industry were 323.9030, 132.0522 and 88.5473 mg/kg, respectively.

The results are consistent with the results of those referred researchers that the best lead(II) adsorption efficiency of the hydrilla was higher than duckweed and water lettuce at high concentration. However, the study of phytoremediation is a challenging goal for researchers because it is a cost-effective remediation technology which is able to treat heavy metal at polluted sites. This environmental friendly method has been successfully implemented in constructed wetland (CWs) which is able to restore the aquatic bio-system naturally. Nowadays, many aquatic plant species are being investigated to determine their potential and effectiveness for phytoremediation application, especially high growth rate plants. Moreover, many researchers have discovered the potential of various plants to absorb a wide range of heavy metals and determined using new technique (Stegemeier, Colman, Schwab, Wiesner, & Lowry, 2017).

4. Removal of heavy metals of other related aquatic plants

Among the various plants species groups, aquatic plants attain greatest interest in the field of phytoremediation. Aquatic macrophytes have great potential to accumulate heavy metals inside their plant bodies. Many years ago, water hyacinths was another aquatic plant that researchers were interested in studying about the efficiency of heavy metal adsorption and widely used because it was found to be an effective metal absorbing plant. In the study of Priya & Selvan (2017), the water hyacinth was cultivated in a plastic bowl containing textile industry effluent and the results showed that 70–90% removal of heavy metals like iron, lead, copper and chromium. (Ajayi & Ogunbayo, 2012) studied the efficiency of water hyacinth in removing Cd, Cu and Fe from various wastewater like textile, pharmaceutical and metallurgical in which it seems to be a good choice for removing cadmium but not so much for the removal of iron and copper. During the 5 week duration of the experiment, the removal of cadmium by the water hyacinth was 94.87% in textile wastewater, 95.59% in metallurgical wastewater and 93.55% in pharmaceutical wastewater. Mokhtar, Morad, & Fizri (2011) reported *E. crassipes* as a hyperaccumulator for copper with an efficiency of 97.3% removal from an aqueous solution containing various concentrations of copper. The root and shoot tissues showed an increase in concentration with a decrease in aqueous solution. (Hasan, Ranjan, & Talat, 2010) reported that water hyacinth biomass (WHB) has shown high potential for the removal of hexavalent chromium from aqueous solution with Box–Behnken RSM design in which the R^2 value was 99.8%. But, Elangovan, Philip, & Chandraraj (2008) reported that among various aquatic plants studied, water hyacinth efficiency was good with removal of Cr^{3+} rather than Cr^{6+}. Jayaweera, Kasturiarachchi, Kularatne, & Wijeyekoon (2008) concluded in their study that water hyacinths grown under nutrient-poor conditions are ideal to remove iron from wastewater. Mahmood et al. (2005) reported that the water hyacinth plant could be able to remove metal ions like chromium, zinc and copper from the textile effluent collected from Lahore district, Pakistan. The feasibility of water hyacinth to treat wastewater from five textile effluent samples was investigated for a period of 96 h and it was observed that the water hyacinth containing textile effluent wastewaters have the potential to remove a maximum of 94.78% reduction in chromium, 96.88% in zinc and 94.44% reduction in copper.

Interestingly, high concentrations of lead(II) resulted in stunted growth, reduced biomass production and produced characteristic visible effects similar to those described by other researchers in different plant species. Favas, Pratas, & Prasad (2012) investigated the potential of aquatic plants for bio-indication and/or phyto-filtration of arsenic from contaminated water. The highest concentration of arsenic for the 18 most representative plant species, was found in Callitriche lusitanica (2346 mg/kg DW), Callitrichebrutia (523 mg/kg DW), L. minor (430 mg/kg DW), A. caroliniana (397 mg/kg DW), R. trichophyllus (354 mg/kg DW), Callitriche stagnalis (354 mg/kg DW) and Fontinalis antipyretica (346 mg/kg DW). These results indicated the potential application of these species for phytofiltration of arsenic through constructed treatment wetlands or introduction of these plant species into natural water bodies. Favas, Pratas, Varun, D'Souza, & Paul (2014) determined uranium concentrations in water and aquatic plants in the uraniferous region of Beiras, Central Portugal. Uranium concentrations in surface waters ranging from 0.23 to 1217 μg L^-1. In general, submerged plants exhibited higher uranium content followed by rooted emergent and free floating species. The highest uranium concentrations were observed in the bryophyte Fontinalis antipyretica (up to 4979 mg kg^{-1}) followed by Callitrichehamulata (379 mg kg^{-1}), Ranunculus eltatus subsp. saniculifolius (243 mg kg^{-1}), Callitriche stagnalis (1963 mg kg^{-1}), Callitriche lusitanica (218 mg kg^{-1}), and Ranunculus trichophyllus (65.8 mg kg^{-1}).

Furthermore, Pratas, Paulo, Favas, & Venkatachalam (2014) selected the species of Callitriche stagnalis Scop., Potamogeton natans L. and Potamogeton pectinatus L. of the native plant community of the uraniferous Beiras (Central

Portugal) region because they are autochthonous and showed high accumulation levels and/or high biomass production. The performance of this system was very effective. The uranium concentration in the water was dropped to 220 μg/L in 24 h and after 2 weeks it was decreased to 72.3 μg/L. The uranium concentration increased in C. stagnalis from 0.98 to 1567 mg/kg, in P. natans from 3.46 to 270.9 mg/kg and in P. pectinatus from 2.63 to 1588 mg/kg. The results showed the effectiveness of these plants in removing uranium from the water. Malar, Sahi, Favas, & Venkatachalam (2015) performed an experiment focusing on the responses of Eichhornia crassipes to mercury-induced oxidative stress. E. crassipes seedlings that were exposed to varying concentrations of mercury to investigate the level of mercury ion accumulation, changes in growth patterns, antioxidant defense mechanisms, and DNA damage under hydroponics system. The results showed that plant growth rate was significantly inhibited (52 %) at 50 mg/L treatment. The accumulation levels of mercury ion level were 1.99 mg/g dry weight, 1.74 mg/g dry weight, and 1.39 mg/g dry weight in root, leaf, and petiole tissues, respectively.

In addition, Bello, Tawabini, Khalil, Boland, & Saleh (2018) investigated the phytoremediation ability of *Phragmites australis* to remove cadmium, lead and nickel from contaminated water, studied the effect of pH and salinity on its removal of cadmium, lead, and nickel, and estimated the pattern of accumulation of these metals in the roots, shoots, and leaves of the plant. The experiments were carried out in a deep-water hydroponic system and 5 mg/L was used as a concentration of each of the heavy metals. The results showed that *P. australis* had a residual of 7% (93% removal) of cadmium, 5% (95% removal) of lead and 16% (84% removal) of nickel over a 6-week period. (Chanu & Gupta, 2016) discovered *Ipomoea aquatica* Forsk., an aquatic macrophyte, was assessed for its ability to accumulate lead by exposing it to graded concentrations of this metal. The accumulation of lead was the highest in root followed by that in stem and leaf with translocation factor (TF) values of less than unity. On the other hand, all bioconcentration factor (BCF) values in root, stem and leaf were greater than unity. (Török, Gulyás, Szalai, Kocsy, & Majdik, 2015) studied the association between heavy metal removal capacity and phytochelatin synthesis, that was compared through the examination of three aquatic plants: *Elodea canadensis*, *Salvinia natans* and *Lemna minor*. In case of a cadmium treatment, or a cadmium treatment combined with copper and zinc, the highest removal capacity was observed in *L. minor*. The correlation analysis indicated that the higher phytoremediation capacity of *L. minor* was associated with the synthesis of PCs and their higher degree of polymerization.

Furthermore, aquatic plants were found that *Eichhornia crassipes* was actually able to treat toxins, especially with chromium metal. Chromium was found to accumulate in all parts of the plant which can be verified by using X-ray spectroscopy. ((Lytle et al., 1998). The results showed that *Eichhornia crassipes* (water hyacinth), supplied with Cr(VI) in nutrient culture, accumulated nontoxic Cr(III) in root and shoot tissues. The reduction of Cr(VI) to Cr(III) appeared to occur in the fine lateral roots. This suggested that *E. crassipes* detoxified Cr(VI) upon root uptake and transported a portion of the detoxified chromium to leaf tissues. Cr-rich crystalline structures were observed on the leaf surface. The chemical species of chromium in other plants, collected from wetlands that contained Cr(VI)-

contaminated wastewater, was also found to be Cr(III). They proposed that this plant-based reduction of Cr(VI) by E. crassipes had the potential to be used for the in situ detoxification of Cr(VI)-contaminated waste streams. In addition, there are a few researchers who studied the treatment of chromium metal with aquatic plants. Espinoza-Quiñones et al. (2008) investigated the trivalent and hexavalent chromium phytoaccumulation by three living free floating aquatic macrophytes: Salvinia auriculata, Pistia stratiotes, and Eicchornia crassipes growing in hydroponic solutions. The Cr(III) removal efficiencies were about 90%, 50%, and 90% for the E. crassipes, P. stratiotes, and S. auriculata, respectively, while it was rather different for Cr(VI) one, with values about 50%, 70%, and 90% for the E. crassipes, P. stratiotes, and S. auriculata, respectively. Augustynowicz, Kołton, Baran, Kostecka-Gugała, & Lasek (2013) studied the qualitative and quantitative analysis of chromium detoxification strategy of Callitriche cophocarpa. The emphasis of the work was placed on the redox reaction of Cr(VI) → Cr(III) which is considered to be remediation mechanism of highly reactive and mobile Cr(VI) ions. Chromium was effectively removed from the solution up to the extent of ca.58% or 35% of the starting amount, in the case of Cr(III) and Cr(VI), respectively. No plant-induced Cr(VI) reduction accompanying chromium accumulation was observed in Cr(VI) solutions.

As mentioned above, this information can be concluded that the adsorption efficiency of the different aquatic plants in various forms to adsorb heavy metals is listed in Table 3, where most of the studies were carried out on the adsorption of heavy metals from the aqueous metal solution.

Table 3 Heavy metal adsorption capacity of the different aquatic plants

No.	Aquatic plant	Heavy Metal	Source	Adsorption capacity	Reference
1	Water lettuce, hydrilla, duckweed	Pb	Synthetic wastewater	hydrilla (100%), duckweed (100%), water lettuce (97.886%)	This work
2	Vetiver grass (Montoya), water hyacinth and hydrilla	Pb and Cd	Synthetic wastewater	Water hyacinth was significantly higher lead treatment efficiency than vetivergrass and hydrilla for every concentration level ($p \leq 0.05$),	(Krutthoob & Wachirawongsakorn, 2015)
3	Ceratophyllum demersum Linn.	Pb, Cu and Zn	Synthetic wastewater	87.0887, 28.3333 and 375.2654 mg/kg for drinking water standard 134.5899, 48.2372 and 2,834.1719 mg/kg for household and agriculture standard, and 323.9030, 132.0522 and 88.5473 mg/kg for industry standard	Jumpa, 2007)

4	Phragmites australis	Pb, Cd, and Ni	Contaminated water	(93% removal) of cadmium, 95% removal) of lead and 16% (84% removal) of nickel	(Bello et al., 2018)
5	Water hyacinth	Cu, Fe, Pb and Cr	Aqueous solution	70–90% removal of heavy metals	Priya & Selvan, (2017)
6	Water hyacinth	Cu, Cd and Fe	Aqueous solution	Removal of cadmium at 94.87% in textile wastewater, 95.59% in metallurgical wastewater and 93.55% in pharmaceutical wastewater	Ajayi & Ogunbayo, (2012)
7	E. crassipes	Cu	Aqueous solution	97.3% removal of copper	Mokhtar, Morad, & Fizri, (2011)
8	Water hyacinth	Cu, Zn and Cr	Aqueous solution	94.78% reduction in chromium, 96.88% in zinc and 94.44% reduction in copper.	Mahmood et al., (2005)
9	Water lettuce, azolla and hydrilla.	As	Synthetic wastewater	60-80% of arsenic removal	Punyauppa-path et al., 2015)
10	18 most representative plant species	As	Running waters	Callitriche lusitanica (2346 mg/kg DW), Callitriche brutia (523 mg/kg DW), L. minor (430 mg/kg DW), A. caroliniana (397 mg/kg DW), R. trichophyllus (354 mg/kg DW), Callitriche stagnalis (354 mg/kg DW) and Fontinalis antipyretica (346 mg/kg DW)	(Favas et al., 2012)
11	28 species of submerged, free-floating and rooted emergent plants	U	Water in the uraniferous region of Beiras, Central Portugal	Fontinalis antipyretica (up to 4979 mg kg− 1) Callitriche stagnalis (1963 mg kg− 1), Callitriche hamulata (379 mg kg− 1), Ranunculus peltatus subsp. saniculifolius (243 mg kg− 1), Callitriche lusitanica (218 mg kg− 1), and Ranunculus trichophyllus (65.8 mg kg− 1).	(Favas et al., 2014)

12	Native plant community of the uraniferous Beiras (Central Portugal)	U	Water in the uraniferous region of Beiras, Central Portugal.	Callitriche stagnalis Scop., from 0.98 to 1567 mg/kg, Potamogeton natansL. from 3.46 to 270.9 mg/kg, and Potamogeton pectinatus L. from 2.63 to 1588 mg/kg.	(Pratas et al., 2014)
13	Eichhornia crassipes	Hg	Synthetic wastewater	Mercury ion level at 1.99 mg/g dry weight, 1.74 mg/g dry weight, and 1.39 mg/g dry weight in root, leaf, and petiole tissues, respectively.	Malar, Sahi, Favas, & Venkatachalam, 2015)
14	Lemna minor and Egeria densa. L.	Se	Hoagland solution	Selenium removal efficiency (97%)	(Ohlbaum, Wadgaonkar, van Bruggen, Nancharaiah, & Lens, 2018)
15	Callitriche cophocarpa.	Cr	Aqueous solution	Ca.58% or 35% of the starting amount, in the case of Cr(III) and Cr(VI), respectively.	Augustynowicz, Kołton, Baran, Kostecka-Gugała, & Lasek, 2013)
16	Salvinia auriculata, Pistia stratiotes, and Eicchornia crassipes	Cr(III) Cr(VI)	Hydroponic solutions	90%, 50%, and 90% for Cr(III) removal efficiency, and 50%, 70%, and 90% for Cr(VI) removal efficiency	Espinoza-Quiñones et al., 2008)

Moreover, phytoremediation can be applied to treat other toxins as well as expanding a variety of experimental methods. Ohlbaum et al. (2018) studied the phytoremediation of selenium-containing Hoagland solution using two aquatic plants: *Lemna minor* and *Egeria densa*. *L. minor*. The results showed the highest selenium removal efficiency (97%) in the Hoagland solution with BCF of 504.35 (±0.83). In artificial soil leachate with addition of 2 mg L^{-1} $MnSO_4$, *L. minor* and *E. densa* showed a selenium removal efficiency of 77% and 60%, respectively. de Souza, Borges, Braga, Veloso, & de Matos (2019) investigated the influence of the parameters of pH, phosphate concentration, and nitrate concentration in the process of arsenic absorption by *Lemna valdiviana* Phil. It could absorb a greater amount of arsenic when cultivated under pH conditions between 6.3 and 7.0, readily available phosphorus (P-PO_4) concentration of 0.0488 mmol L^{-1}, and nitrogen in the form of 7.9 mmol L^{-1} nitrate. Under these conditions, the plants were able to accumulate 1190 mg kg^{-1} as (in dry weight) from the aqueous media and reduce 82% of its initial concentration. Furthermore, Putra, Cahyana, & Novarita (2015) examined the mixed of electro-assisted system and hydroponic phytoremediation which is hereinafter referred as hydroponic EAPR system for rapid removal of Pb^{2+} and Cu^{2+} from contaminated water using water lettuce (*Pistia stratiotes* Linn.). The results showed that the accumulation of lead and copper were high in the plant roots. The overall metal up-taken in plant system was higher under EAPR system than one compared with phytoremediation process.

CONCLUSIONS

Phytoremediation treatment system for the removal of pollutants and contaminants from various natural sources is well-established for an environmental protection technique. The adsorption efficiency of lead(II) of all three aquatic plants at different concentrations found that only two types of the hydrilla and duckweed experimented for 2 days at 5 ppm showed the highest adsorption efficiency of lead(II) at 100%, followed by water lettuce. Interestingly, the hydrilla at 10 ppm concentrations could withstand the adsorption of lead(II) ions longer than seaweed. In addition, it was found that all aquatic plants at concentration at 15 ppm showed significant decrease in adsorption efficiency. Therefore, the adsorption efficiencies of lead(II) were hydrilla > duckweed > water lettuce, respectively.

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