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Phytoremediation of iron in ex-sand mining waters by water hyacinth (*Eichhornia crassipes*)

QADAR HASANI[1,2,♥], NIKEN T.M. PRATIWI[3,♥♥], YUSLI WARDIATNO[3,4], HEFNI EFFENDI[3,4], ARTHO NUGRAHA MARTIN[5], EKO EFENDI[5], PURNA PIRDAUS[6], WAGIRAN[6]

[1]Doctoral Program in Aquatic Resources Management, Graduate School, Institut Pertanian Bogor. Jl. Agatis, IPB University Campus Dramaga, Bogor 16680, West Java, Indonesia

[2]Department of Aquatic Resources, Faculty of Agriculture, Universitas Lampung. Jl. Prof. Sumantri Brojonegoro No 1., Gedong Meneng, Rajabasa, Bandar Lampung 35145, Lampung, Indonesia. Tel./fax.: +62-721-770347, ♥email: masqod@fp.unila.ac.id

[3]Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Institut Pertanian Bogor. Jl. Agatis, IPB University Campus Dramaga, Bogor 16680, West Java, Indonesia. Tel./fax.: +62-251-8622909, ♥♥email: niken_tmpratiwi@yahoo.com

[4]Center for Environmental Research, Institute for Research and Community Development, Institut Pertanian Bogor. Jl. Lingkar Akademik, IPB Dramaga Campus, Bogor 16680, West Java, Indonesia

[5]Department of Aquaculture, Faculty of Agriculture, Universitas Lampung. Jl. Prof. Sumantri Brojonegoro No 1., Gedong Meneng, Rajabasa, Bandar Lampung 35145, Lampung, Indonesia

[6]Integrated Laboratory and Center for Technological Innovation, Universitas Lampung. Jl. Prof. Sumantri Brojonegoro No 1., Gedong Meneng, Rajabasa, Bandar Lampung 35145, Lampung, Indonesia

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Abstract. *Hasani Q, Pratiwi NTM, Wardiatno Y, Effendi H, Martin AN, Efendi E, Pirdaus P, Wagiran. 2021. Phytoremediation of iron in ex-sand mining waters by water hyacinth (*Eichhornia crassipes*). Biodiversitas 22: 838-845.* The high concentration of iron (Fe) has allegedly caused the water quality of lakes at sand mining area, in East Lampung District, Indonesia. The poor water quality, in which high concentration of Fe will to a reduction in aquaculture production. This study verified the ability of water hyacinths (*Eichhornia crassipes* (Mart.) Solms.)) as a phytoremediation agent for iron (Fe) concentration in water at the sand mining area, to be adequate for aquaculture. The study was carried out with 4 treatments and 3 replication each, including the treatment of: (A) without water hyacinths (B) 25% water surface coverage, (C) 50% water surface coverage, and (D) 75% water surface coverage of water hyacinths. Measurement of Fe concentrations, bioconcentration factor (BCF) and translocation factor (TF) once a week, until Fe concentrations in water are adequate for aquaculture. This was achieved for 21 days. The results showed that the highest percentage reduction of Fe (97.96%) was observed at water hyacinths cover area 50%. The highest value of BCF was 2,385.51, while the highest TF was 1.14 in stems and 1.02 in leaves. The results of this study open opportunities for use of water in ex-sand mining areas for aquaculture by community and its management by the Government of East Lampung District, Lampung, Indonesia.

Keywords: Aquaculture, iron, phytoremediation, sand mining, water hyacinth

INTRODUCTION

Sand mining activities cannot be separated from negative impacts on the environment and ecosystem (Mngeni et al. 2016; Atejioye and Odeyemi 2018) such as land degradation at the ex-sand mining site without any efforts to utilize and land reclamation (Kurniawan and Surono 2013; Rizqan et al. 2016). Sand mining activities can cause physical, biological, and chemical impacts on soil and waters (Siswanto et al. 2012; Asabonga et al. 2017). Physical impacts can include changes in the landscape, changes in surface water flow patterns and underground waters (Marini et al. 2014), changes in the shape of the land surface due to erosion (Yudhistira et al. 2011; Octorina et al. 2017), change in soil structures (Asabonga et al. 2017), the formation of large holes or puddles of former sand excavation (Hasibuan 2006; Asabonga et al. 2017; Zhou et al. 2017; Gavriletea 2017). Meanwhile, chemical impacts can be in the form of water pollution due to waste (Ramadan et al. 2001), water pollution due to waste (Romiyanto et al. 2015), and high concentration of heavy metals in waters (Darmayanti et al. 2000); Hasani et al. 2021).

The most common heavy metals such as Iron (Fe), Aluminium (Al), Lead (Pb), Cadmium (Cd), Zinc (Zn), and Copper (Cu) that are often found in the area of sand mines (Darmayanti et al. 2000; España 2008). The Fe is the highest concentration of metals in sand about 30%. The Fe can be found in the forms of black colored magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$), also red-colored hematite and maghemite (Fe_2O_3) compounds (Darmayanti et al. 2000). High concentrations of metal can be sourced from nature (Schumann et al. 2015; Atejioye and Odeyemi 2018; Hasani et al. 2021), or geogenic activities and waste input from the outside. It can pollute the waters of ex-sand mines (Khatri et al. 2017).

Based on measurements by the Department of Maritime and Fisheries Affairs of Lampung Province, Indonesia, in 2017, Fe concentrations in the ex-sand mining area in the Pasir Sakti Subdistrict ranged 0.22-1.54 mg/L in water and 1.75-36.46 mg/100 gr in meat of fish that was caught on the ex-sand mining waters. Several attempts can be made to reduce the concentration of metals in water. Reduction of Fe can be carried out biologically using metal-induced bacterial isolates (Ilić et al. 2019; Singh and Gupta 2019), mycorhizomediation by fungi (Bishnoi and Garima 2005; Oladipo et al. 2018), and phytoremediation by aquatic plants/macrophyte (Elumalai et al. 2011; Ajibade et al. 2013). Regarding the efficiency and the effectiveness to apply the method phytoremediation by aquatic plants is considered the best, efficient, and economic method to reduce the concentration of heavy metals in water (Elumalai et al. 2011; Ali et al. 2013; Shawai et al. 2017).

It is generally known that more than 400 species of plants can be used as phytoremediation agents (Ali et al. 2013), one of which is water hyacinth (*Eichhornia crassipes* (Mart.) Solms). Water hyacinth has been proven to be effective and efficient in reducing variety of heavy metals such as Calcium (Ca), Magnesium (Mg), Lead (Pb), Cadmium (Cd), including Fe which will be focused in this study (Elumalai et al. 2011; Ajibade et al. 2013; Elisa et al. 2016; Rezania et al. 2016). Water hyacinth with different biomass is able to reduce Fe in domestic waste by 71.2% (Ajibade et al. 2013). Rezania et al. (2016) state that water hyacinth by treated metal composition in different wastewater can reduce Fe by 98%. Water hyacinth with different concentrations of clay soil can reduce Fe and Manganese (Mn) concentrations by 88.98% (Elisa et al. 2016). Sidek et al. (2018) revealed that water hyacinth from three types of plants tested could reduce Fe by 90.5%. Whereas Yunus and Prihatini (2018) stated that water hyacinth with phytoremediation using artificial wetlands was able to reduce Fe by 95.28%. Based on several previous studies showed that water hyacinth is considered capable of reducing the Fe in the waters. This study focuses on reducing the Fe in waters by water hyacinth so that the water quality in the ex-sand mining area in Pasir Sakti Subdistrict, East Lampung District, Lampung, Indonesia, make it adequate for aquaculture.

MATERIALS AND METHODS

Research site

This research was carried out around the waters of ex-sand mining sites in Pasir Sakti Subdistrict, East Lampung District, Lampung, Indonesia. According to The Department of Marine and Fisheries Affairs of East Lampung, the potential area of sand mining in the Pasir Sakti Subdistrict reaches 20,000 ha, with sand deposits 1.2 billion m^3. The mined land covers area of 1,600 ha, forming lakes with a depth of 4-8 meters. These sites were previously land for oil palm, rubber plantations, and community housing. The experiments were conducted on a semi-laboratory scale at the ex-sand mining site. Experimental ponds have been built in Rejomulyo Village, Pasir Sakti Subdistrict, East Lampung District, Indonesia, at the coordinates 5º31'46.83" S and 105º46'23.71" E.

Research design

The experimental container has been made in the form of tarpaulin containers with a size of $1.5 \times 2.5 \times 1.0$ m^3. The containers were cleaned by rinsing use clean water then drained. Water from the ex-sand mining site was put into each container with a height of 70 cm. Treatment has been constructed using different percentages of water hyacinths cover in the experimental ponds as follows: A: Without water hyacinth; B: Treatment with 25% surface coverage area of water hyacinths; C: Treatment with 50% surface coverage area of water hyacinths and D: Treatment with 75% surface coverage area of water hyacinths. Each treatment was carried out on 3 replications.

Experimental procedure

Water hyacinths have been taken from waters around the sand mining area with uniform size and amount. Water hyacinths are then cleaned using clean water to remove impurities, eggs of small organisms, and insect larvae. Water hyacinths that have been cleaned are put into the experimental containers according to the treatments (without water hyacinth, 25%, 50%, and 75% water surface coverage).

Water quality measurement

Measurement of Fe in the waters, leaves, stems, and roots of the water hyacinth was performed once a week. Ammonia, nitrate, and phosphate were measured in the laboratory at the beginning and the end of the experiments. Measurement of pH, dissolved oxygen (DO), and temperature have been carried out in-situ for each experiment units every 2 times a day for 21 days. The remediation experiment process lasts for up to water quality suitable for aquaculture. During the experiment, the water was not replaced except the addition of water due to the evaporation process to equalize to the initial volume. Measurement of Fe concentration was carried out before the experimental process took place to find out the Fe concentration at the beginning before treatment. Measurement of Fe concentration, refers to the EPA 2007 (5^{th} Revision) method (APHA 2012), using Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) (Manning and Grow 2019); Velitchkova et al. 2013; Tsanaktsidou and Zachariadis 2020). Considering the level of precision of the measurement results, all water samples are handled as soon as possible in the laboratory. Each water sample was measured by 3 replications. The result of the average measurement is the used value. Water samples were analyzed at the Integrated Laboratory and Center for Technological Innovation Center, Lampung University, Indonesia.

Response design and data analysis

Calculation of removal efficiency of Fe (%) by water hyacinths

The response that we want to know from this experiment is the ability of water hyacinth to reduce Fe including decreasing Fe concentration in water and increasing Fe concentration in roots and leaves of water hyacinths. Water sampling was carried out by taking water samples from each treatment container as much as 1 liter by using dark bottles so that sunlight does not enter the bottles. Water hyacinths samples were taken at the beginning and end of the experiment. Samples were then tested at the Integrated Laboratory and Technology Innovation Center of Lampung University, Indonesia with reference to the EPA 2007 (5th revision) method. The removal potential (%) of water hyacinths for Fe concentration was calculated by the equation of (Sidek et al. 2018; Kumar et al. 2019; Kumar et al. 2020).

$$\text{Removal efficiency (\%)} = \frac{\text{Initial Fe conc.}(C_o) - \text{Final Fe conc.}(C_f)}{\text{Initial Fe concentration }(C_o)} x\ 100\%$$

Calculation of Bioconcentration Factor (BCF)

Bioconcentration factors (BCF) was used to ensure Fe concentrations absorbed by water hyacinths from the water. This value is used to measure the ability of plants to accumulate Fe particles from water (Arnot and Gobas 2006). Measurement of Fe in roots and leaves of water hyacinth was carried out at the beginning and end of the treatment. The concentration of Fe in roots and leaves using the Atomic Absorption Spectrophotometer (AAS) method, through the digestion phase (Kord et al. 2010). The relationship of Fe concentration absorbed by water hyacinth and Fe in water is calculated by the equation according to (Ghosh and Singh 2005; Kumar et al. 2020).

$$\text{Bioconcentration Factor} = \frac{\text{Metals conc. in plant (mg/L)}}{\text{Metals conc. in water (mg/L)}}$$

The higher the value of BCF, the more suitable the plant as a phytoremediation agent (Ndimele and Jimoh 2011). According to Arnot and Gobas (2006); Testi et al. (2019) the value of bioconcentration factor classified as: Low ability (<250); Medium ability (250-1000); and high ability (>1000).

Calculation of Translocation Factor (TF)

The translocation factor (TF) is calculated to evaluate the potential of water hyacinth as a phytoremediation agent. TF indicates the ability of plants to transfer metals from roots to stems and leaves (Arnot and Gobas 2006). TF are calculated by the following formula (According to Mellem et al. 2012; Shingadgaon and Chavan 2019).

$$\text{Translocation factor} = \frac{\text{Metal conc. in plant parts (mg/L)}}{\text{Metal conc. in the roots (mg/L)}}$$

Metals are accumulated by plants and mostly stored in roots of the plants. These are indicated by TF value, if the TF <1, plants are less able to transfer metals to stems and leaves. Meanwhile, if TF > 1, the plant is able to transfer the metal in the roots to the stems and leaves (Mellem et al. 2012).

Statistical test

The study applies the one-way analysis of variance (ANOVA) followed by least significant difference (Fisher's LSD) test to determine the effect of water hyacinth coverage on the percentage decrease in Fe concentration in water in the experimental containers, BCF and TF value on the roots, leaves, and stems of water hyacinths. The Fisher's LSD test for multiple comparisons with p-values less than 0.05 were considered significant.

RESULTS AND DISCUSSION

Fe concentration in water

The results of measurement of Fe concentration during the experiment showed a positive response. Decrease in Fe concentration occurred in all treatments, including treatment A (without water hyacinth cover). The decrease in Fe concentration to water quality suitable for fish culture medium (0.03 mg/L) has been achieved on the 21st day. However, this value was not achieved in treatment A (without water hyacinth coverage). Graph of Fe removal in water from sand mining for 21 days of experiment is presented in Figure 1 and Figure 2.

The highest removal efficiency of Fe was obtained in treatment C (97.96%). Whereas treatment B and D were 95.74% and 94.84%, respectively (Figure 3). ANOVA test results with a 95% confidence interval showed a significant difference between treatments. Based on the LSD test, it showed that treatments A and C were significantly different, while treatments B and D did not show significant differences. These results indicate that the different treatment of water hyacinth coverage influences decreasing the concentration of Fe in water. However, this effect can increase the percentage reduction in Fe concentration or vice versa (Santoso et al. 1999). The result of this study are in accordance with Elumalai et al. (2011); Elisa et al. (2016); Kumar et al. (2019) that the application of differences in the area of closure or density of aquatic plants can affect the absorption of contaminant in water. Applying the appropriate coverage area of water hyacinths can make the absorption of substances including metals can be more effective without disrupting the activity of bacteria for oxidizing Fe (Elumalai et al. 2011; Ilić et al. 2019). The area covered should be no more than 75%. If it exceeds the area of the cover, it will interfere with bacteria and microalgae to degrade organic material and oxidize metals which will be difficult to absorb by plants (Putra and Hastika 2018). In the end, it will be difficult to reduce Fe. This condition is thought to occur in treatment D (75% cover area) which showed no significant difference from treatment B (25% cover area).

The results of this study support the statement (Rezania et al. 2016; Putra and Hastika 2018) that water hyacinth has a high absorption of Fe in waters. Water hyacinths are also effective in reducing heavy metals Fe, Ca, and Mg (Elumalai et al. 2011). Water hyacinths have been proven effective in reducing Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn in polluted waters (Eid et al. 2019). The removal efficiency of water hyacinths against Fe in this study was higher than the results of study by Ajibade et al. (2013) that the removal efficiency of Fe by water hyacinths was 71.2%; up to 90.5% (Sidek et al. 2018); and 95.28% (Yunus and Prihatini 2018). Water hyacinths were also able to reduce the concentration of Fe and Manganese (Mn) by 88.98% (Elisa et al. 2016). However, the results of this study are lower than the results of the study by Rezania et al. (2016), which states that the removal efficiency of water hyacinths against Fe can reach 98%. Therefore, water hyacinths are a promising candidate to remediate Fe concentration in water in ex-sand excavated land.

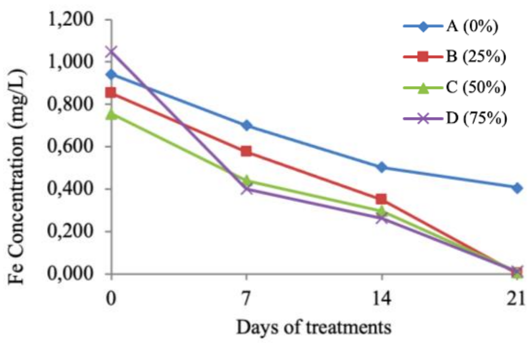

Figure 1. Decreased concentration of Fe in water for 21 days of treatment

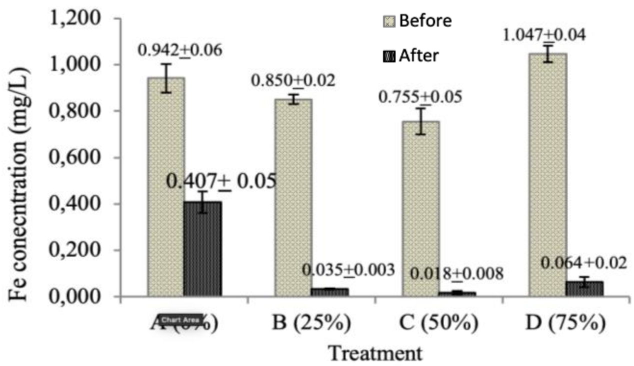

Figure 2. Fe concentration in the water before and after treatments

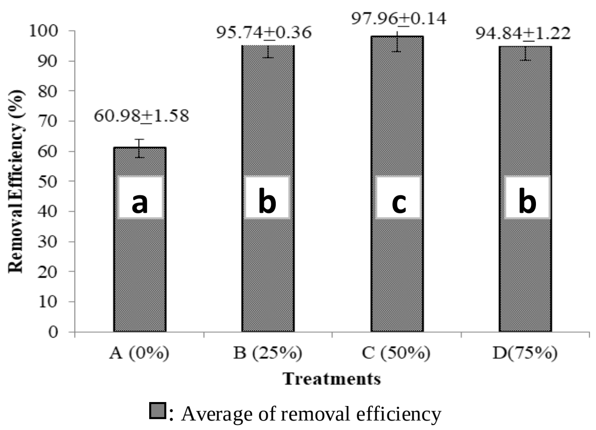

Figure 3. Percentage averages of Fe concentration decrease in the water base on the treatments. Notes: a, b, c, d: Different letters indicate significant differences. Treatments B (25% coverage of water hyacinths) and D (75% coverage of water hyacinths) showed no significant difference

Waters quality parameters

In general, there is no significant difference in water quality parameters in all treatments. The pH tends to be acidic, ranging from 3.8-6.8 in all treatments, this pH condition will affect the form of Fe in water (Khatri et al. 2017). The concentration of nutrients (nitrate, phosphate, and ammonia) tended to increase consistently at the beginning to the end, in treatments A, B, and C. Whereas in treatment D, nutrients increased on the first, seventh to 14th day, then decreased on 21st day. The pH in treatment D also tends to be more acidic (Table 1), this condition causes the removal efficiency of Fe inclined to decrease.

Dissolved oxygen in treatment D was lower among all treatments. This occurs because oxygen is used by water hyacinths for the respiration process, while the diffusion of oxygen from air to water is reduced because the surface area of open water is smaller, although the photosynthetic process may produce more oxygen (Wijaya et al. 2016). Increasing dissolved oxygen will affect the oxidation process of Fe^{2+} to Fe^{3+} (Khatri et al. 2017), so that it is not available for absorption by plants (Gonzalez and Guo 2018). Treatment D at the end of the study had the highest Fe concentration, because Fe uptake decreased along with decreasing nutrient concentration in water.

Fe concentration in the water hyacinths

The concentration of Fe in water is reduced because it is absorbed by water hyacinths. This absorption occurs through the roots network which will then be transported to other tissues by translocation process. The transfer of Fe concentrations between tissues of water hyacinths are presented in Figures 4, 5, and 6. Fe concentration in roots was found to be the lowest in treatment C. This condition occurs because the initial concentration of Fe in water is lowest, also because the translocation of Fe from roots to leaves is going well. Whereas in the stems and leaves, the lowest Fe concentration was found in treatment D. This condition is presumably due to treatment D, the process of translocation of Fe from roots to stems and leaves did not occur properly (Usman et al. 2019), due to the inability of water hyacinths due to lack of nutrients (Table 1). This condition can also be seen from the low value of translocation in treatment D (Table 2).

Bioconcentration and translocation factors

Bioconcentration factors are used to ensure metals (Fe) concentrations are reduced as a result of being absorbed by plants/water hyacinths from water (Ghosh and Singh 2005; Ndimele and Jimoh 2011; Kumar et al. 2011). Table 2 shows that bioconcentration and translocation factors are different between treatments (based on ANOVA test with p-values less than 0.05).

The results of Fisher's LSD test showed that the bioconcentration factor in treatment B was significantly different from other treatments ($p<0.05$). While treatment C was not significantly different from treatment D, because, in treatment D, Fe was only accumulated at the root and could not be absorbed to make the bioconcentration value high while translocation was low (Shingadgaon and Chavan 2019; Testi et al. 2019). There are several factors that can affect the value of bioconcentration in an organism, including the size or number of organisms, contact duration, and concentration of substances in the media (Arnot and Gobas 2006; Usman et al. 2019). The more the amount, the smaller the value of the bioconcentration factor. This happens because the absorption process will be carried out by many individual organisms so that what is absorbed will be far more evenly distributed than a few individuals (Testi et al. 2019).

Discussion

The decreasing of Fe concentration can be influenced by water quality. Changes in pH and fluctuations of oxygen can change the form of Fe^{2+} to Fe^{3+} and vice versa (Runtti et al. 2018). The low pH value occurs due to the influence of a high population of water hyacinths. The higher the water hyacinth population, the lower the pH because of the exudate released by roots of water hyacinths (Ndimele and Jimoh 2011; Ajibade et al. 2013). This substance contains acids such as organic acids, amino acids, and fatty acids (Runtti et al. 2018).

Fe concentration in treatment D decreased rapidly in the first week, then the rate of decline in Fe concentration decreased, even at the end of the study the concentration of Fe in treatment D was higher than other treatments. This is due to the greater number of water hyacinth population will be faster to absorb Fe, but then will be reduced because of the availability of nutrients that are decreased rapidly. This condition occurs because the amount of water hyacinths population will be able to absorb more nutrients. This condition is in accordance with the results of research (Lestari et al. 2011), who discovered the fact that the phytoremediation treatments with the highest water hyacinths cover area did not produce better metal absorption during 6 days of treatments. such conditions can be caused by water and nutrient quality (Purwaningsih 2012). Factors of plant and biomass quantity and contact duration were factors that influenced the results and effectiveness of phytoremediation (Purwaningsih 2012; Mutmainnah et al. 2015).

The concentration of nutrients decreases along with the absorption of nutrients by water hyacinths, metals will also be absorbed and eventually enter the plant tissues (Khatri et al. 2017). At the end of this study, the lowest concentrations of nitrate, phosphate, and ammonia occurred in treatment D. The high amount of water hyacinth will cause the absorption of nutrients more quickly so that the concentration of nutrients in the water decrease. Low nutrient concentration causes the ability of photosynthesis to be reduced and the absorption of Fe is also reduced. Therefore, the Fe concentration at the end of the study in treatment D was the highest. Nitrate is a common form of N in waters that are utilized by plants (Crawford and Glass 1998; Glass 2009). Nitrate is the final form that is produced from the oxidation process of ammonia to nitrite which will then become nitrate (Crawford and Glass 1998; Mustofa 2015). This is the cause of higher nitrate concentrations than ammonia. In addition, the pH can affect ammonia concentration (Wurts 2003; Guo et al. 2017). In Table 1, the pH tends to be low (<7) therefore the ammonia concentration will decrease, and nitrate concentration will rise. The availability of nutrients can increase the ability of phytoremediation by plants 1.09-1.34 times faster than the absence of nutrients (Purwaningsih 2012).

Table 1. Range of water quality parameters for each treatment

Days to-	Parameters	Treatments			
		A (0%)	B (25%)	C (50%)	D (75%)
0	pH	5.5-6.5	5.6-6.6	5.5-6.7	5.6-6.6
	DO (mg/L)	4.4-8.7	4.3-8.0	4.3-7.3	4.4-7.2
	Temperature (°C)	26.6-30.9	26.5-29.9	26.7-29.8	26.4-29.7
	Nitrate (mg/L)	0.265-0.742	0.332-0.860	0.166-0.654	0.061-0.625
	Phospate (mg/L)	0.001-0.001	0.001-0.001	0.001-0.001	0.001-0.001
	Ammonia (mg/L)	0.143-0.432	0.142-0.524	0.085-0.401	0.021-0.401
7	pH	4.8-6.2	5.5-6.5	5.4-6.6	5.3-6.4
	DO (mg/L)	4.8-7.8	4.4-8.7	4.4-7.5	4.6-7.0
	Temperature (°C)	27.1-30.5	26.6-30.9	25.5-30.6	26.7-30.2
	Nitrate (mg/L)	0.587-2.179	0.698-1.258	0.612-1.226	0.327-0.708
	Phospate (mg/L)	0.003-0.006	0.009-0.010	0.009-0.012	0.011-0.012
	Ammonia (mg/L)	0.071-0.240	0.198-0.381	0.182-0.497	0.139-0.157
14	pH	4.7-6.0	5.1-6.2	4.9-6.1	4.7-5.9
	DO (mg/L)	4.6-6.8	5.8-8.4	4.8-7.5	4.4-6.8
	Temperature (°C)	26.8-30.1	26.5-29.8	26.1-29.5	26.0-30.0
	Nitrate (mg/L)	0.290-1.240	0.564-1.846	0.587-2.179	0.297-1.258
	Phospate (mg/L)	0.005-0.008	0.005-0.008	0.004-0.007	0.005-0.007
	Ammonia (mg/L)	0.035-0.091	0.117-0.279	0.061-0.241	0.032-0.094
21	pH	3.8-5.9	4.7-6.8	4.6-6.8	3.9-5.8
	DO (mg/L)	4.2-6.9	6.0-7.2	4.9-7.7	4.2-6.6
	Temperature (°C)	27.3-29.8	26.5-29.7	26.2-30.0	26.3-29.6
	Nitrate (mg/L)	0.016-0.091	0.304-0.342	1.118-0.198	0.018-0.071
	Phospate (mg/L)	0.004-0.006	0.005-0.009	0.004-0.007	0.003-0.004
	Ammonia (mg/L)	0.324-0.707	0.133-0.145	0.339-0.757	0.076-0.084

Table 2. Bioconcentration Factor and Translocation of Fe in water hyacinths

Treatments	Bioconcentration	Translocation	
		Stems	Leaves
A	-	-	-
B	2,385.51±163.49[b]	1.14±0.03[b]	1.02±0.02[b]
C	1,701.34±441.61[a]	1.03±0.02[b]	1.02±0.02[b]
D	1,520.93±339.49[a]	0.62±0.06[a]	0.58±0.06[a]

Note: Different letter notations in the table show significantly different values with p-values less than 0.05. Bioconcentration in treatment C was not significantly different from treatment D, but significantly different from treatment B.

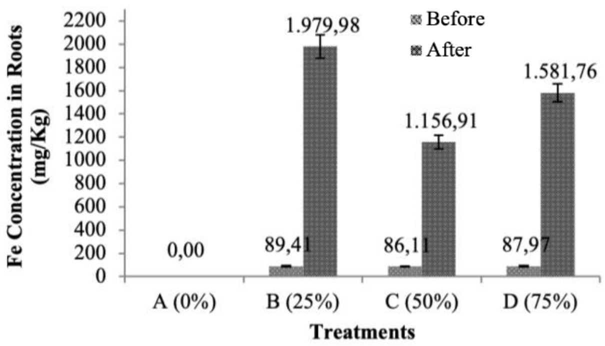

Figure 4. Fe Concentration in the roots of water hyacinths before and after treatments

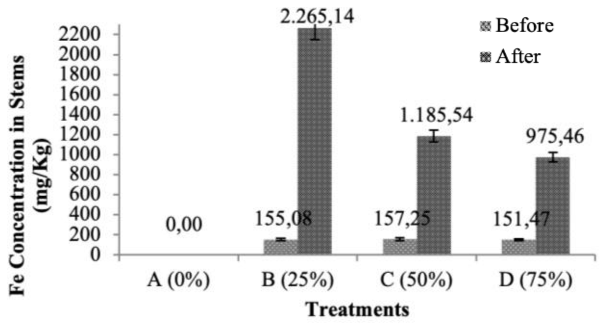

Figure 5. Fe Concentration in the stems of water hyacinths before and after treatments

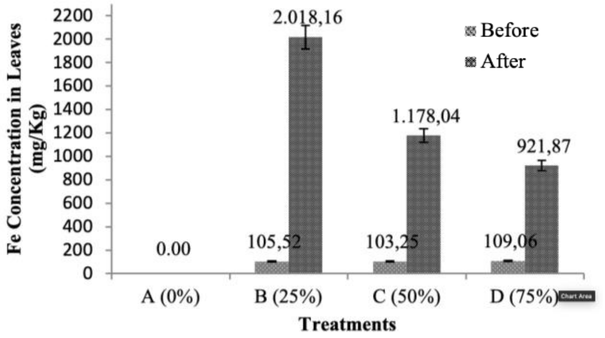

Figure 6. Fe Concentration in the leaves of water hyacinths before and after treatments

Fe concentrations in stems of water hyacinths tend to be higher than in the leaves. It is reasonable because there is parenchyma on the outer layer of the water hyacinth stems which are composed of xylem and phloem transport networks that function to absorb substances in the water so that it makes the metal more absorbed in the stems (Khatri et al. 2017). The concentration of Fe in leaves in treatment D was the lowest, because the concentration of Fe accumulated in the roots, this indicated that the translocation of Fe from root to leaf was not going well. Fe concentration in leaves is lower than stems but higher than roots except in treatment D. pH and nutrient factors are thought to be responsible for this condition (Shingadgaon and Chavan 2019).

Several studies on bioconcentration in water hyacinths have been carried out, among others by (Ndimele and Jimoh 2011) which stated the bioconcentration value of water hyacinth was 28.38 (0.25 mg/L Fe). Ajayi and Ogunbayio (2012) mention the bioconcentration value of water hyacinth to Fe has ranged from 2,197.73 to 5,022.73. In this study, the bioconcentration values obtained ranged from 1,520.93 to 2,385.51. According to Djo et al. (2017), the reduction effectivity for COD, Cu, and Cr by water hyacinth were 42.36%, 68.73%, and 42.4%. The adsorption capacity was 0.1232; 0.0016; and 0.0051 mg/g water hyacinth respectively. Ajayi and Ogunbayio (2012) research results show that average bioconcentration factors obtained for cadmium, copper, and iron were 583.83, 734.41, and 2,982.95 respectively. According to Shingadgaon and Chavan (2019; Testi et al. (2019), bioconcentration values > 1,000 mean high absorption ability. This indicates that water hyacinths are reliable used as a phytoremediation agent (Ndimele and Jimoh 2011; Ajayi and Ogunbayio 2012; Djo et al. 2017).

The concentration of Fe in the roots will then be transferred to other tissues, i.e stems, and leaves which are reflected by the translocation value (Table 2). The ANOVA test results with a 95% confidence interval showed significant results between treatments. Fisher's LSD tests showed that the translocation factor in the stems and leaves in treatments B and C were not significantly different but were significantly different from treatment D. This condition is because, in treatment D, Fe in the roots is higher than in the stems and leaves (Figure 4) because in treatment D the plant is unable to absorb Fe and transfer it to the stem and leaves due to the translocation process that is not going well (Deval et al. 2012; Shingadgaon and Chavan 2019). This is due to the disruption of the process of photosynthesis due to A lack of nutrients to be able to support the process (Table 1). The value of the translational factor > 1 can be said that the plant is reliable to transfer the metal in the roots to the stems and leaves (Arnot and Gobas 2006; Mellem et al. 2012; Shingadgaon and Chavan 2019).

The results of this study have proven that water hyacinths is able to reduce Fe in water from ex-sand mining area. Therefore, in terms of water quality remediation, water hyacinths are potential and can be recommended as strong accumulators for improving water quality with high Fe concentrations. This is in accordance with the results of research by (Elumalai et al. 2011; Ajayi and Ogunbayio 2012; Ajibade et al. 2013; Rezania et al. 2016; Sidek et al. 2018; and Yunus and Prihatini 2018). Direct application of water hyacinths in ex-mining lakes can be carried out by considering several things: (i) the ex-sand mining landscape in the form of a large lake, the direct application of water hyacinth will require large costs and energy; (ii) water hyacinth is an invasive plant, where direct application in the field will pose ecological and environmental risks (Ali et al. 2019). Given its high nutritional value, it is better if water hyacinths are harvested and its leaves can be used as animal feed (Su et al. 2018). In general, the metal content of contaminated water hyacinth leaves is usually well below the maximum tolerable levels for rodents, poultry, sheep, cattle, and fish (Du et al. 2020). However, if the roots and stems of water hyacinth are used as animal feed, it can be used as biofuel to generate heat or electricity, which can bring economic benefits and prevent the disposal of potentially hazardous biomass (Rezania et al. 2016; Du et al. 2020).

In conclusion, this research shows that water hyacinths can reduce Fe in the water, with a removal efficiency of up to 97.96%. Therefore, in terms of water quality remediation, water hyacinths are potential and can be recommended as strong accumulators for improving water quality with high Fe concentration. This research was performed on a semi-laboratory scale, using tarpaulin containers/ponds. In terms of the utilization of the ex-sand mining land in East Lampung District for aquaculture by utilizing water hyacinths as a phytoremediation agent to be potentially carried out by the tarpaulin ponds method as well as the application of floating ponds. In the case of water use in ex-sand mining areas for aquaculture, it is recommended to apply phytoremediation with 50% water hyacinths cover area for 21 days so that the water quality is adequate for aquaculture.

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