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Phytoremediation of diamond mines wastewater using water hyacinth

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Abstract

Phytoremediation is used as a technology that utilizes plants and microorganisms to treat diamond mine wastewater. The water is known to pollute the Basung River which flows in the area. According to data from the results of water quality monitoring by the Banjarbaru City Environmental Agency in 2016 showed that the Basung River water quality was in the medium polluted category and the water was not suitable for consumption. Water Hyacinth (*Eichornia crassipes*) was chosen to remediate diamond mine wastewater. Unfortunately, the ideal amount of water hyacinth (biomass) used to remediate wastewater has not been much studied. Therefore, this research aims to determine the proper water hyacinth biomass used for phytoremediation in reducing the value of the diamond mine wastewater pollution index. This research was conducted by varying the water hyacinth biomass to 0g, 250g, 500g, 750g, 2000g. The parameters in this research were temperature, pH, Turbidity, total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), Ammonia, Nitrate, Nitrite, Iron, Manganese. Water sample testing would be carried out on days 0, 3rd, 5th and 7th. The results showed that in all variations of biomass, water hyacinth was able to reduce levels of pollutants in diamond mine wastewater more than 50% with the highest reduction efficiency by using the variation of water hyacinth biomass 500g.

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Introduction

Water is very important for human life and other living creatures because it is a major component of cells, tissues, and living organisms. Banjarbaru City is one of the cities that is developing very rapidly in South Kalimantan Province with its characteristic is diamond mining activities in Cempaka District. Sand mining and diamond mining activities are carried out traditionally, this causes many problems, one of which is in the form of diamond mine wastewater that pollutes the Basung river. According to data from the monitoring of water quality by the Banjarbaru City Environmental Agency in 2016 shows that the Basung River water quality is in the category of being polluted moderately and not suitable for consumption (BLH, 2016). The diamond mine wastewater generates Iron (Fe) and Manganese (Mn) pollution (Indriyatie, 2011).

The diamond mines are located in Pumpung Village which is topographically is a flat area so that groundwater will be affected by river flow. River flow with high order has a larger discharge so that river water will move to groundwater. This type of groundwater causes groundwater contamination by rivers (Jarwanto, 2008). Therefore, river water pollution by diamond mines waste has great potential to pollute groundwater. If the groundwater is used by the surrounding community as a source of clean water, public health will be disrupted. Also, in terms of quantity of diamond mine wastewater has the potential as a clean water alternative. Because of this, diamond mine wastewater treatment is needed to reduce the pollution index and can be used as a source of clean water.

Diamond mine wastewater treatment can be done with active and passive treatment. Passive treatment technology is being developed because it is cheaper and easier to operate compared to active treatment. Passive treatment is recommended to be applied as it is considered more environmentally friendly. Researchers continue to improve the efficiency and effectiveness of passive treatment (Prihatini and Soemarno, 2017). Phytoremediation is one of the most studied passive treatment technologies.

Phytoremediation is used as a technology that utilizes plants and their associated microorganisms to deal with diamond mine wastewater. From a phytoremediation perspective, *Eichornia Crassipes* is a plant species that has the potential for natural repair of water bodies and/or wastewater contaminated with Zn, Cr, Cu, Cd, Pb, Ag, Ni (Muramoto and Oki, 1983; Odjegba and Fasidi, 2007), Fe and Mn (Yunus and Prihatini, 2018), also capable in reducing total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD) and other elements of water (Saha, *et al.*, 2017). *E. crassipes* by 2kg of plant density can reduce the concentration of Fe and Mn in domestic sewage greater than *E. crassipes* by 1kg of plant density (Ajibade, *et al.*, 2013). So, Water Hyacinth (*Eichornia crassipes*) was chosen to remediate diamond mine wastewater. Unfortunately, the ideal amount of water hyacinth (biomass) used to remediate wastewater has not been much studied. Therefore, this research aims to determine the proper water hyacinth biomass used for phytoremediation in reducing the value of the diamond mine wastewater pollution index.

Material and method

Experimental Design

Phytoremediation experiments using water hyacinth are carried out in a plastic tub with dimensions of 40cm x 50cm x 30cm, then each of them is filled with 45 liters of wastewater. One-month-old water hyacinth plants are used with a complete and healthy plant structure. Water hyacinth acclimatized for 5 days by using aquadest. The water hyacinth biomass was weighed based on variations of observations namely 250g, 500g, 750g and 1000g, then placed in a plastic tub for 7 days. Water samples were taken on days 0, 3rd, 5th, and 7th to analyze the parameters of temperature, pH, Turbidity, TSS, TDS, DO, BOD, COD, Ammonia, Nitrate, Nitrite, Iron, Mn. The design of phytoremediation experiments using water hyacinth is shown in Fig. 1.

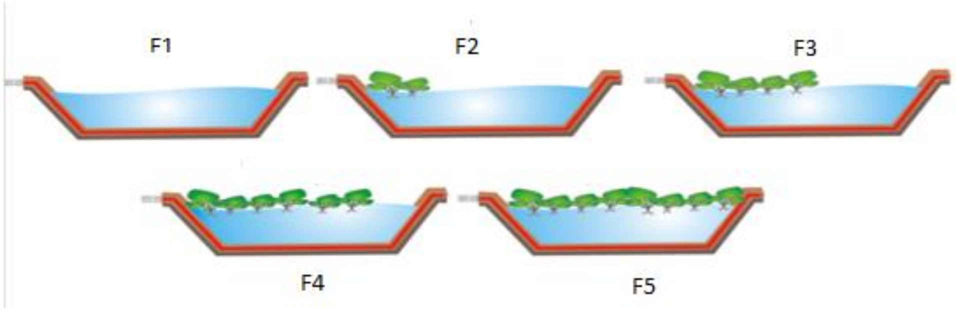

Fig. 1. Phytoremediation Experiment Design.

Note :

F1: Variation without water hyacinth (0g)

F2: Weight Variation of Water Hyacinth Biomass 250g

F3: Weight Variation of Water Hyacinth Biomass 500g

F4: Weight Variation of Hyacinth Biomass 750g

F5: Weight Variation of Hyacinth Biomass 2000g

Data Analysis

Data from the analysis of water quality parameters are used to calculate remediation efficiency with water hyacinth for each treatment with the following formula:

$$\text{Efisiensi} = \frac{a-b}{a} \times 100\%$$

Note:

a: concentration before treatment

b:concentration after treatment

To determine the category of pollution classes in this study, performed a calculation using the pollutant index (IP) method, by using laboratory analysis results data with the pollutant load calculation formula as follows:

$$IP_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)_M^2 + \left(\frac{C_i}{L_{ij}}\right)_R^2}{2}}$$

Note:

Lij = concentration of water quality parameters stated in the Water Quality Standards (j),

Ci = concentration of water quality parameters (i) obtained from the analysis of water samples at a sampling location from a river channel,

IPj = Pollution Index Measurement Results for the designation (j) which is a function of Ci / Lij.

M = maximum, R = average.

Index class categories:

0 ≤ IP ≤1,0 = meet the quality standard (good)

1.0 <IP ≤5,0 = slightly polluted

5.0 <IP ≤10 = moderately polluted

IP> 10.0 = heavily polluted

The effectiveness of phytoremediation of pollutant levels by water hyacinth is determined by the greatest decrease in pollutant index (IP).

Result and discussion

In this research, the reduction in the level of diamond mine wastewater pollutants was carried out by using the phytoremediation method with water hyacinth. The technique involved in this event was precisely called rhizofiltration, which is part of phytoremediation. The phytoremediation research was performed as a function of temperature, pH, Turbidity, TSS, TDS, DO, BOD, COD, Ammonia, Nitrate, Nitrite, and Besi. The experiment was carried out initially in 200 L of diamond mines wastewater. The quality of the processed water from diamond mines wastewater was determined before and after the treatment with water hyacinth plants. The results for all the parameters determined are presented in Table 1.

The results indicated that the water hyacinth was very efficient in reducing the Turbidity, BOD, COD, Ammonia, Fe and Mn concentration of diamond mines wastewater (Table 1). Table 2 shows the test results and the effectiveness of each parameter. :Statistical test results on effectiveness show that in the Phytoremediation method experiment with the analysis of the significance level of variance 0.05, it was found that the repetition of the seven variations had no significant difference, and it was considered to be the same or homogeneous with a calculated f value of more than 1, 7.2. According to Duncan's Multiple Range Test (DMRT), the seven variations were significantly different and obtained the best ratings of treatment were F3 and F4.

Table 1. Characteristics of elements from diamond mines wastewater before and after the phytoremediation experiment.

Parameters	Initial (0 Day) value Conc Mean	Final (7 Day) value Conc Mean	Quality Standart (PerGub KalSel 05/2007)
Temperature (°C)	29,57	29,17	+_ 3
Turbidity (NTU)	156	24	25
TSS (mg/l)	245	50	50
TDS (mg/l)	182	97	1000
pH	7,02	7,11	6-9
DO (mg/l)	4,11	4,69	6
BOD (mg/l)	8,92	3,21	2
COD (mg/l)	22,05	8,75	10
Ammonia (mg/l)	2,52	0,63	0,5
Nitrite (mg/l)	0,46	0,16	0,06
Nitrate (mg/l)	7,6	5,46	10
Fe (mg/l)	3,53	0,68	0,3
Mn (mg/l)	1,37	0,17	0,1

Table 2. The effectiveness of phytoremediation experiments.

Variant	Effectiveness (%)										
	Turbidity	TDS	TSS	DO	BOD	COD	Ammonia	Nitrite	Nitrate	Fe	Mn
F1	39,8	14,3	35,6	14,75	43,4	49,9	41,9	14,1	1,8	8,1	12,4
F2	80,7	33,5	74,6	13,50	55,1	63,5	68,1	54,3	19,4	75,6	83,8
F3	84,6	46,8	79,7	14,44	64,0	70,3	74,8	64,9	28,2	80,6	87,7
F4	81,5	34,7	75,6	14,75	56,9	65,1	69,4	54,7	23,4	76,5	84,1
F5	77,6	23,4	70,7	14,75	48,2	57,7	62,7	46,3	14,5	71,9	80,2

Turbidity

Fig. 1. shows the results of diamond mines wastewater Turbidity (NTU) analysis for 7 days of treatment. Turbidity shows the presence of organic and inorganic materials that are suspended and dissolved in water (Davis and Cornwell, 1991). The variant of F3 with 500g of water hyacinth biomass can reduce Turbidity to below the specified quality standard (24,05 NTU) while the variant of F5 with 2000g of water hyacinth biomass only reduce Turbidity to 35 NTU. It shows that the amount of water hyacinth biomass is not directly proportional to the reduction of Turbidity in the water. However, the presence of water hyacinth plants affects a decrease in Turbidity in the water. This is indicated in the variant of F1, where there is no water hyacinth but it has the highest Turbidity value (Fig. 1).

Total Suspended Solid (TSS)

Based on Fig. 2, it can be seen that TSS levels in F1 variations where there are no water hyacinths have decreased in the first 3 days, they tend to increase again on the next day. Meanwhile, TSS tends to decrease in other variations that contained water hyacinth plants (F2, F3, F4, and F5). The effect of the existence of water hyacinth plants in reducing the amount of total suspended solids (TSS) contained in wastewater is the occurrence of a deposition process whose mechanism is assisted by plant body parts, especially in the roots section. This is one of the stages in the phytoremediation mechanism, namely the Rhizofiltration process (Kalsum, 2014). These results are consistent with previous research that water hyacinth (*Eichornia crassipes*) is a plant that can be used in phytoremediation (Fauzi 2011). Water hyacinth has been known to have cellulose up to 72.63% and it is useful for absorption of certain ingredients. The results of the Tosepu study in 2012 showed that water hyacinth can reduce TSS levels by 25%, whereas in this study the highest reduction in TSS levels was a variation of the combination of 500 g water hyacinth biomass which could reduce TSS levels up to 79.9%.

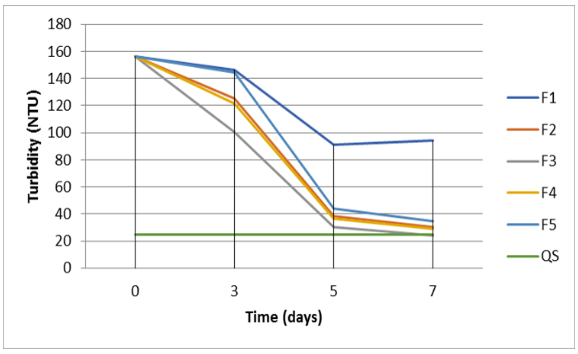

Fig. 1. Turbidity Parameter (NTU).

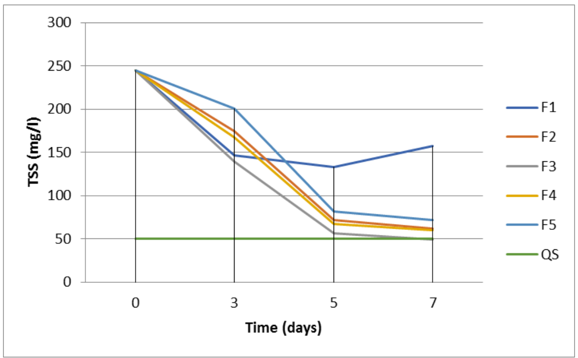

Fig. 2. TSS level diagram of the phytoremediation process.

Variation F3 with water hyacinth biomass 500g is the variant with the largest TSS retention. On the 7th day, the TSS value for the F3 variant was below the Quality Standard (QS), while the other variants were still above the quality standard. This is also shown by Fig. 2 which shows the effectiveness of reducing TSS levels by the phytoremediation method using water hyacinth based on variations in biomass. The greatest efficiency occurred on the third day on the F3 variant (500g water hyacinth biomass). The variation of water hyacinth influences the decrease in Total Suspended Solid. It has the meaning that the effect of water hyacinth variation on the decrease in TSS concentration is 79.7%. The remaining 25.9% is influenced by other factors such as detention time, plant age and other factors.

Total Dissolved Solids (TDS)

Fig. 3 showed the levels of TDS in the phytoremediation process with water hyacinth plants. The results of the study showed that the TDS levels of all treatments were below the established quality standards. There was a difference between F1 variants without water hyacinth with other variants that contain water hyacinth plants. F1 variants have the highest TDS compared to other variants that have water hyacinth plants. This shows that the presence of water hyacinth affects the water TDS parameters.

Comparison between the variation of water hyacinth biomass in variants F2, F3, F4 and F5 shows that the F3 variant with 500g water hyacinth biomass has the lowest TDS content after 7 days of treatment. This shows that there is an influence of water hyacinth biomass on water TDS. TDS is usually caused by inorganic substances in the form of ions commonly found in waters, such as sodium (Na), Calcium (Ca), Magnesium (Mg), Bicarbonate (HCO_3), Sulfate (SO_4), Chloride (Cl), Iron ions (Fe), Strontium (Sr), Potassium (K), Carbonate (CO_3), Nitrate (NO_3), Fluoride (F), Boron (B), Silica (SiO_2) (Effendi, 2003).

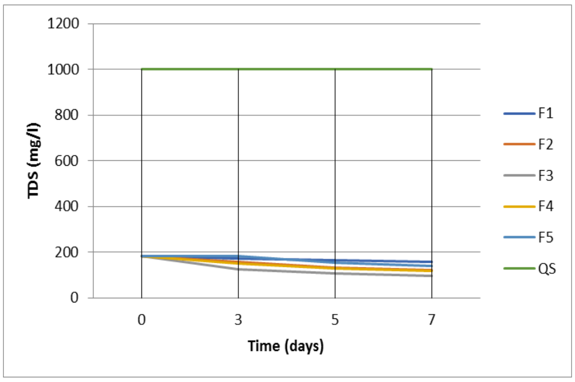

Fig. 3. TDS (mg/L) level diagram.

pH

The results of pH measurements toward before and after treatment show that all variants of treatment in phytoremediation experiments are still within the quality standard (QS). During the 7-days phytoremediation trial period, there was no significant change in pH. The pH value greatly affects the biochemical processes of the waters (Effendi, 2003). Fig. 4 shows the pH value in phytoremediation experiments, the range of pH values from 7.0 to 7.5 supports the growth of water hyacinth better than those that grow at low or high pH. (Widyanto, 1981). The growth of water hyacinth will support the phytoremediation process of diamond mines wastewater.

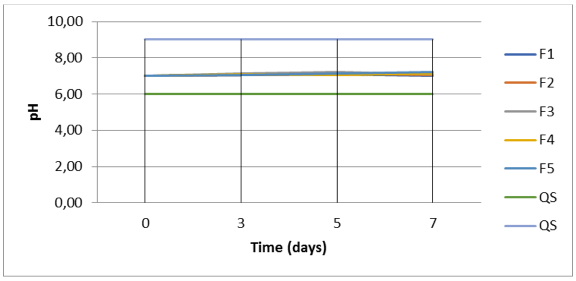

Fig. 4. The value of pH parameter.

Dissolved Oxygen (DO)

Fig. 5 shows the results of measurement of DO parameters in phytoremediation experiments for 7 days. DO values tend to increase from day to day but it still does not meet the specified quality standards (QS). The minimum DO value to be used as clean water is 6mg/L. The level of dissolved oxygen in water experiences daily fluctuations depending on the mixing and turbulence of water masses, photosynthetic activity, respiration and pollutants in water (Effendi, 2003). The process of degradation of pollutants in water, especially organic pollutants requires dissolved oxygen so that in this experiment the value of dissolved oxygen is still below the quality standard.

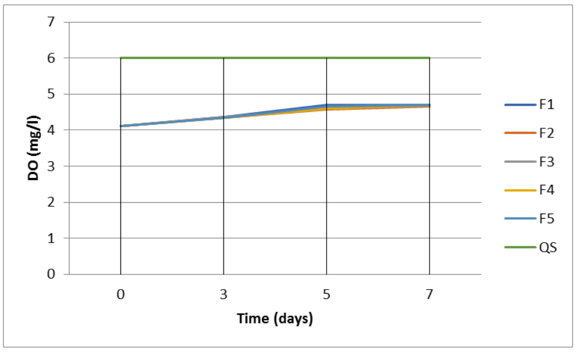

Fig. 5. DO Parameter.

Biochemical Oxygen Demand (BOD)

Based on Fig. 6, it is known that the greatest decrease of BOD levels in the F3 variant (variation in the combination of 500g water hyacinth biomass) after 7 days of BOD treatment was 3.21mg / l. However, the BOD value is still above the established Quality Standards (QS). The process of reducing BOD levels is aided by the activity of microorganisms associated with water hyacinth plants. These microorganisms degrade organic compounds in water. Microorganisms attached on water hyacinth roots is 1.5 x 10^6 to 2.5 x 10^6 CFU/g (Loan *et al.*, 2014). Oxygen required for bacterial oxidation in the lagoons is provided by atmospheric diffusion, production by algal photosynthesis, and release from water hyacinth roots. The first two processes transfer oxygen directly into the water column, while oxygen released by the plant roots is captured by the attached bacterial biofilm (Sooknah, 2000).

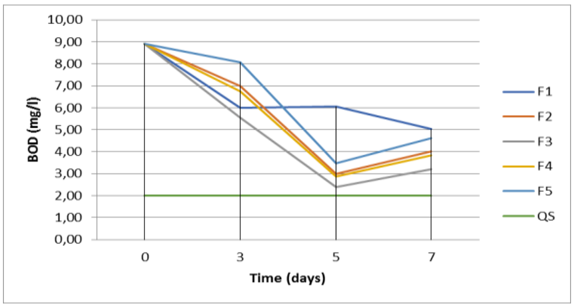

Fig. 6. BOD level diagram.

Chemical Oxygen Demand (COD)

The results of the study shown in Fig. 7 showed that the lowest COD level in the F5 variant (Variation of water hyacinth biomass 500g) is 6.54mg / l, this value is already below the established quality standard (QS). The biggest COD reduction efficiency is 70.3%. The results of this study are in line with the results of Gao's study (2015) which within 18 days of water hyacinth in reducing COD parameters reached 66-75% (Gao *et al.*, 2015). This is also influenced by the structure of the water hyacinth which supports to influence the ability to absorb organic materials and other substances in water. According to Penfound and Earle, water hyacinth (Eichhornia crassipes) has a large stomata hole, which is twice as large as most other plants and the distance between stomata is eight times the size of the hole (Rahmaningsih, 2006).

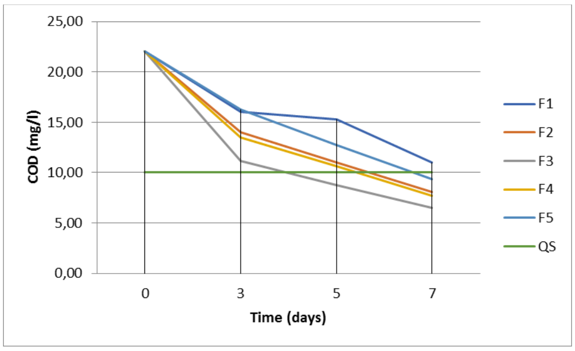

Fig. 7. COD level diagram.

Ammoniacal nitrogen (NH3-N)

Fig. 8 showed NH3-N levels in diamond water waste. Variation F3 (variation combination of 500g water hyacinth biomass) has NH3-N levels of 0.63mg/l. Ammoniacal nitrogen removal in diamond mines wastewater needs to be done because (i) depletion of oxygen levels in the water stream due to the existence of Ammoniacal nitrogen, ii) excessive Ammoniacal nitrogen contributes to toxicity towards biological life in water bodies, and iii) formation of chloramine by reaction between Ammoniacal nitrogen and chlorine which can interfere with disinfection (Ting, *et al.*, 2018). In the phytoremediation process, it is recommended to reduce Ammoniacal nitrogen levels in wastewater. Water hyacinth plants like other plants in wetlands play a significant role to remove ammoniacal nitrogen content in wastewater through both direct (i.e. plant uptake) and indirect (microbial activity at rhizosphere) ways (Ting, *et al.*, 2018).

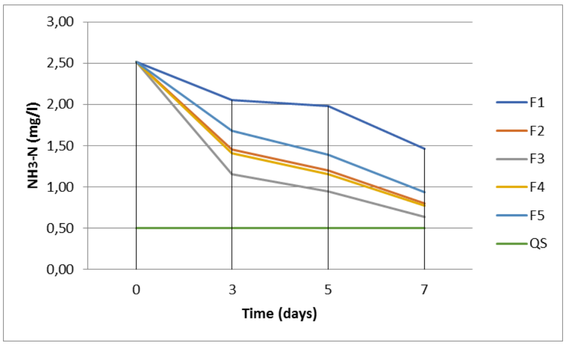

Fig 8. Graph of NH3-N levels.

Nitrite (NO_2) and Nitrate (NO_3)

Based on Fig 9 and Fig 10 can be known the lowest levels of nitrite and nitrate in the F3 trial variant (variation of the combination of water hyacinth (*Eichhornia crassipes*) biomass 500g) that is the amount of 0.16mg/l and 5.46mg/l. However, the nitrite level is still above the required quality standard while the nitrate level has fulfilled the quality standard. High concentrations (>1-2mg/L) of nitrate or nitrite in surface waters or groundwater generally indicate agricultural contamination from fertilizers and manure seepage. The result of this research is similar with result of the research done by Rahmaningsih (2006) and Wenwei *et al.*, (2016) that indicate the nitrate in agriculture eutrophic wastewater can be utilized by water hyacinth as nitrogen nutrition and can promote plant growth by using soluble sugar and amide to synthesis amino acids and protein.

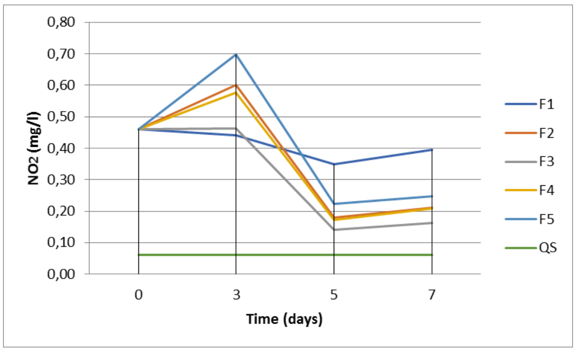

Fig 9. Graph of NO_2 level.

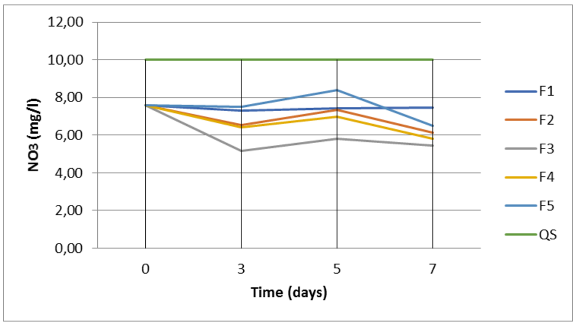

Fig 10. Graph of NO_3 level.

Iron (Fe)

E. crassipes absorbs heavy metal especially from roots and is only transferred 6-25% of the shoots. In the previous research, can be known that mostly *E. Crassipes* roots are covered by reddish or brownish layer. That layer contains mucus, particulates such as clay and various microorganisms (including bacteria, protozoa and diatoms). Water hyacinth roots not only provide a surface for particulate filtration and provide habitat for microbes to grow. Microbes have the same ability as plants in tolerating and resisting heavy metals. The mechanism resistance metal by bacteria that popular is cyanobacteria which produce metallothionein. Based on the Fig. 11, we can know the level of iron after the process used phytoremediation method the higher variation biomass on the days 3rd until 7th is F5 (Variation of water hyacinth biomass 2000g) amount of 0,99mg/l. The lowest level after on the 3rd until 7th is F3 (variation of water hyacinth biomass 500g) amount of 0,68mg/l.

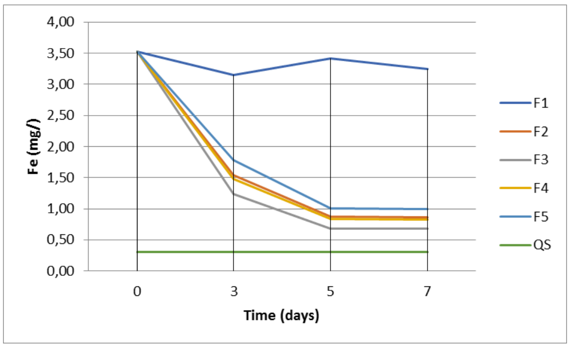

Fig 11. Graph of Iron Concentration.

Manganese (Mn)

Water hyacinth has the ability to reduce the level of heavy metal in the water of former diamond mine excavation. The content and stem structure in the water hyacinth could absorb heavy metal of manganese in the water. The absorbability is caused by protoplasm and *Eichornia crassipes* system that there is a lot of a large amount of space (Stephany, 2013).

In this research, the highest decrease of the heavy metal level of Mn by used water hyacinth is on (Fig. 12) in the days 5th up to 7th on the 500g biomass which is 87,7%, and the lowest decrease is on 1000g biomass which is 80,3%. Meanwhile, the decrease of heavy metal Fe used water hyacinth the highest on the day 5th.

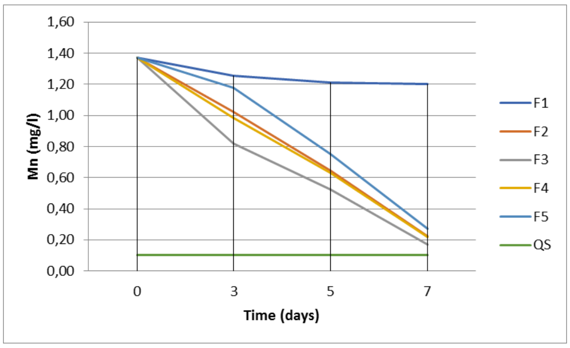

Fig 11. Graph of Mn Concentration.

Based on the graphic Fig. 12 , it can be known that the level of manganese after the process used phytoremediation method the highest variation biomass on the days 3rd up to 7th is F5 (Variation water hyacinth biomass 2000g) amount 0,27mg/l. The lowest level after on the days 3rd up to 7th is F3 (Variation of combination water hyacinth biomass 500g) amount 0,17mg/l.

Index Value of Water Pollution by Used Phytoremediation Method

The analysis result of the research shows that Index of Pollution before and after phytoremediation process, such as Index Pollution amount 5,31, while IP on days 3rd up to 7th the lowest is on the treatment F3 (Variation of combination water hyacinth biomass 500g) in days 3rd amount 4,33, day 5th amount 3,44, and day 7th amount 2,41. Water hyacinth (*Eichhornia crassipes)* showed the satisfactory result as a phytoremediation agent has a very significant decrease in organic material on the 7th (seventh) because water hyacinth has a supportive structure to influence the ability to absorb organic materials and other substances in the water.

The effectiveness phytoremediation process for decrease the pollution level could be seen from calculating the effectiveness decrease of IP (Table 3). Each of the treatment increased effectiveness on the day 3rd up to 7th, except on the F1 (control) decreased the percentage of effectiveness. The effectiveness IP on the day 3rd until 7th the biggest is in the treatment of F3 (variation of water hyacinth biomass 500g), that is on the day 3rd is 18.33%, the day 5th is 20.69% and the day 7th is 29.98%. The results of filtration experiments showed that the effectiveness of pollutant index values decreased from 22.88% to 29.98% with a peak reduction in average on day 5th. The variant variability with the greatest effectiveness was F3 with water hyacinth biomass of 500g.

Table 3. The Effectiveness Value on All Variant of The Phytoremediation Study.

No	Variation	Effectiveness value (%)
1	F3 : Weight variation of water hyacinth biomass 500 g	54,6
2	F4 : Weight variation of water hyacinth biomass 750 g	46,5
3	F2 : Weight variation of water hyacinth biomass 250 g	46
4	F5 : Weight variation of water hyacinth biomass 2000 g	40
5	F1 Weight variation of water hyacinth biomass 0 g	6,8

Conclusion

The ability of the phytoremediation method using water hyacinth in reducing levels of pollutants in the pond water of the former mining excavated diamonds in all variations can reduce levels of pollutants by more than 50% and the highest variation is the variation of the combination of water hyacinth biomass 500g.

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