J E M T
Journal of Earth and Marine Technology
homepage URL: ejurnal.itats.ac.id/jemt

The Effect of Phytoremediation on The Reduction of Mercury-Contaminated Water from Gold Processing Using Water Kale (*Ipomoea Aquatica Forsk*)

Fitra Kurniawan *[1], Tedy Agung Cahyadi[1], Rika Ernawati[1]
[1] Department of Mining Engineering, UPN Veteran Yogyakarta, Indonesia
*e-mail: tedyagungc@upnyk.ac.id

Info article
Receive:
Dec 27, 2023
Revised:
Feb 5, 2024
Accepted:
Mar 27, 2024
Published:
Mar 31, 2024

Keywords:
Phytoremediation, mercury-contaminated water, water spinach, liquid NPK fertilizer

Abstract

Gold ore processing is carried out by amalgamation techniques where mercury (Hg) is used as a medium to bind gold which results in water pollution around the processing area, so it is necessary to remediate water. One way to manage mercury-contaminated water is phytoremediation the use of water kale (*ipomoea aquatica forsk*) to help the phytoremediation process, ingredients are needed that can help the growth of water kale in increasing the absorption of Hg concentrations, namely the addition of liquid NPK fertilizer. This study aims to analyze water kale without liquid NPK fertilizer and use liquid NPK fertilizer against water kale in reducing the concentration of Hg, pH, and TSS metals in water. This study used an experimental method with an experimental box (container) consisting of 4 treatments, then an *Analysis of Variance* (ANOVA) test of 5%, and the *Duncan Multiple Rang Test* was carried out. The results showed that liquid NPK fertilizer influenced reducing the concentration of Hg, pH, and TSS in water. Based on the results of experiments using liquid NPK fertilizer, the best treatment results were obtained in mercury absorption by water kale and reducing Hg concentration in water, namely treatment D (contaminated water + water kale + liquid NPK fertilizer) on the 14th day, as evidenced by a decrease in Hg concentration in water by 0.56 mg / l to 0.00486 mg / l, pH 10.1 to 6.86 and TSS 1695 mg / l to 1 mg / l and an increase in nitrate levels, Phosphate and potassium in water can accelerate absorption by water kale.

1. Introduction

The use of mercury in the gold processing process has the potential to have an impact on environmental damage and the health of living things. Mercury in the environment comes from several sources, namely geogenic and anthropogenic, and has toxicity properties [1]. Gold mining activities using amalgamation technology cause significant mercury contamination in water and soil, and the problem of mercury pollution is very serious [2]. According to some studies, mercury-contaminated water can cause serious threats to water supplies that will affect the quality of agriculture [3]; [4].

This research was located in gold mining in Kalirejo Village, Kokap District, Kulon Progo Regency, Yogyakarta Special Region Province. Gold processing activities are carried out using an amalgamation technique where mercury (Hg) is used as a material to bind gold which produces a waste substance, namely *tailings*. Mercury pollution occurs during the processing process, the remaining tailings *are scattered and when the condition of the reservoir is full, so that* the tailings overflow and flow into the river, especially if there is rain, mercury contamination occurs in the surrounding environment. Heavy metal elements in *tailings* ponds can react physically and chemically such as diffusion, dispersion, desorption, and dissociation to form contamination [5].

The results of initial testing of wastewater *(tailings*) in the pond resulting from gold processing in the study area, showed a very high Hg concentration value of 560 µg / l or about 0.56 mg / l, pH (*Power of Hydrogen*) 10.1 and TSS (*Total Suspended Solids*) of 1695 mg / l. These contaminants can move out of *the tailings* storage pondcan seep into the ground and can go to rivers until carried tens of kilometers [6]. This is very dangerous for living things around the river, so it is necessary to remediate the water.

Various ways have been researched to stabilize contaminated water, in a more cost-effective and environmentally friendly way.

Phytoremediation is a technology that uses various plants to stabilize, remove, or destroy contaminants in the environment. In this study, the phytoremediation method used water kale plants (*ipomoea aquatica forsk*) with a *batch* system. A *batch system is* a process in which all contaminated water is brought together at the beginning of the process and the product is removed at the end of the process. The *batch system* will provide an overview of the ability of adsorption by inserting plants with stagnant water that remains in constant quantity and observing changes in quality at certain intervals [7]. One plant that can absorb heavy metal content in high enough quantities is water kale [8]. The added fertilizer can be in the form of inorganic fertilizer, namely liquid NPK fertilizer. The addition of liquid NPK fertilizer to water kale (*ipomoea aquatica forsk*) can increase fertility at optimal doses, nitrate, phosphate, and potassium nutrients are essential nutrients for plants. Increasing the dose of nitrogen fertilization in soil and water can directly increase protein levels and plant growth, but the fulfillment of nitrate elements alone without phosphate and potassium will cause plants to fall off easily, be sensitive to pest attacks, and decrease production quality [9].

Research on phytoremediation using water kale has been numerous, but research with the addition of liquid NPK fertilizer to help the phytoremediation process of water contaminated with mercury metal has never been done before. Therefore, the purpose of this study was to determine the effect of liquid NPK fertilizer on water kale (*ipomoea aquatica forsk*) in reducing the concentration of Hg, pH, and TSS in water. In the analysis, it is expected that there are results that prove water kale with the addition of liquid NPK fertilizer is capable of managing mercury-contaminated water.

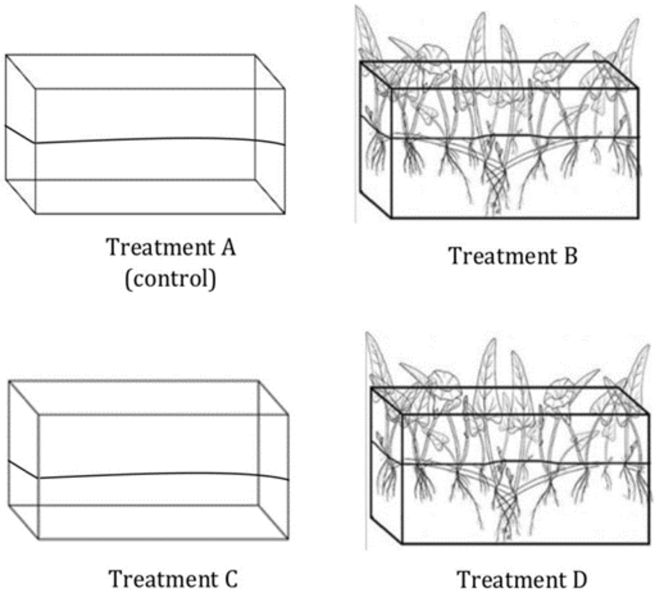
2. Methodology

The sample used here is mercury-contaminated water from a small-scale gold processing, Kulon Progo, with coordinates S 07° 50' 01.5" E 110° 03' 45.8. The tools and materials used in the study are:
1) Container container as a medium for test box.
2) Water Kale (Ipomoea aquatica forsk)
3) Water as a growing medium;
4) Liquid NPK fertilizer as a nutrient for water kale.

The container used for artificial ponds has a size of 36 cm x 27 cm x 17cm. The treatment in this experiment was a combination of water kale and liquid NPK fertilizer as presented in Table 1.

Table 1. Description of the treatment provided to the trial pool

Treatment	Description
A	Contaminated water (7 liters)
B	Animated water (7 liters) + water kale (7 sticks)
C	Contaminated water (7 liters) + liquid NPK fertilizer (70 mg)
D	Animated water (7 liters) + water kale (7 sticks) + liquid NPK fertilizer (70 mg)



Notes:
Treatment A : Contaminated water
Treatment B : Contaminated water + Ipomoea aquatica forsk
Treatment C : Contaminated water + liquid NPK fertilizer
Treatment D : Contaminated water + Ipomoea aquatica forsk + liquid NPK fertilizer

Figure 1. Test box scheme in each treatment

Samples of each treatment were tested for levels of Hg, pH, TSS, No_3, P, and K in the laboratory. The parameter value is measured every seven days for 14 days. Table 2 shows the methods of analyzing water samples used in the study.

Table 2. Water sample analysis methods

Sample	Parameter	Analysis Methods	Laboratory
Water	Hg (mg/l)	*Mercury Analyzer*	LPPT UGM
	Ph	SNI 06-6989.11-2019	BBTKLPP Yogayakarta
	TSS (mg/l)	*In House Method*	BBTKLPP Yogyakarta
	Nitrate (mg/l)	APHA 2017, *Section* 4500-NO3B	BBTKLPP Yogyakarta
	Phosphate (mg/l)	APHA 2017, *Section* 4500-P-D	BBTKLPP Yogyakarta
	Sodium (mg/l)	APHA 2017, *Section* 3500-K	BBTKLPP Yogyakarta

2.1 Work Procedures and Preparatory Stage

At this stage, the preparation of tools and materials used in research is carried out.

2.2 Growing Water Water Water (Ipomoea aquatica forsk)

The water kale used in this study was first analyzed by analyzing mercury analysis to determine the presence of Hg metal in water kale. After that water kale is taken, then the best water kale is chosen. Then cleaned up. After that, it is done to uniform the age of water kale planted in the area where it grows. After 20 days of kale life, water kale is ready to be treated.

2.3 Stages of Implementation of Behavior
Water kale planted for 20 days is taken and cleaned the roots, then water kale is planted into a container box that has been given equates of 1000 ml, Hg, and 70 mg / l NPK liquid as a growing medium for water kale. To keep the kale growing upright, the kale stem is surrounded by rock wool. The number of kale for each container box is 7 sticks and water is 7 liters/container box. Each container box is labeled. To ensure that water kale can grow well and in water quality conditions, water kale and water are placed in a place that gets enough sunlight, namely in a simple greenhouse.

2.4 Observations
Observations were made to see changes in water concentration that occurred in each treatment. In the first 7 days of the container box, TSS decreased when compared to the initial test (control) and experienced a significant decrease on day 14. Maintenance is carried out to avoid pest attacks that arise during the experiment until it is complete so that pests do not interfere with the growth of water kale in absorbing heavy metals and monitoring is carried out 3 times a day at 07.00, 12.00 and 17.00 WIB.

2.5 Sample Analysis Stage
After the treatment water was taken in each experimental box on days 0, 7, and 14 using an HDPE bottle. A water sample is taken 250 ml with a measuring flask, filter with filter paper with a pore of 0.45 µm with a Buchner funnel using a vacuum pump. Then Mercury measurement with an Automatic Mercury Analyzer. Make a working solution of mercury metal with a concentration of 0.05 µg/L; 0.1 µg/L; 0.2 µg/L; 0.4 µg/L; 0.8 mg / L; 1.6 µg/L; 3.2 mg / L, by pickpocketing 0.05 ml each; 0.1 ml; 0.2 ml; 0.4 ml; 0.8 ml; 1.6 ml; 3.2 ml of 10 µg/L raw solution, put in a 10 ml measuring flask, correct until the mark with aquades, put in the vial, place the vial on the Auto Sample Automatic Mercury Analyzer instrument and take measurements according to the SOP of tool operation. Take a sample that has been filtered, and put it in a tube/vial. Place the vial on the Auto Sample Automatic Mercury Analyzer instrument and measure by the SOP for tool operation (LPPT UGM).

3. Results and discussion
This study compared water kale in reducing the concentration of Hg, pH, and TSS in water without liquid NPK fertilizer and tested water quality in water treatment contaminated with mercury metal (Hg), pH (power of hydrogen), and TSS (Total Suspended Solids). The following treatment of water contaminated with Hg, pH, and TSS metals is:

3.1 Changes in mercury (Hg) in water
The test results on Hg heavy metal test parameters conducted on days 0, 7 and 14 showed a decrease in Hg concentration in water. Figure 2 presents the change in Hg concentration in water.

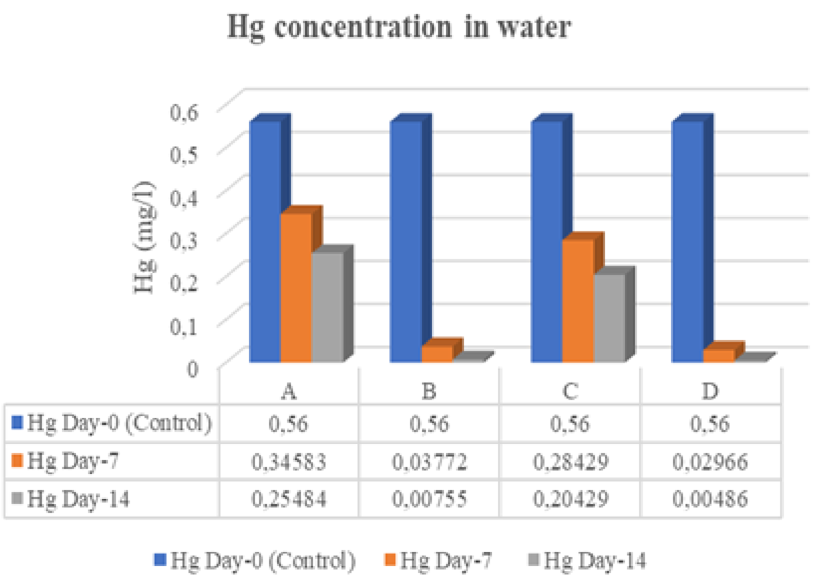


Figure 2. Changes in Hg Concentration in Water

The results of the analysis showed the concentration of Hg metal in water without liquid NPK fertilizer. On day 0 (initial test) results were obtained on water of 0.56 mg / l which will be used as a reference for comparison of treatment A (contaminated water) and B (contaminated water + water kale). Day 7 treatment without liquid NPK fertilizer, namely treatment A (contaminated water) decreased Hg concentration from 0.56 to 0.34583 mg / l and 0.25484 mg / l on day 14, the decrease was influenced by chemical transformation or some microorganisms in water can change the form of mercury such as merculophilic bacteria can change organic mercury (*methylmercury*) being a less toxic inorganic form, then methyl mercury can be taken up by living organisms or subjected to volatilization into the atmosphere. Treatment B (contaminated water + water kale) decreased Hg higher than treatment A from 0.56 to 0.03772, and 0.00755 mg/l day 14. The decrease in concentration in treatment B is influenced by the absorption of water kale which can reduce the concentration of Hg in water and treatment time and volatilize into the atmosphere through leaves in the form of water vapor (phytovolatization). Then the analysis results showed the concentration of Hg metal in water without liquid NPK fertilizer.

On day 0 (initial test) results were obtained on water of 0.56 mg / l which will be used as a reference for comparison of treatment A (contaminated water) and B (contaminated water + water kale). Day 7 treatment without liquid NPK fertilizer, namely treatment A (contaminated water) decreased Hg concentration from 0.56 to 0.34583 mg / l and 0.25484 mg / l on day 14, the decrease was influenced by chemical transformation or some microorganisms in the water can change the form of mercury such as merculophilic bacteria can change organic mercury into a less toxic inorganic form, Then methyl mercury can be taken up by living organisms or subjected to volatilization into the atmosphere. Treatment B (contaminated water + water kale) decreased Hg higher than treatment A from 0.56 to 0.03772, and 0.00755 mg/l day 14. The decrease in concentration in treatment B is influenced by the use of water kale can reduce the Hg concentration in water and treatment time and volatilize into the atmosphere through leaves in the form of water vapor. This is in line with the research of Suhar et al [10], that water kale can reduce mercury content in contaminated water. Research Sinunglinga, et al [11] also stated, that the use of water kale water can potentially reduce the bioavailability and leaching of heavy metals and organic pollutants in water through adsorption. Based on the results of the ANOVA test, it can be concluded that the variable water kale without liquid NPK fertilizer and using fertilizer influences treatment factors, and day factors, found differences in Hg heavy metal concentrations in water in each measurement.

3.2 Changes in pH (Power of Hydrogen) in water

Based on the results of water pH testing shows that changes can be seen in Figure 3.

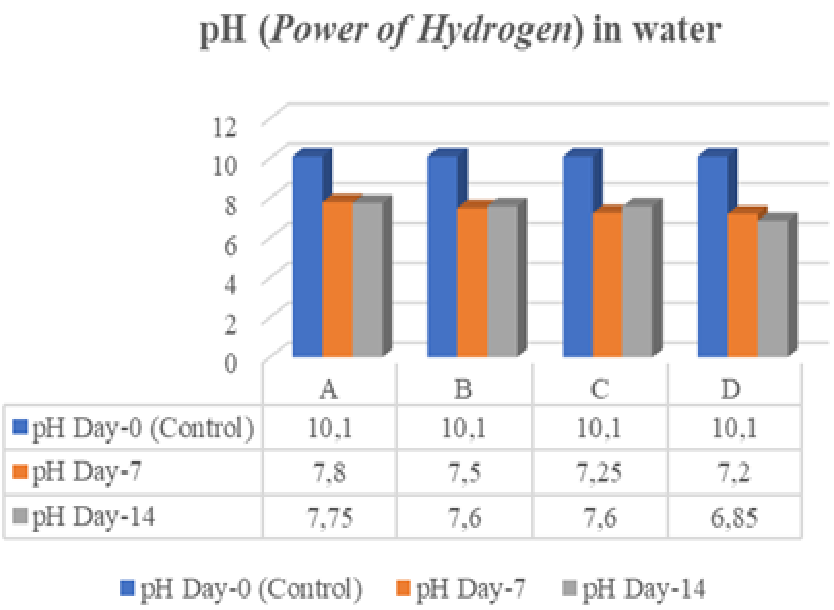


Figure 3. Changes in pH (Power of Hydrogen) in water

The results of the analysis showed that on day 0 (initial test) treatment A and B had a water pH of 10.1 alkaline, caused by gold processing wastewater pollution which can cause an increase in water pH to alkaline. The test results decreased the pH of the water on the 7th day of treatment A (contaminated water) from 10.1 to 7.8 and 7.75 on the 14th day, which was influenced by the absorption of carbon dioxide (CO_2) or water in the atmosphere can naturally interact with carbon dioxide from the air to form carbonic acid (H_2CO_3), which then increases the acidity of the water. This process is called carbon dioxide absorption, when carbon dioxide is dissolved in water, it will form carbonic acid which can lower the pH of the water. Treatment B (contaminated water + water kale) decreased from 10.1 to 7.5 and 7.76 on the 14th day, the decrease in water pH was influenced by organic compounds produced by water kale can react with water and release organic acids. The results of this study stated that the more organic acids are leaped into the water by water kale, the pH (*Power of Hydrogen*) in the water decreases (neutral). Then the analysis results showed that on day 0 (initial test) treatment C and D had a water pH of 10.1 alkaline, caused by gold processing wastewater pollution which can cause an increase in water pH to alkaline. The test results decreased the pH of the water on the 7th day of treatment C (contaminated water + liquid NPK fertilizer) from 10.1 to 7.25 and 7.6 on the 14th day, which was influenced by the absorption of carbon dioxide (CO_2) or water in the atmosphere can naturally interact with carbon dioxide from the air to form carbonic acid (H_2CO_3), which then increases the acidity of the water. This process is called carbon dioxide absorption, when carbon dioxide is dissolved in water, it will form carbonic acid which can lower the pH of the water. Treatment D (contaminated water + water kale + liquid NPK fertilizer) decreased from 10.1 to 7.2 and 6.86 on the 14th day, the decrease in water pH was influenced by organic compounds produced by water kale can react with water and release organic acids. The results of this study stated that the more organic acids are leaped into the water by water kale, the pH (*Power of Hydrogen*) in the water decreases. Based on the results of the ANOVA test, it can be concluded that the variable water kale without liquid NPK fertilizer has an influence on the day treatment and there is a difference in the concentration of heavy metals pH (*Power of Hydrogen*) in the water in each measurement.

3.3 Changes TSS (Total Suspended Solids) in water

Based on the test results showing very significant changes in TSS (*Total Suspended Solids*) in treatment A, B, C and D on days 7 and 14 can be seen in Figure 4.

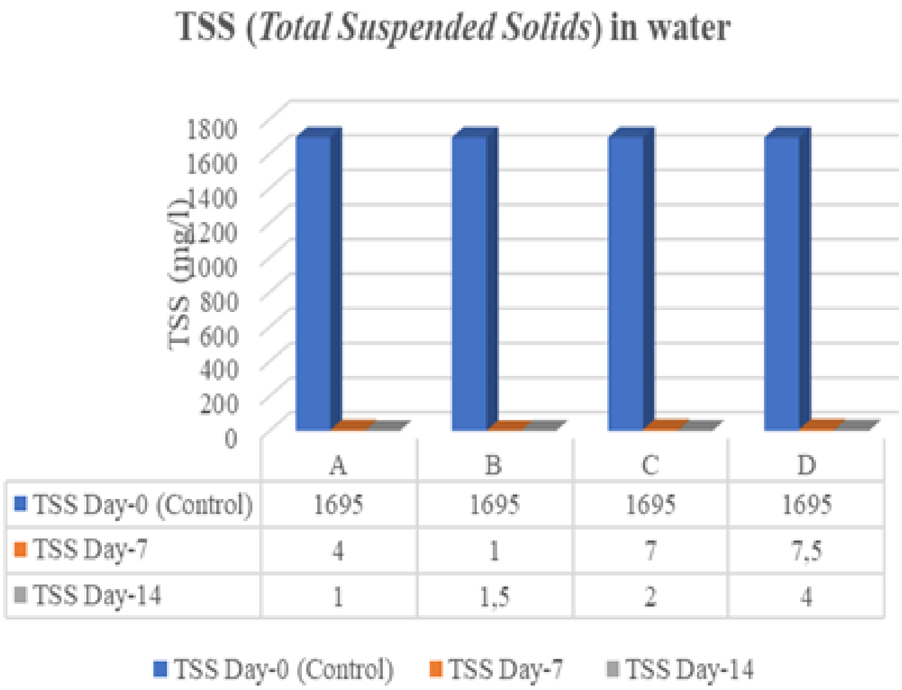
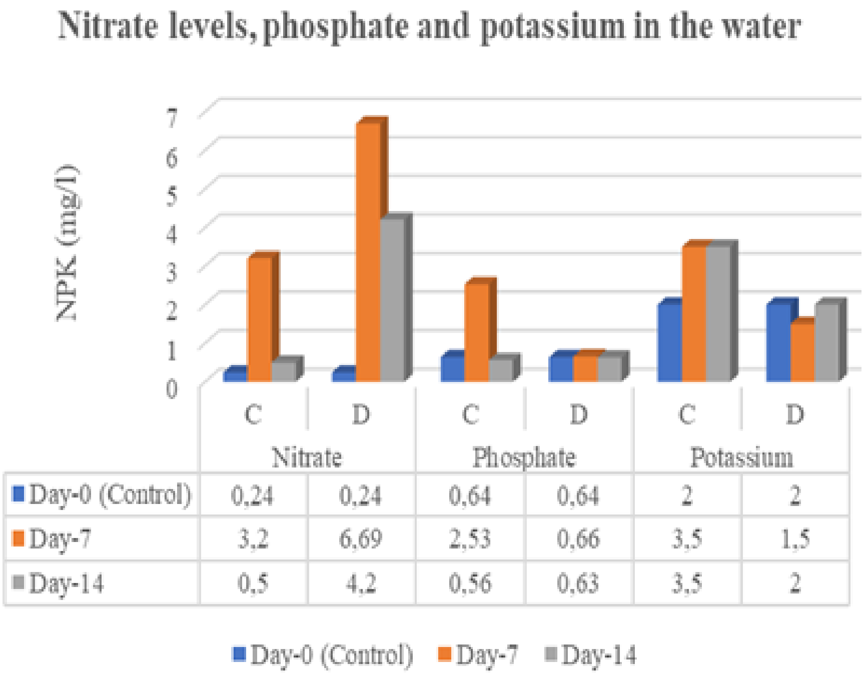


Figure 4. Changes in TSS (Total Suspended Solids) in water



	Nitrate C	Nitrate D	Phosphate C	Phosphate D	Potassium C	Potassium D
Day-0 (Control)	0,24	0,24	0,64	0,64	2	2
Day-7	3,2	6,69	2,53	0,66	3,5	1,5
Day-14	0,5	4,2	0,56	0,63	3,5	2

Figure 5. Changes in nitrate, phosphate, and potassium levels in water

The results of the analysis showed a decrease in TTS (*Total Suspended Solids*) in each treatment decreased significantly. Day 0 TSS testing (initial test) on very high water of 1695 mg/l, which comes from gold processing waste. Treatment A (contaminated water) showed a decrease from 1695 mg/l to 4 mg/l on day 7 and 1 mg/l on day 14, which was affected by precipitation in water or its weight exceeding buoyancy and thus settling naturally. The *batch* system affects the deposition process on particles/solids leading to a decrease in TSS in water. In treatment B (contaminated water + water kale) day 7 experienced a significant decrease compared to treatment A from 1695 mg / l to 1 mg / l and 1.5 mg / l on day 14. The results of the analysis showed a decrease in TTS (*Total Suspended Solids*) in each treatment decreased significantly. Then the TSS test day 0 (initial test) on very high water of 1695 mg / l, which comes from gold processing waste. In treatment C (contaminated water + liquid NPK fertilizer) day 7 showed a decrease from 1695 mg / l to 7 mg / l and 2 mg / l on day 14, which is affected by precipitation in water that can settle to the bottom or weigh more than buoyancy so that it settles naturally. The use of a *batch system* affects the deposition process of particles leading to a decrease in TSS in water. In treatment D (contaminated water + water spinach + liquid NPK fertilizer) day 7 experienced a significant decrease compared to treatment A from 1695 mg / l to 2 mg / l and 4 mg / l on day 14. Based on the results of the ANOVA test, it can be concluded that the variable water kale using liquid NPK fertilizer has an influence on the day factor, and treatment factor and found a difference in TSS in water in each measurement.

3.4 Changes in nitrate, phosphate, and potassium levels in water

NPK testing on water has increased levels of nitrate, phosphate, and potassium. Changes in NO3, PO4, and K levels can be seen in Figure 5.

The results of the NPK test analysis on water have increased levels of nitrate, phosphate, and potassium. The initial test results of nitrate, phosphate, and potassium content in water amounted to NO_3 (0.24 mg / l), PO4 (0.64 mg / l), and K (2 mg / l) derived from gold processing, had low levels of nitrate, phosphate, and potassium. Based on the results of NPK testing water has increased levels of NO 3, PO4, and K. The nitrate content has changed in treatment C (contaminated water + liquid NPK fertilizer) from 0.24 mg / l to 3.20 mg / l and 0.50 mg / l on day 14, nitrate levels have increased due to the addition of liquid NPK fertilizer on day 0 with a dose of 70 mg/container and decreased on day 14 which was influenced by the absorption of water kale. The phosphate content decreased from 0.64 to 2.35 mg / l and 0.56 mg / l on the 14th day, which had been adsorbed by water kale. The potassium content increased from 2 mg / l to 3.51 mg / l and 2 mg / l, increased on the 7th day due to the addition of liquid NPK fertilizer to the treatment at a dose of 70 mg/container and decreased on the 14th day which had been adsorbed by water kale. In treatment D (contaminated water + water kale + liquid NPK fertilizer) nitrate value decreased on day 7 by 6.69 mg / l to 4.20 mg / l, content from 0.64 mg / l to 0.63 mg / l on day 14 after addition, while potassium content showed an increase in value from 2 mg / l to 1.50 mg / l and increased by 2 mg / l on day 14, which is influenced by biological activity. If there are living organisms involved in the experiment, they can affect the concentration of potassium in water through metabolic processes or potassium absorption. Based on the results of the ANOVA test, it can be concluded that the variable water kale, the addition of liquid NPK fertilizer has no effect and there is a difference in the concentration of heavy metal Hg in water in each measurement.

The potential of Water Kale (Ipomoea aquatica Forsk) in phytoremediation for mitigating mercury contamination in water sources, particularly from gold processing, presents a viable solution to a significant environmental challenge. This discussion integrates findings from various studies to underscore the effectiveness and mechanisms of Water Kale in mercury phytoremediation.

Water Kale's ability to absorb and accumulate heavy metals from contaminated environments is well-documented. Mello et al. (2020) highlight the role of endophytic bacteria in enhancing the phytoremediation capacity of plants through increased bioaccumulation and volatilization of mercury [12]. This interaction suggests that Water Kale could be further optimized for mercury removal by manipulating its microbial environment. Research conducted by Rahmawati et al. (2021) explores the application of Water Kale in the phytoremediation of different pollutants, demonstrating its capacity to reduce hazardous elements in hospital wastewater [16]. This versatility in treating various contaminants suggests that Water Kale could be similarly effective in mercury-contaminated water from gold processing. Moreover, the practical applications of phytoremediation strategies are evident in the study by Putra et al. (2020), which provides technical guidance for reducing mercury levels in water affected by amalgamation processes in gold mining [13]. Their findings emphasize the need for localized treatment solutions, where Water Kale could be implemented as part of a broader integrated phytoremediation strategy.

Supporting the use of Water Kale in broader phytoremediation contexts, Tang et al. (2017) demonstrate its effectiveness in the co-remediation of cadmium and nitrate from contaminated soils [18]. Although this study focuses on soil rather than water, the demonstrated capacity for heavy metal uptake is pertinent to its potential applications in water systems. Lastly, Chen et al. (2010) explore the phytoremediation of chromium by Water Kale, noting the enhanced removal efficiency in the presence of chelating agents [20]. This finding suggests that similar methods could enhance mercury phytoremediation, potentially increasing the efficiency of Water Kale in removing mercury from water bodies.

4. Conclusion

The results of the study reveal that treatment without liquid NPK fertilizer, specifically Treatment B involving contaminated water and water kale, demonstrated the most effective reduction in mercury levels after 14 days. Mercury concentrations decreased significantly from 0.56 mg/L to 0.00755 mg/L. This treatment also improved water quality by reducing the pH from 10.1 to 7.6 and total suspended solids (TSS) from 1695 mg/L to a mere 1.5 mg/L. Conversely, Treatment D, which included the addition of liquid NPK fertilizer to the contaminated water and water kale, resulted in the lowest mercury concentration of 0.00486 mg/L. While this represents a substantial reduction, the presence of liquid NPK altered other water quality parameters less favorably, lowering the pH to 6.85 and TSS to 4 mg/L. Furthermore, the use of liquid NPK fertilizer significantly increased the levels of nitrates, phosphates, and potassium in the water—from 0.24 mg/L to 6.69 mg/L for nitrates, 0.64 mg/L to 2.53 mg/L for phosphates, and 2 mg/L to 3.50 mg/L for potassium, indicating a potential nutrient overload.

These findings suggest that while the addition of liquid NPK fertilizer can enhance certain aspects of water quality and reduce mercury concentrations slightly more than treatments without fertilizer, it also introduces higher levels of nutrients which could have downstream environmental impacts. Additionally, the increase in mercury concentration within the water kale itself when liquid NPK is used poses further considerations for the application of this treatment in phytoremediation strategies. Thus, while NPK fertilizer may improve phytoremediation efficiency, its impact on water chemistry and plant uptake of mercury warrants careful management and further study.

Reference:

[1] Marrugo, N. J., Durango, H. J., Pinedo, H. J., Olivero, Verbel, J., & Díez, S. 2015. Phytoremediation of mercury-contaminated soils by Jatropha curcas. Chemosphere, 127, 58-63

[2] Li, L., Flora, J. R., Caicedo, J. M., & Berge, N. D. 2015. Investigating the role of feedstock properties and process conditions on products formed during the hydrothermal carbonization of organics using regression techniques. Bioresource technology, 187, 263-274.

[3] Horvat, M., Nolde, N., Fajon, V., Jereb, V., Logar, M., Lojen, S., & Drobne, D. 2003. Total mercury, methylmercury and selenium in mercury polluted areas in the province Guizhou, China. Science of the Total Environment, 304(1-3), 231-256.

[4] Qiu, G., Feng, X., Wang, S., & Shang, L. 2005. Mercury and methylmercury in riparian soil, sediments, mine-waste calcines, and moss from abandoned Hg mines in east Guizhou province, southwestern China. Applied Geochemistry, 20(3), 627-638.

[5] Zhang, X., Yang, H., & Cui, Z. 2018. Evaluation And Analysis Of Soil Migration And Distribution Characteristics Of Heavy Metals In Iron Tailings. Journal Cleaner Production Vol. 172. USA.

[6] Bortnikova, S., Yurkevich, N., Bessonova, E., Karin, Y., & Saeva, O. 2013. The Combination Of Geoelectrical Measurements And Hydro-Geochemical Studies For The Evaluation Of Groundwater Pollution In Mining Tailings Areas. Threats To The Quality Of Groundwater Resources. Springer, Berlin.

[7] Ruthven, D. M. 1984. Principle of Adsorption & Adsorption Process. John Wiley & Sons: New York,124-141.

[8] Kurniawan, F., Cahyadi T, A., Ernawati, R., Bargawa, S, B &; Amri, A, N., 2022. Overview of phytomediation methods against heavy metal absorption in contaminated water using aquatic plant species. ReTII, 247-254.

[9] Rauf, A., Shepard B. M., Johnson, M., W. 2000. Leafminers in vegetables, ornamental plants and weeds in Indonesia: surveys of host crops, species composition and parasitoids. International Journal of Pest Management 46: 257-266.

[10] Suhar., Mistar, M. E., Hasmita, I., Zulfikar, M. T., 2022. The effectiveness of water kale plants (Ipomoea aquatic Forsk) as a medium to absorb mercury (Hg). Journal of the Shield, LPPM-Universiatas Serabi Mecca. pp 83-89.

[11] Sinulingga, N., Nurtjahja, K., Karim, A. 2015. phytoremediation of mercury metal (Hg) in water media by water kale (Ipomoea aquatica Forsk). Journal of Environmental Biology, Industry, Health. pp 75-81.

[12] I. Mello, S. Targanski, W. Pietro-Souza, F. Stachack, A. Terezo, and M. Soares, "Endophytic bacteria stimulate mercury phytoremediation by modulating its bioaccumulation and volatilization," *Ecotoxicology and Environmental Safety*, vol. 202, 110818, 2020. [Online]. Available: https://doi.org/10.1016/j.ecoenv.2020.110818

[13] D. Putra, A. Sungkowo, and E. Muryani, "Arahan Teknis Pengolahan Limbah Hasil Proses Amalgamasi untuk Menurunkan Kadar Merkuri di Desa Cihonje, Kecamatan Gumelar, Kabupaten Banyumas, Jawa Tengah," *JILK*, vol. 2, no. 1, pp. 13-23, 2020. [Online]. Available: https://doi.org/10.31315/JILK.V2I1.3286

[14] M. Gomes, R. Souza, V. Teles, and É. Mendes, "Phytoremediation of water contaminated with mercury using Typha domingensis in constructed wetland," *Chemosphere*, vol. 103, pp. 228-233, 2014. [Online]. Available: https://doi.org/10.1016/j.chemosphere.2013.11.071

[15] K. Oh, S. Takahi, S. Wedhastri, H. Sudarmawan, R. Rosariastuti, and I. Prijambada, "Phytoremediation of mercury contaminated soils in a small scale artisanal gold mining region of Indonesia," *International Journal of Biosciences*, vol. 3, 2015.

[16] S. Rahmawati, I. Said, N. Armiyanti, and N. Thamrin, "The use of water spinach plants (Ipomoea aquatica Forsk.) for phytoremediation of hospital waste," *Journal of Physics: Conference Series*, vol. 2126, 012026, 2021. [Online]. Available: https://doi.org/10.1088/1742-6596/2126/1/012026

[17] S. Al-Idrus, R. Rahmawati, S. Hadisaputra, and H. Qudratuddarsi, "Phytoremediation of Detergent Levels in Waters Using Water Plants: Eichornia crassipes, Ipomoea aquatica, Pistia

stratoites and Their Combinations," *EJCHEM*, vol. 1, no. 5, 2020. [Online]. Available: https://doi.org/10.24018/EJCHEM.2020.1.5.12
[18] L. Tang, W. Luo, W. Chen, Z. He, H. Gurajala, Y. Hamid, M. Deng, and X. Yang, "Field crops (Ipomoea aquatica Forsk. and Brassica chinensis L.) for phytoremediation of cadmium and nitrate co-contaminated soils via rotation with Sedum alfredii Hance," *Environmental Science and Pollution Research*, vol. 24, pp. 19293-19305, 2017. [Online]. Available: https://doi.org/10.1007/s11356-017-9146-7
[19] L. Chanu and A. Gupta, "Phytoremediation of lead using Ipomoea aquatica Forsk. in hydroponic solution," *Chemosphere*, vol. 156, pp. 407-411, 2016. [Online]. Available: https://doi.org/10.1016/j.chemosphere.2016.05.001
[20] J. Chen, K. Wang, H. Chen, C. Lu, L. Huang, H. Li, T. Peng, and S. Chang, "Phytoremediation of Cr(III) by Ipomonea aquatica (water spinach) from water in the presence of EDTA and chloride: effects of Cr speciation," *Bioresource Technology*, vol. 101, no. 9, pp. 3033-3039, 2010. [Online]. Available: https://doi.org/10.1016/j.biortech.2009.12.041
[21] J. Marrugo-Negrete, G. Enamorado-Montes, J. Durango-Hernández, J. Pinedo-Hernández, and S. Díez, "Removal of mercury from gold mine effluents using Limnocharis flava in constructed wetlands," *Chemosphere*, vol. 167, pp. 188-192, 2017. [Online]. Available: https://doi.org/10.1016/j.chemosphere.2016.09.130