Development concept of horizontal subsurface flow-rain garden systems: Potential of Purun Tikus (*Eleocharis dulcis*) plants to overcome heavy metals contamination (Fe and Mn) in stormwater runoff

Cite as: AIP Conference Proceedings **2493**, 030002 (2022); https://doi.org/10.1063/5.0109939
Published Online: 05 December 2022

Rijali Noor, Nova Annisa and Hafiizh Prasetia

Development Concept of Horizontal Subsurface Flow-Rain Garden Systems: Potential of Purun Tikus (*Eleocharis dulcis*) Plants to Overcome Heavy Metals Contamination (Fe and Mn) in Stormwater Runoff

Rijali Noor[1)], Nova Annisa [1)], and Hafiizh Prasetia[2, 3, 4, a)]

[1]*Department of Environmental Engineering, Faculty of Engineering, Lambung Mangkurat University, Banjarmasin, Indonesia, 70123*

[2]*Research Center for Chemistry-National Research and Innovation Agency (BRIN), Tangerang Selatan, Indonesia, 15314*

[3]*Research Center for Chemistry- Indonesian Institute of Sciences (LIPI), Tangerang Selatan, Indonesia, 15314*

[4]*Research Center for Policy and Management of Science, Technology, and Innovation, National Research and Innovation Agency (BRIN), Jakarta, Indonesia, 12710*

[a)] Corresponding author: hafiizh.prasetia@lipi.go.id

Abstract. The main problem of stormwater runoff is the change of quality of surface runoff due to the decrease of catchment areas and the accumulation of urban residues. As a result, the surface water flow will receive pollutants during its disposal, i.e., mud, logs, leaves, urban industrial waste, etc. This water contamination will vary according to the area in which it through. The types of impurities are physical, chemical, and bacteriological contamination. The development of the horizontal subsurface flow concept in a rain garden system utilizing Purun Tikus (*Eleocharis dulcis*) plants can be an alternative to resolve the water quality in stormwater runoff. Purun Tikus (*E. dulcis*) plants in the horizontal subsurface flow-rain garden system reduced the pollutants of Fe and Mn with a percentage reduction of more than 70%. The Purun Tikus plant used in this study also has positive responses, such as surviving and adapting to stormwater runoff conditions with a concentration of 25 ppm Fe and 15 ppm Mn.

INTRODUCTION

Urbanization activities in most urban areas will fundamentally change the pattern of water balance, increase the volume and rate of stormwater runoff, and reduce water quality in receiving water bodies [1–3]. Stormwater runoff will carry pollutants and other harmful chemicals for humans such as heavy metals (Fe, Pb, Cd, Cr, Cu, Mn, Zn), COD, BOD, TSS, and organic pollutants materials [4]. If harmful substances are absorbed into the soil, it can interfere with soil fertility. If waterways carried that into canals, rivers, and the sea, it can also harm the ecosystem. Contaminated substances carried by stormwater runoff were originated from roads and yards. Pollutant levels were generally high before the peak flow of stormwater runoff occurred [5–12].

Rain garden technology was technically designed to be able to resolve the problem of stormwater runoff. This technology effectively reduced the peak flow rate of stormwater runoff and reduced flooding [13–16]. Rain garden integrated the function of reducing pollutants in stormwater runoff and absorbing water to enter the soil [17]. For this function, it was possible to develop rain garden technology with a horizontal subsurface flow system to increase its efficiency. The horizontal subsurface flow system in the rain garden was a relatively new rainwater treatment

Proceedings of the 7th International Symposium on Applied Chemistry 2021
AIP Conf. Proc. 2493, 030002-1–030002-7; https://doi.org/10.1063/5.0109939
Published by AIP Publishing. 978-0-7354-4265-8/$30.00

system. The process was conducted by making water flow below the media's surface horizontally through the plant's root zone. A rain garden with a subsurface flow system consisted of channels or shallow pools filled with soil, sand, or porous media (stone or gravel), which will help the water filtration process. Stormwater runoff streamed below the surface of the media horizontally through the root zone of the plants between the gravel and sand. In this subsurface drainage system, microorganisms played a significant role in removing contaminants. Microorganisms attached to roots decompose pollutants aerobically; Aerobic substrate conditions near plant roots were caused by the oxygen supply from plant roots [18].

In this research, the plant used in the Horizontal Subsurface Flow – Rain Garden was Purun Tikus (*E. dulcis*). The plant is a wild plant that can grow and adapt well to acid sulfate tidal swampland. Purun Tikus (*E. dulcis*) is also a type of plant that can withstand low pH (acidic) conditions [18]. Purun Tikus can be used as a biofilter to improve water quality in the dry season by absorbing toxic compounds dissolved in water inlet (irrigation) and water outlets (drainage) such as Al, Fe, Mn, and SO_4. A biofilter is a technology to improve water quality by reducing the concentration of heavy metals in water. Purun Tikus (*E. dulcis*) is a weed that grows and thrives in muddy tidal marshes. This plant belongs to the family *Cyperaceae*. The stem is cylindrical and 2-3 mm in diameter, up to 150 cm high, non-branch, leafless, and green, so photosynthesis is carried out through the stem. Flowers are located at the end of the stem. This plant has a rhizome root where the rhizome is 6-8 weeks old, and it will form tillers. Flower formation occurred after the tiller appeared above the water surface, approximately 15 cm of high. After flowering, this plant will create a new rhizome at the end of the stolon, about 12.5 cm long. After 7-8 months, the rhizomes were no longer productive, so the stems began to dried out and slowly died. This plant can be widely developed because it has an abundance of 2.5-10 tons. ha^{-1} [18–24].

FIGURE 1. Purun Tikus (E. dulcis)

Because of its ability to maintain or restore the hydraulic conductivity of the filter bed, Horizontal Subsurface Flow – Rain Garden was expected to be more effective in reducing pollutant levels when compared to non-plant filters. In contrast, plant-less filters must be treated to regain their hydraulic conductivity by removing a few centimeters of the top of the substrate. Plants also played an essential role in the processing process. Plants provided a suitable environment for microbial growth and significantly increased oxygen transfer to the root areas of the filter bed [18]. Therefore, this research was conducted to combine Horizontal Subsurface Flow – Rain Garden using Purun Tikus plant.

MATERIAL AND METHODS

This research was conducted by draining stormwater runoff made synthetic by adding a standard solution of iron (Fe) and manganese (Mn) with a minimum purity of 99.0%. The iron concentration used in this study was 25 ppm, and the manganese concentration was 15 ppm. This runoff was channelled through a rain garden system with a continuous horizontal subsurface flow. This study was carried out under laboratory conditions, so it was ideal to understand the heavy metal removal mechanism and compare it with controls [1]. The flowed disposal was about 5 liters/day. The water flow passed through 5 reactors, which consisted of a rain garden reactor planted by Purun Tikus (sapling stage) with a distance between plants of 15 cm with two replications and one control. No addition of Purun Tikus plants distinguished this control. The reactor was made of wood with dimensions of 100 cm x 30 cm x 35 cm. This reactor was a modification of the last reactor that has been reported its utilize [18]. Data analysis was presented in tabulated data in the form of tables and graphs and analyzed descriptively. Descriptive research was needed to determine the percentage reduction of iron and manganese from each of the reactors.

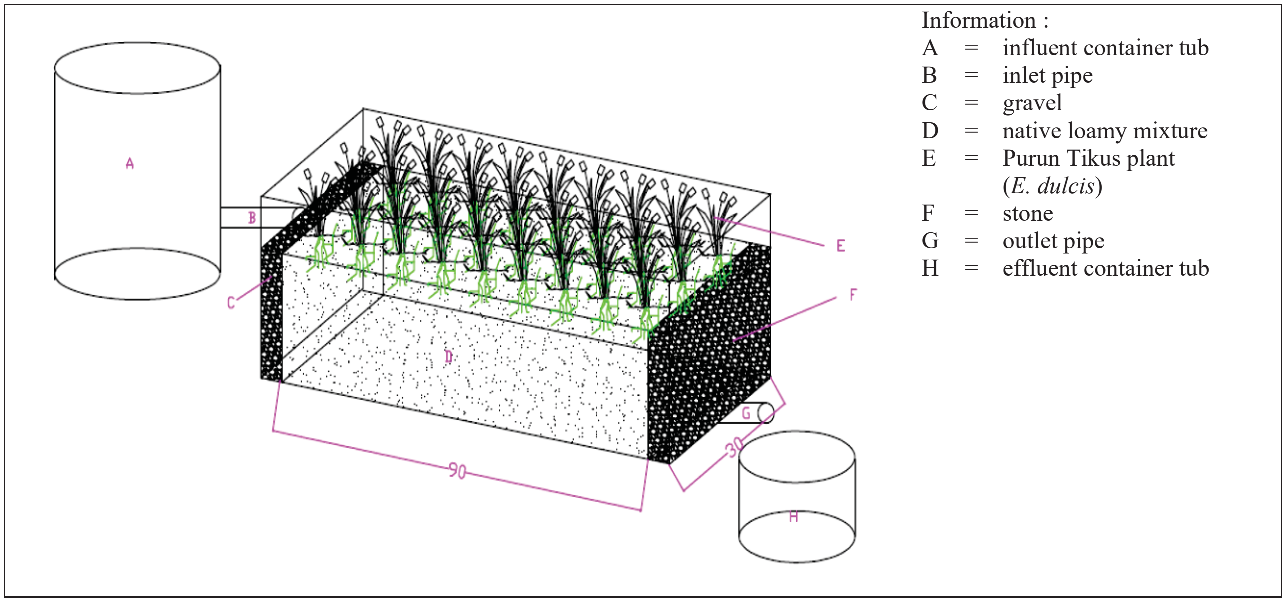

FIGURE 2. Rain garden reactor design

RESULTS AND DISCUSSION

The results show that this Purun Tikus plant can grow well in the reactor. The growth of Purun Tikus can be seen from the increase in its height. The height of Purun Tikus plant in each reactor was measured from the first day until the fourth day. The initial height of the plants used in this study is about 17.9 cm on average. Plant height differently increased in each of reactor (Figure 3). The plant height growth in the rain garden reactor model is carried out to see the plants' response after synthetic through stormwater runoff contaminated with Fe and Mn metals. This plant has a positive response, i.e. can survive and adapt to these conditions.

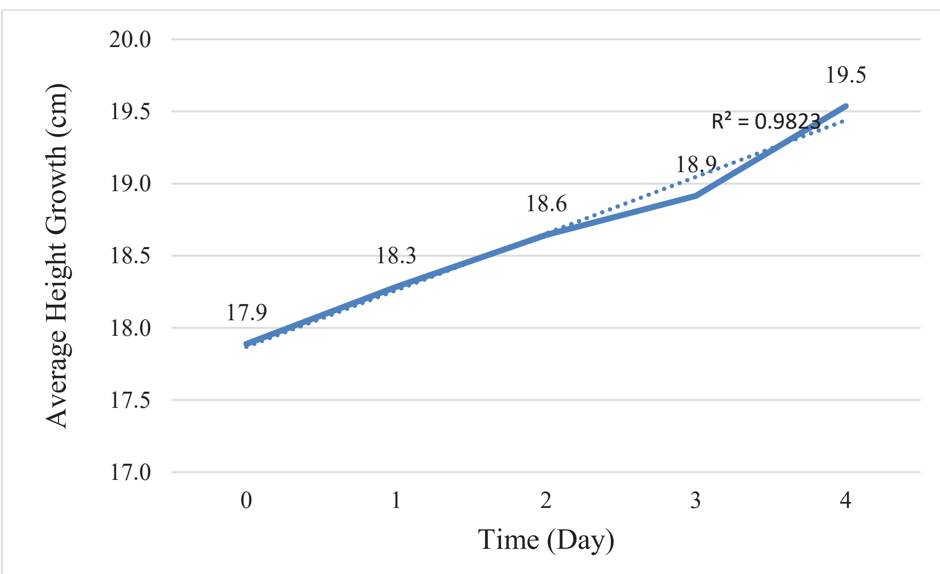

FIGURE 3. Average Height Growth of Purun Tikus (*Eleocharis dulcis*)

The results on stormwater runoff on Fe and Mn contents after passing through the horizontal subsurface flow - rain garden show decreasing concentration in each of tested reactor. The initial concentration of ferrous metal given in the reactor was 25 ppm. After passing through the rain garden, the average iron concentration was 7.2 ppm (71.3%) with a standard deviation of 0.64. The initial concentration of manganese is given at 15 ppm. After passing through the rain garden, the average of manganese concentration is 4.3 ppm (71.4%) with a standard deviation of 1.56 (Table 1). Because of its ability to maintain or restore the hydraulic conductivity of the filter bed, this horizontal subsurface flow – rain garden system has been shown to have a significantly higher rate of pollutant reduction when compared to non-plant filters.

The decrease in concentration is due to a complex process in the horizontal subsurface flow – rain garden, which includes a combined environmental Physico-chemical, and biological method [18]. These processes involve plants, media, and microorganisms present in the horizontal subsurface flow – rain garden. The Physico-chemical processes include filtration, adsorption, and sedimentation processes. In this filtration process, iron and manganese flow into the rain garden reactor that will be filtered through the Purun Tikus plant and rain garden media. The filtration process with Purun Tikus plants occurs in the root system. This system will form a filter to retain dissolved iron and manganese in stormwater runoff. In soil media, the filtration process occurs when stormwater runoff passes through the soil pores. These soil pores will filter iron and manganese metals that dissolve with stormwater runoff. Finally, the iron and manganese adsorption method will stick to the parts that attract them, namely plant roots, plant stems, and soil media. Microorganisms also help facilitate the adsorption process so that plants can easily adsorb the metals. From this process, plants get iron and manganese to fulfil the needs of micronutrients used for growing. The sedimentation process occurs in the soil, where the soil will increase iron concentration. Microorganisms carry out this biochemical process. These microorganisms patch near the roots to decompose aerobic pollutants; Aerobic substrate conditions near plant roots are caused by the supply of oxygen from plant roots [1,3,6,25–30].

TABLE 1. Result of measurement of Fe and Mn concentrations in Rain Garden Reactor

Treatment Repetition	Fe Concentration (ppm)		Mn Concentration (ppm)	
	Before Treatment	After Treatment	Before Treatment	After Treatment
1	25	6.7	15	3.2
2	25	7.6	15	5.4
Average	25	7.2	15	4.3
Deviation Standard	0	0.64	0	1.56
Control	25	35	15	7.79

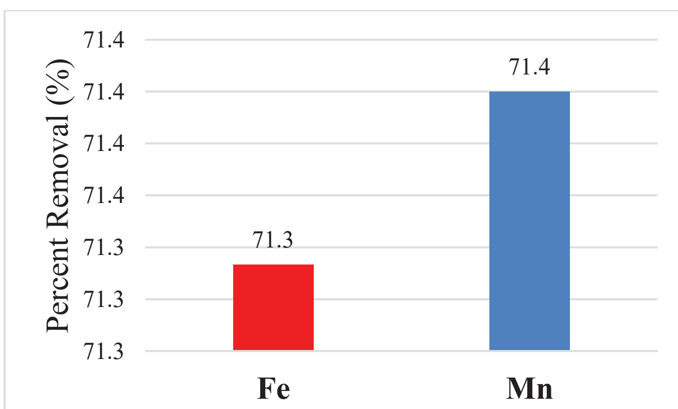

FIGURE 4. Average percent removal of heavy metal contamination (Fe and Mn)

In this study the decrease in Fe and Mn concentrations was found above 70% (Figure 4). This number is smaller than those of Yunus & Prihatini (2018)[19], Lange *et al* (2020)[9], Wulan *et al* (2020)[22], and Nugraha *et al* (2020)[24] (Table 2). However, Purun Tikus plants with Horizontal Subsurface Flow – Rain Garden are much more effective than *Bidens pilosa* L. plants with the Treated pots process. These results prove that Horizontal Subsurface Flow – Rain Garden is very potential and effective for removing heavy metal pollutants in stormwater runoff.

TABLE 2. The comparison of heavy metal decrease in this study to others

Authors and year	Usage Type	Plants	Percent Removal (%)
Annisa *et al.* (2021) (This Research)	Horizontal subsurface flow – rain garden	*Eleocharis dulcis*	– Fe: 71.3% – Mn: 71.4%
Lange *et al.* (2020)[9]	Bioretention system	*Carex vesicaria, Spartina pectinata*	– Total metal (Cd, Pb, Cu, Zn): >95%
Yunus & Prihatini (2018)[19]	Artificial wetland system (LBB)	*Eichhornia crassipes, Eleocharis dulcis*	– Fe: 87.11 - 95.28% – Mn: 70.08 – 79.84%
Wulan *et al*. (2020)[22]	Treated pots (Diameter 40 cm and height 20 cm)	*Eleocharis dulcis*	– Fe: 80.1%
Nugraha *et al*. (2020)[24]	Anaerobic wetland system	*Typha latifolia*	– Fe: 93%
Dai *et al.* (2021)[25]	Treated pots	*Bidens pilosa L.*	– Cd: 15 - 27%

The ability of the roots of the Purun Tikus plant to absorb metal compounds in the water is inseparable from the root system it has and the physiological aspects of the plant. The roots of the Purun Tikus plant with an extensive root cavity (cortex) cause the absorption process faster. Ion absorption in the roots occurs actively where ions from the epidermis get into and then are transported to the cytoplasm or root tissue cells through the epidermis into the protoplasm among root tissue cells, namely the cortex endodermis, pericycle, and xylem. There is a Caspary band in the endodermis due to a thickening filled with suberin, impermeable to water, as is the case with cutin and lignin in the leaf cuticle causing the accumulation of heavier particles in the roots. The presence of this Caspary band becomes a control on the absorption of ions by the roots. In addition, the roots of the Purun Tikus plant can also form a chelating substance (Phytosiderophores). This substance will bind the metal and then carry it into the root cells. To increase metal absorption, the root membrane forms reductase molecules [31]. With the formation of chelating substances and reductase molecules, it will be easier for metals to cross the root epidermis and enter root cells resulting in high metal accumulation. This corresponds to the results of scanning electron observations on the root surface of Purun Tikus (*E. dulcis*), which found Iron-plaques on the plant root cells (Figure 5). The accumulation in the roots is also due to the active absorption of ions in the roots, so metal ions are actively accumulated in the epidermis [6,19,21,25,28,32].

FIGURE 5. Electron scanning root surface Purun Tikus (*E. dulcis*) with Iron-plaques

The pH value in the horizontal subsurface flow - rain garden reactor increased after treatment, ranging from 0.6-1.1 from the initial conditions. This pH range is under the conditions that allow biological processes and sedimentation of several types of heavy metals to occur. This increase in pH is caused by the exchange of hydrogen ions with alkaline or alkaline earth cations in the soil medium. An increase in pH can also be caused by the exchange of dissolved metal ions such as iron, manganese, alkaline, or alkaline earth metal ions. In addition, Purun Tikus plants also play a role in increasing the plants that will absorb substances, which cause acidity in stormwater runoff. This condition reduces the number of hydrogen ions in the water so that the pH will increase. The relationship between pH and a decrease in concentration (Fe and Mn) is very clear inversely proportional based on the data above[18,31]. If the pH increases, the solubility of heavy metals will decrease so that the concentration of heavy metals will be low, and vice versa. If the pH decreases, the solubility of heavy metals will increase, so the engagement will increase.

TABLE 3. pH value in each of tested reactor

Treatment Code	pH Value	
	Before Treatment	**After Treatment**
Fe-1	5	6.1
Fe-2	5	6
Mn-1	5	5.7
Mn-2	5	5.6
Control	5	5
Average	5	5.68

The temperature in the horizontal subsurface flow reactor - rain garden is related to the life of microorganisms and plants that play a role in decomposing the pollutants in the liquid waste. The temperature will affect the reaction, where every 10°C the increase of temperature will increase the response 2 – 3 times faster. The results carried out on temperature measurements in the rain garden are almost identical in each reactor. On average, the temperature in the reactor is about 28°C per day (Figure 6). This temperature has an essential role in the biological process because the activity of microorganisms takes place at the temperature of 15°C-35°C. At temperatures below 15°C the movement of contaminant-decomposing microorganisms will decrease, while temperatures above 35°C it will reduce the level of solubility in the aerobic process [18]. Therefore, the measured temperature seems to be supported the decomposition processes in the rain garden.

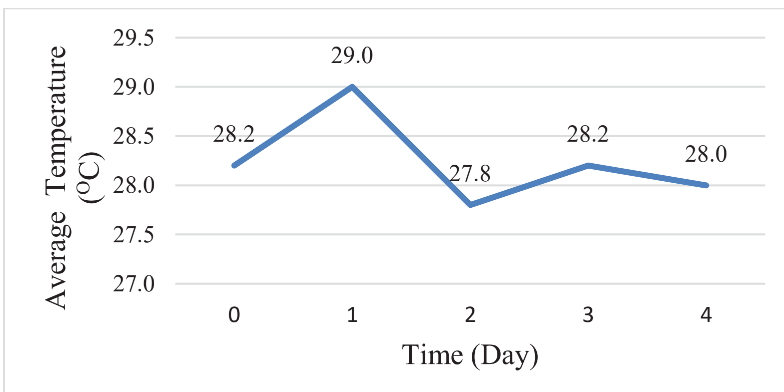

FIGURE 6. Average temperature (°C) in each reactor

Temperature affects the absorption of metal elements by the Purun Tikus plant. The higher the temperature of the plant environment, the higher the absorption by plants, where the ambient temperature will cause an increase in the photosynthesis process, so that the absorption of metals by plants will also increase. During photosynthesis plants require carbon in the air, in the carbon dioxide formula (CO_2). If the plant wants to absorb more CO_2, then the stomata must be opened wide. Consequently, if the stomata are wide open, more plants will lose water and get into heavy metals in the air [6,9,18,22,29,31].

CONCLUSION

The horizontal subsurface flow-rain garden model (reactor) with Purun Tikus plant reduced iron and manganese concentrations with a percentage reduction of more than 70%. The decrease in concentration is due to a complex process in the horizontal subsurface flow – rain garden, which includes a combination of environmental and biological Physico-chemical processes. These processes involve Purun Tikus, media, and microorganisms present in the horizontal subsurface flow-rain garden. This environmental Physico-chemical process includes filtration, adsorption, and sedimentation processes. In addition, the Purun Tikus plant used in this study had a positive response, was able to survive and adapt to stormwater runoff conditions with a concentration of iron of 25 ppm and manganese of 15 ppm. Environmental factors such as pH and temperature are also known to influence the process of reducing pollutant levels in this study.

ACKNOWLEDGMENTS

This Study was fully supported by The National Priority Research Program at home program in the Deputy for Scientific Services, Indonesian Institute of Sciences (LIPI), and The APC was funded by Lambung Mangkurat University. Special appreciation was addressed to our colleagues, Ary Mauliva Hada Putri and Aprilia Nur Tasfiyati for Proof reading & Plagiarism checker this paper.

REFERENCES

1. J. Fronczyk and K. Markowska-Lech, Sci. Total Environ. **770**, 145199 (2021).
2. Y. Ma, M. Gong, H. Zhao, and X. Li, Sci. Total Environ. **698**, 134243 (2020).
3. L. Rosenberger, J. Leandro, S. Pauleit, and S. Erlwein, J. Hydrol. **596**, 126137 (2021).
4. F. Maleteng, Dsp. Univ. Islam Indones. **14513094**, (2018).
5. C. Pla, D. Benavente, J. Valdes-Abellan, and Z. Kovacova, J. Contam. Hydrol. **239**, 103778 (2021).
6. M. T. I. Shajib, H. C. B. Hansen, T. Liang, and P. E. Holm, Environ. Pollut. **248**, 584 (2019).
7. H. Jeong, J. Y. Choi, J. Lee, J. Lim, and K. Ra, Environ. Pollut. **265**, 115028 (2020).
8. X. Fu, M. E. Hopton, and X. Wang, J. Clean. Prod. **289**, 125146 (2021).
9. K. Lange, H. Österlund, M. Viklander, and G. T. Blecken, Sci. Total Environ. **724**, (2020).
10. C. Jiang, J. Li, H. Li, Y. Li, and Z. Zhang, J. Hydrol. **585**, 124803 (2020).
11. P. Shen, D. T. McCarthy, G. I. Chandrasena, Y. Li, and A. Deletic, Sci. Total Environ. **709**, 136157 (2020).
12. Y. Luo, X. Yue, Y. Duan, A. Zhou, Y. Gao, and X. Zhang, Sci. Total Environ. **705**, 135893 (2020).
13. H. Prasetia, N. Harijati, and N. Annisa, *Rain Garden* (CV IRDH, Malang, 2018).
14. N. Annisa, R. Riduan, and H. Prasetia, Jukung J. Tek. Lingkung. **2**, 22 (2016).
15. N. Annisa and H. Prasetia, Jukung (Jurnal Tek. Lingkungan) **3**, 47 (2017).
16. N. Annisa, R. Riduan, and H. Prasetia, **2**, 78 (2016).
17. N. Annisa, H. Prasetia, and Q. Sholihah, IOP Conf. Ser. Mater. Sci. Eng. **1011**, 012013 (2021).
18. N. S. Prihatini and Soemarno, in *Phytorestoration Abandon. Min. Oil Drill. Sites*, edited by K. Bauddh, J. Korstad, and P. Sharma (Elsevier, 2021), pp. 409–438.
19. R. Yunus and N. S. Prihatini, Sainsmat J. Ilm. Ilmu Pengetah. Alam **7**, 73 (2018).
20. A. Amrullah, O. Farobie, and R. Widyanto, Bioresour. Technol. Reports **13**, 100642 (2021).
21. S. F. S. Draman, S. A. Khalid, N. M. Sidek, S. R. S. Abdullah, and N. Anuar, IOP Conf. Ser. Mater. Sci. Eng. **808**, (2020).
22. S. N. Wulan, T. Apriadi, and W. R. Melani, Limnotek Perair. Darat Trop. Di Indones. **27**, 67 (2020).
23. S. A. M. Thamrin, J. Litbang Pertan. **31**, 35 (2012).
24. F. A. Nugraha, H. Kirmi, B. Haryanto, and M. Afiffa, SPECTA J. Technol. **4**, 35 (2020).
25. H. Dai, S. Wei, L. Skuza, and Q. Zhang, Chemosphere **273**, 129652 (2021).
26. E. V. Lopez-Ponnada, T. J. Lynn, S. J. Ergas, and J. R. Mihelcic, Water Res. **170**, 115336 (2020).
27. A. Wina, ReTII **2020**, 201 (2020).
28. R. F. Al-Thani and B. T. Yasseen, Environ. Pollut. **259**, 113694 (2020).
29. M. S. Sabovljević, M. Weidinger, A. D. Sabovljević, J. Stanković, W. Adlassnig, and I. Lang, Environ. Pollut. **256**, (2020).
30. J. Lee and K. Gil, Ecol. Eng. **150**, 105823 (2020).
31. U. Singh, C. S. Praharaj, S. S. Singh, and N. P. Singh, Biofortification Food Crop. 1 (2016).
32. M. Zhao, S. Zeng, S. Liu, Z. Li, and L. Jing, Ecol. Eng. **148**, 105790 (2020).