Azolla for Water and Land Phytoremediation Against Heavy Metals: A Mini Review

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Abstract. The progressive growth in various industries is followed by products in the form of waste – among them are heavy metal waste such as Pb, Cd, Cr, Hg, Zn, and Cu. The substances are often found in the form of pesticide, heavy metal, and radioactive remains, which can degrade water and land through industrial waste discharge. Wastewater management to meet the quality standard as detailed in the Decree of the Ministry of Environmental Affairs and Forestry – Republic of Indonesia prior to discharge is a must. Azolla can eradicate heavy metal pollutants thanks to its heavy metal hyperaccumulating ability, allowing it to decontaminate industrial waste, water reservoir, and any water bodies. Azolla also can absorb iron (Fe) as an essential substance which is proven beneficial. In newly-opened rice fields where Fe poisoning frequently occurs due to oxidation-reduction process, rice growth and production is badly affected – applying azolla should not only bioremediate field water, but also contribute organic biomass as well as supply nitrogen while, at the same time, serve as antibiotics to support good rice yield.

Keywords: Environmentally friendly, minimize heavy metal, mosquito fern, pollution reduction, waste control management.

1 Introduction

Land and water are fundamental life elements, and maintaining their quality is therefore imperative for wholesome living environments. However, development on technology and industry in order to satisfy human needs produces a hefty amount of pollutants. As land and water pollutants such as pesticides, heavy metals, and radioactive compounds are often found in industrial liquid waste, operative industries in Indonesia need to conduct proper liquid

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waste management to meet the regulated quality standard (the Decree of the Ministry of Environmental Affairs and Forestry – Kep-03/MNKLH/II/1991) prior to discharge. Additionally, the raising awareness on healthy living has been encouraging various attempts on overcoming environmental problems concerning land and water – Go Organic, an Indonesian governmental program founded in 2010, is one has been dealing with environmental degradation due to agricultural activities.

Waste management technology may apply either physical, chemical, or biological method [1, 2]. Bioremediation, a procedure employing organisms to eliminate pollutants, encompasses phytoremediation and remediation [2, 3]. Phytoremediation, a feasible and frugal technique, should be efficient for removing heavy metals from liquid waste and rendering it harmless as water plants have potentials to absorb and extract a large amount of heavy metals in their roots then release them in the air [3–6]. Utilizing water plants in liquid waste management is not only environmentally friendly, but also easy to apply and control. This should be an answer to manage liquid waste from industrial heavy metal pollutants in water and land.

Azolla Lam (genus), with common name: mosquito fern, duckweed fern, fairy moss, water fern is a water plant species that owns aforementioned features. Cyanobacteria have been proven applicable in agriculture, fishery, bioremediation, and other biological activities [7, 8] referring to their ability to generate various essential pharmacological bioactive compounds with high commercial values, such as antibacterial, antifungal, and antioxidant instruments [9–11], and azolla – despite its unwanted presence in rice field – can even serve as Fe phytoremediation agent [12–15].

2 Source

A comprehensive literature review towards the potential of azolla in phytoremediation, this study features a number of references published between 2012 and 2023. In addition to reputable scientific journals like International Journal of Phytoremediation, Biotechnology and Bioprocess Engineering, Plant Nutrition Soil Science, International Aquatic Research, and Chemosphere, other articles on azolla specifically in water and land phytoremediation.

3 Azolla for water and land phytoremediation

3.1 Azolla for water phytoremediation

Heavy metal-containing waste production often follows industrial advancement, even small-scale home industry like laundry service. Heavy metals such as Pb, Cd, Cr, Hg, Zn, and Cu in the waste that accumulate in soil and water bring negative impacts for the environment as well as human health. Fat and organic compounds in detergent – among them are natrium tripolyphosphate, linear alkylbenzena sulfonat, and sodium tripolyphosphate [16–18, 9] – endanger water biota, particularly basic organism (demersal), as surfactant build up into sediment in a water body. As of major-scale industry, nuclear power generation is known to release highly toxic uranium waste. Demands on uranium have been increasing globally despite the fact that its waste has been seriously damaging the environment in China for the last 20 yr. To comply with the quality standard detailed in the Decree of the Ministry of Environmental Affairs and Forestry – Republic of Indonesia, liquid waste must pass chemical indicators of pH, Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) to prevent environmental degradation [19, 20].

Plants employed as absorber in phytoremediation need to have the ability to eliminate pollutant and tolerate any damage it caused [21], grow fast, produce high biomass, absorb a
large amount of heavy metals, convey heavy metals to the surface, and endure heavy metal toxicity [1, 7]. Azolla sp. corresponds to absorb metals of Cu, Zn, Ni, and Cd [22] as well as Cr [7]. It is often used as an effective agent to phyto remediate organic and anorganic waste – the quality of hyper-accumulating heavy metals should make it fit to manage industrial waste and polluted reservoir. Addressing to the first case, azolla has been recorded to lower COD rate in laundry waste of 150 g 30 L−1 density from 133.43 mg L−1 into 41.52 mg L−1 after 7 d, from 585 mg L−1 into 157 mg L−1 after 6 d, from 585 mg L−1 into 148 mg L−1 after 9 d, and from 585 mg L−1 into 90.4 mg L−1 after 12 d [23, 18]. As of the second case, study by Xinwei et al. [2] reveals that azolla was able to accumulate uranium from 0.317 mg L−1 into 0.039 mg L−1 and, at the same time, eliminate Fe, Mn, Cu, Zn, Pb, Cd, total nitrogen, total phosphorus and SO4 from waste.

Numerous pollutants are found in water, so a range of azolla species have been scrutinized for their functions in order to allow accurate assignments. While Azolla filiculoides Lam is able to tolerate up to 4 mg L−1 hidrazin as well as Cd, Cr, Cu, Ni, and Zn at 10 000 mg L−1, 1 990 mg L−1, 9 000 mg L−1, and 650 mg L−1, consecutively [24, 25]. Azolla caroliniana Lam. is adept in absorbing pollutant up to the concentration of As 386.1 g g−1 dry weight [26] and Azolla pinnata R.Br. is capable of degrading pollutant in contaminated river water [27]. One confirmed utility in agriculture is azolla-anabaena symbiosis in rice field maintenance. Producing toxin in aquatic water ecology – neurotoxin and anatoxin alkaloid, microcystin (a kind of hepato toxin) and cylindrospermopsin – azolla improves field water quality by impeding microbial growth, absorbing oil and heavy metals, and releasing nitrogen. As a result, as cited in study by Oktaviansyah dan Oktari [10], Azolla Lam (genus) inhibits the risk of bacterial and fungal infection in rice plants. As of in fishery, Azolla phyto remediates water quality by absorbing feed, feces, and pollutant remains [28].

The above explanation shows azolla’s eminence in phyto remediating non-essential heavy metals, which makes it a strong candidate for an environmentally friendly green alternative to tackle heavy metal pollution. Iron (Fe), on the other hand, is an essential heavy metal required by living organisms in small amounts for their vital physiological and biochemical functions. The plant’s ability and its management in dealing with excessive Fe content is explicated in the next section.

3.2 Azolla for land phyto remediation

Rice fields require water pooling to allow rice growth, and this system causes iron dominant in their chemical feature compared to other heavy metals. Fe toxicity frequently occurs in newly opened fields due to oxidation-reduction. Iron in dry land at Fe3+ oxidative level will be reduced into toxic Fe2+ when turned into wet land. Fe2+ poisoning hinders plant growth that results in low yield. Rice requires higher amounts of iron than other plants, but too much iron obstructs the absorption of essential nutrients, especially phosphate. It is recorded that after 3 wk to 4 wk of pooling, Fe concentration increases up to 600 mg L−1 [29], ≥ 200 mg L−1 [30], 0.27 g kg−1 to 4.87 g kg−1 that equals 270 mg L−1 to 4 870 mg L−1 [31], and > 300 mg L−1 [32] – in these conditions, Fe becomes toxic for rice plants.

Excessive Fe damages plants as it impedes Ca, P and K absorption; consequently, plants have low – even zero – productivity [32–34, 29]. Fe poisoning poses indications of short growth, small number of bunch and panicle, bronzing leaf, short root, late blossoming, and late panicle development [35, 36, 32]. These are significant in rice production [29, 32, 33].

To control Fe poisoning, amelioration – adding certain organic substances in soil in order to enhance the environment for certain agricultural plants to grow better – are often applied. When in symbiosis with anabaena, azolla is able to fixate free N from the air. Anabaena azollae Strasb. contributes N towards growing rice plants without taking other nutrients required for rice growth. Adding azolla once a new field is filled with water and letting it
grow should allow it to absorb iron when Fe\(^{3+}\) turns into Fe\(^{2+}\). When covering the whole field water, the plant also filters ammonia from evaporating. Once the field is ready for production, azolla biomass can be mixed with the soil to serve as organic fertilizer.

Nitrogen in rice agriculture is paramount, making urea a necessity due to the fast response shown by rice plant in both vegetative and generative growth. However, nitrogen absorption in rice plant is relatively low as an effect of high ammonia denitrification, sluicing, and evaporation. Covering field area with azolla during plant growing phase should reduce ammonia evaporation. Additionally, azolla helps to reduce air pollutant \([37–39]\).

It is therefore conclusive that azolla has an important role in rice field as a remediation agent of polluted water, an organic biomass contributor, nitrogen supplier, and antibiotic.

### 4 Phytomediation mechanism

A method to heavy metal remediation is by planting hyperaccumulator plant of which roots grow in water instead of soil like Azolla sp. Despite physiological, biochemical, and molecular genetics researches to discover the exact accumulating point and contributory factor to it, information on fundamental mechanisms of such plant such as heavy metal absorption, translocation, and accumulation is very limited.

Phytoremediation mechanism and efficiency lay on the type of contaminant and soil characteristics \([40]\) and each mechanism impinges on the volume, mobility, and contaminant toxicity in its practice \([41, 1]\). Out of three schemes of soil, sediment, and water treatments – phytoextraction, rhizofiltration, and phytovolatilization – Azolla sp. fits rhizofiltration as the method restores water by allowing roots to absorb contaminants in it. Study by Hafez et al. \([42]\) claims that A. pinnata has been apparent to get rid of iron contaminant in water after 20 d of incubation, and Fe, Mn, Cu, Zn, Pb, Cd, and U contaminant after 30 d \([2]\).

While having a good potential as feed due to its fast growth and high protein content, pollutant-infused Azolla sp. need to be properly disposed of once phytoremediation process is concluded. It is likely that the bioaccumulated pollutants in the plant are high it can endanger animal – and human – health. Recycling it into bioenergy —biogas should be of better reliability.

It is hoped that the use of heavy metal absorbing plants for organic fertilizer can also cause heavy metals to be organically fixed and associated with organic materials. Organic fertilizer from plant biomass can add volume to organic soil and increase its negative charge which is useful for capturing metal cations - organic materials have a high affinity for heavy metals because organic acids are equipped with functional groups that have the ability to form chelates.

The phytoremediation mechanism can also use “candung” technology by using aquatic plants in candung using natural processing processes such as artificial wetlands, namely engineering systems that simulate the processes of natural wetlands. “Candung” technology can be carried out by treating contaminated water in artificial wetlands with the aim of protecting irrigation water before it enters the rice fields to prevent pollution and ensure food (rice) is safe. This can also be applied to the processing of industrial heavy metal waste \([43]\).

In future research "candung" technology should be studied to minimize microplastic pollution in irrigation water \([44–47]\). Likewise, how to proceed with handling these aquatic plants \(e.g.,\) Scirpus articulatis L., Ipomoea aquatic\(a\) Forssk, Neomarica gracil\(i\)ss (Herb.) Sprague, Limnocharis flava (L.) Buchenau, Pontederia crassip\(e\)s Mart, Cyperus sp., Typha sp., and Typhonium sp.] should be studied after the plants have absorbed heavy metals (and microplastics).
5 Conclusion

Azolla is competent in getting rid of heavy metal pollutants in water and land. With its heavy metal hyperaccumulating ability towards Cu, Zn, Ni, and Cd should facilitate it to manage industrial waste and polluted reservoir water, serving well in phytoremediation attempts. Specifically in rice agriculture, azolla is focal for remediating polluted water while contributing organic biomass and supplying nitrogen as well as providing antibiotic function.

It is forwarded with deep regret that Prof. Dr. Maftuchah Maftuchah, one of the authors of this article, passed away on February 13, 2024. The authors wish to extend their sincere appreciation for her enthusiasm and dedication to the writing process of this manuscript. This manuscript was funded by funds from the Ministry of Education, Culture, Research, and Technology - Directorate General of Higher Education of the Republic of Indonesia in the Doctoral Dissertation Research Grant scheme No.0557/E5.5/AL.04/2023 and No. 013/SP2H/PT/LL7/2023.

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