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RESEARCH ARTICLE

Enhanced Phytoremediation of Domestic Wastewater Using Lepironia Articulata, Monochoria Vaginalis and Typha Angustifolia: Comparative Performance and Efficacy

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ABSTRACT - The generation and composition of wastewater are influenced by various factors, including human behavior, lifestyle, and industrial activities. Household waste comprises both solid and liquid components, which can be managed and treated through sustainable practices and advanced technologies. Phytoremediation, using aquatic plants, offers an environmentally friendly method to treat wastewater and remove heavy metals, which are significant inorganic contaminants. This study investigates the efficacy of three aquatic plants—*Monochoria vaginalis*, *Typha angustifolia*, and *Lepironia articulata*—in phytoremediating domestic wastewater collected from an oxidation pond in Pasir Gudang, Johor Bahru. Over an 11-week period, in situ and ex situ experiments were conducted to measure the reduction in concentrations of heavy metals (Copper, Chromium, Iron, Lead, and Zinc) and other parameters (BOD, COD, TSS, Turbidity, and pH). The results demonstrate that all three plants effectively reduced the concentrations of heavy metals and other parameters. Copper, Iron, Lead, and Zinc were completely removed by all three plants, with removal percentages reaching 100%. *Monochoria vaginalis* showed the highest removal efficiency for Chromium (70%) and COD (97%). *Lepironia articulata* exhibited the highest removal efficiencies for BOD (85%), TSS (92%), and Turbidity (97%). *Typha angustifolia* also achieved significant removal of pollutants, particularly showing strong performance in removing heavy metals, with BOD reduction reaching 83% and COD reduction at 90%. These findings confirm the potential of *Monochoria vaginalis*, *Typha angustifolia*, and *Lepironia articulata* as effective phytoremediation agents for treating domestic wastewater and mitigating environmental pollution.

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1. INTRODUCTION

The generation and composition of wastewater are influenced by various factors, including human behavior, lifestyle, standard of living, and the type and scale of industrial activities in a given area. Household waste can consist of both solid waste, such as food scraps, packaging, and paper products, and liquid waste, such as greywater from washing dishes or clothes and blackwater from toilets. The composition of these waste streams can vary depending on household size, diet, and consumption patterns. Waste reduction and improved waste stream composition can be achieved through practices such as reducing food waste through meal planning and composting, using reusable containers and bags, and properly disposing of hazardous materials. Additionally, wastewater can be treated and reused through various technologies and approaches, such as constructed wetlands, membrane bioreactors, and advanced oxidation processes. The reuse of treated wastewater can conserve water resources and reduce the demand for freshwater supplies. Managing household waste and wastewater is a crucial aspect of environmental sustainability, requiring individual actions, technological solutions, and policy and regulatory frameworks. This applies equally to industrial contexts [1].

Heavy metals are a major component of inorganic contaminants, posing significant challenges compared to organic contaminants [2-4]. These elements, including lead, cadmium, mercury, arsenic, and chromium, are toxic to living organisms at high concentrations and can be released into the environment through activities such as mining, industrial processes, and the use of fertilizers and pesticides. Once released, heavy metals can accumulate in soil, water, and living organisms, persisting for many years, and causing serious environmental and health problems, including soil degradation, water pollution, and toxic effects on wildlife and human health. Metals may also be hazardous because they can substitute critical metals in pigments or enzymes, interfering with their function [5]. Consequently, metals make the land unsuitable for plant growth and damage biodiversity [4]. Research over the past few decades has explored the use of green or aquatic plants as viable technologies to treat wastewater contaminants. Phytotechnologies employ plants to remediate or eliminate contaminants in soil, groundwater, and surface water [6]. These technologies are environmentally friendly, safe, technically and economically viable, and represent an alternative to traditional hazardous waste treatment methods when properly designed and managed [7].

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To remove heavy metals from contaminated sites, a combination of phytoremediation and bioremediation methods is employed. Phytoremediation uses natural plant processes and microorganisms associated with the root system to remove, contain, or degrade environmental contaminants in soil, sediment, and water [8]. This technology has been successfully used in various applications, such as the restoration of abandoned metal-mine workings, cleaning up sites contaminated with polychlorinated biphenyls (PCBs), and mitigating ongoing coal mine discharges [9]. In this study, a laboratory approach was used to investigate the critical concentration of heavy metals in domestic wastewater and determine the percentage of heavy metal concentration reduction using aquatic plants as phytoremediation agents. The aquatic plants studied are *Monochoria vaginalis*, *Typha angustifolia*, and *Lepironia articulata*.

2. PHYTOREMEDIATION

Phytoremediation, an established green technology, uses plants to remediate contaminated environments by reducing pollutant movement, particularly groundwater contaminants. Aquatic plants and trees function as natural pumps, drawing contaminated water through their roots, preventing the spread of pollutants to uncontaminated areas [8, 10]. This technology requires time to be effective, with clean-up periods varying based on contaminant concentrations, site size, plant capacity, and environmental factors such as growing seasons [11]. Phytoremediation has been successfully applied to sites contaminated with heavy metals, pesticides, solvents, explosives, and crude oil derivatives, including lead, uranium, and arsenic [12-13].

The concept of "Phytogreen technology" expands on phytoremediation techniques by applying them to environmental management on a broader scale. This technology targets various contaminated sites, including industrial or agricultural areas, landfills, and brownfields. Selected plants are capable of absorbing, breaking down, or stabilizing pollutants in the soil, water, and air. Besides remediating contaminated environments, phytogreen technology also contributes to improving air and water quality, preventing soil erosion, and enhancing biodiversity. Commonly used plants in phytogreen technology include sunflowers, willow trees, poplars, duckweed, and water hyacinth [14-15].

Phytoremediation is a promising environmentally sustainable alternative for managing environmental pollution. Research has demonstrated its effectiveness in restoring polluted ecosystems, supporting its potential for large-scale environmental clean-up [16-17].

3. BIOREMEDIATION

Bioremediation utilizes living organisms, such as bacteria, fungi, or plants, to break down or remove pollutants from contaminated sites. It leverages the natural metabolic capabilities of microorganisms to degrade, transform, or detoxify contaminants into less harmful forms. This method is used to clean up various contaminants, including petroleum hydrocarbons, heavy metals, solvents, pesticides, and other organic compounds [15-18]. The process involves introducing specific microorganisms or plants to the contaminated site and providing the necessary conditions, such as nutrients and oxygen, for them to thrive and degrade pollutants [19]. Bioremediation offers several advantages, such as lower costs compared to traditional methods like excavation and removal, in-situ application, and reduced environmental impact. However, its effectiveness depends on factors such as the type of contaminant, site characteristics, and the conditions provided for microbial activity [20, 21]. For instance, certain bacteria can metabolize pollutants, converting them into less harmful by-products such as water and gases like carbon dioxide and ethane [22].

In cases where natural microbial populations are insufficient, "bioaugmentation" introduces additional microbial strains to enhance the bioremediation process. Optimal conditions—such as the right temperature, nutrients, and food sources—are crucial for success. In suboptimal conditions, microbial activity slows, and pollutants remain. Soil remediation often involves amendments like molasses, vegetable oil, or air to facilitate microbial breakdown of contaminants [23-24]. In the context of this study, bioremediation is particularly relevant for addressing wastewater contamination issues alongside phytoremediation. By combining both approaches, the remediation potential is enhanced, leading to more efficient pollutant removal from domestic wastewater. This combination is especially useful in managing complex contaminants, including heavy metals, which are difficult to remediate through a single method alone [25]. The complementary action of microorganisms and aquatic plants can accelerate the degradation of organic compounds and enhance the uptake of heavy metals, thereby improving the overall efficacy of the wastewater treatment process.

4. METHODOLOGY

4.1 Phytoremediation Experiment Setup

The phytoremediation experiment was carried out at a plantation site, with the experimental tanks located next to the Environmental Laboratory, Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA). Wastewater for the study was collected from a household wastewater oxidation pond at Jalan Besi in Pasir Gudang, Johor Bahru. This pond serves as part of a larger community wastewater treatment system and collects effluents from multiple households in the area. The wastewater used in this experiment reflects typical domestic wastewater composition from this region, primarily consisting of greywater, blackwater, and runoff.

Four tanks were utilized in the experiment: three treatment tanks containing the selected aquatic plants and one control tank without plants. The selected aquatic plants were Monochoria vaginalis, Typha angustifolia, and Lepironia articulata. Water samples were collected periodically over the course of approximately 11 weeks to assess the effectiveness of the plants in reducing contaminant concentrations. The growth rates of the plants were also monitored throughout the study period. Changes in water quality were determined by comparing the initial readings with the final readings of the various parameters.

Water samples were collected from all four tanks, resulting in eleven data points over the course of the study. The eleven data points represent specific instances of data collection at different times throughout the 11-week period. The first data point for each tank was taken at the start of the experiment to establish baseline water quality levels. Subsequent samples were collected periodically, twice a week for most parameters and once a week for BOD, allowing multiple data points for each tank throughout the study to capture variations and trends. The final data points were collected at the end of the experiment to compare with the initial values, determining the overall effectiveness of the phytoremediation process.

4.2 Laboratory Analysis

Laboratory experiments were performed to analyze the following water quality parameters: Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), pH, Turbidity, Chromium, Copper, Iron, Lead, and Zinc. These analyses were carried out twice a week, while Biochemical Oxygen Demand (BOD) was tested once a week. The procedures followed the standard methods as outlined by the American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF) [20]. Additionally, Environmental Protection Agency (EPA) guidelines were adhered to, especially concerning sample handling and preservation, to ensure high-quality data. For instance, metal samples, excluding those for Chromium, were preserved using HNO_3 at pH 2 and could be stored for up to six months.

Water samples were taken from all four tanks, with one sample from the control tank and three samples from the tanks containing the aquatic plants. Certain parameters, such as turbidity, pH, and dissolved oxygen, were measured immediately on-site to avoid degradation or alteration during transport.

4.3 Experimental Considerations

Throughout the study, the tanks were periodically refilled with water to simulate continuous input into the system, mimicking the conditions of an operational wastewater treatment system. The incoming water quality was also tested to account for any variations in the parameters being measured; ensuring that observed changes in water quality could be attributed to the phytoremediation process. The variation in measurement frequency between parameters (i.e., twice a week for some parameters and once a week for others) was due to the different response times and sensitivities of the parameters. For instance, BOD typically shows slower variations compared to parameters like pH or turbidity, which can change more rapidly depending on environmental conditions.

4.4 Experimental Design

Number of Tanks:

a) Four tanks in total:
   - Three treatment tanks containing different selected aquatic plants.
   - One control tank without any plants.

b) Selected Aquatic Plants in Treatment Tanks:
   - Monochoria vaginalis (in one tank)
   - Typha angustifolia (in another tank)
   - Lepironia articulata (in the third tank)

c) Control Tank:
   - One tank without plants to serve as a reference for water quality changes without the influence of plant remediation.

d) Study Duration:
   - Approximately 11 weeks, with periodic water sample collection.

e) Parameters Monitored:
   - Contaminant Concentrations: Monitored by comparing initial and final water samples.

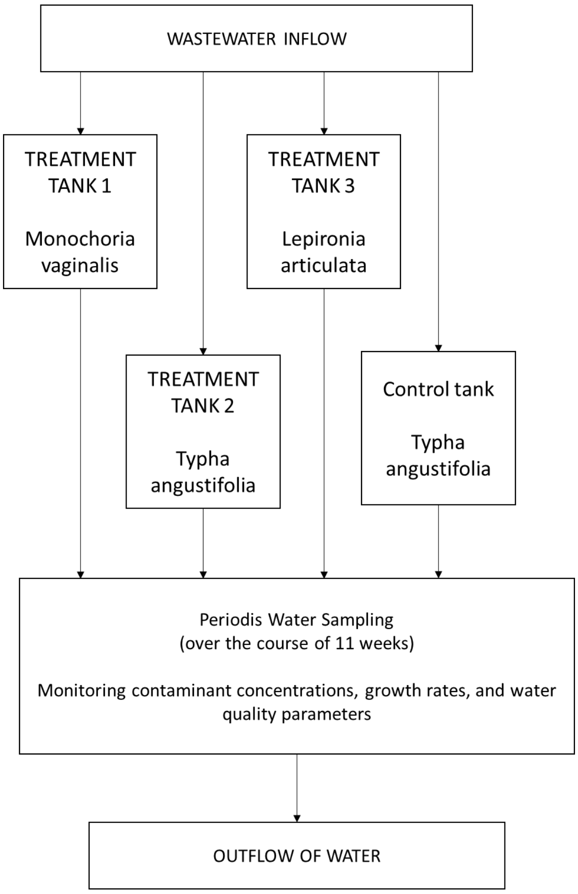

Figure 1. Experimental setup for the phytoremediation tanks

4.5 National Water Quality Standards for Malaysia

The water quality parameters were assessed against the National Water Quality Standards for Malaysia, as follows:

- Biochemical Oxygen Demand (BOD): Standard A limit is 12 mg/l.
- Chemical Oxygen Demand (COD): Standard A limit is 100 mg/l.
- Total Suspended Solids (TSS): Standard A limit is 300 mg/l.
- Turbidity: Standard A limit is 50 NTU.
- Chromium (Cr): Standard A limit is 0.05 mg/l (Cr VI) and 2.5 mg/l (Cr III).
- Copper (Cu): Standard A limit is 0.2 mg/l.
- Iron (Fe): Standard A limit is 5 mg/l (Others).
- Lead (Pb): Standard A limit is 0.05 mg/l.
- Zinc (Zn): Standard A limit is 5 mg/l.

These standards were used as a benchmark to evaluate the effectiveness of the phytoremediation process in reducing various contaminants in the wastewater.

5. RESULTS AND DISCUSSIONS

5.1 Biochemical Oxygen Demand (BOD)

As shown in Figure 2, the results from the weekly data points (D1 to D11, representing approximately 11 weeks of observation) indicate that Lepironia articulata (Grey Sedge) achieved the highest BOD removal efficiency, with an average removal rate of 84.77%. This was followed by Monochoria vaginalis (Oval-Leaf Pondweed) at 84.17% and Typha angustifolia (Narrow-Leaved Cattail) at 84.09%. In contrast, the control tank exhibited a significantly lower average removal of just 1.35%. The blue line in Figure 2 represents Standard A for BOD, which is 10 mg/l as defined by the National Water Quality Standards for Malaysia. These findings demonstrate that Lepironia articulata outperformed the other species in reducing BOD. The positive removal percentages indicate successful remediation by the aquatic plants. The percentage removal is calculated using Equation 1:

$$Percentage\ Removal\ (\%) = \left(\frac{BODinitial - BODfinal}{BODinitial}\right) \times 100 \quad (1)$$

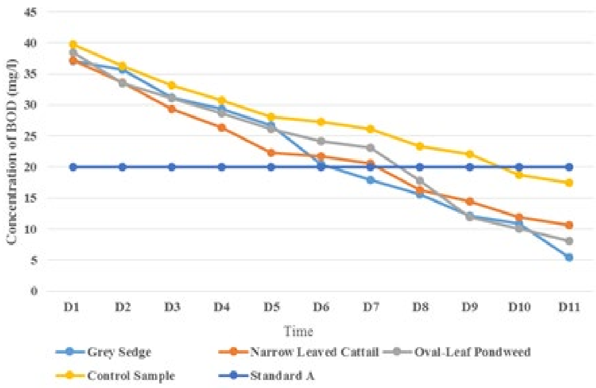

Figure 2. Biochemical Oxygen Demand (BOD) values for four different samples

5.2 Chemical Oxygen Demand (COD)

As illustrated in Figure 3, Monochoria vaginalis demonstrated the greatest removal of COD with a value of 96.68%, followed by Typha angustifolia and Lepironia articulata with removal rates of 89.46% and 84.61%, respectively. The control sample exhibited only a 3.24% reduction in COD. The blue line in Figure 3 represents Standard A for COD, which is 50 mg/l as defined by the National Water Quality Standards for Malaysia. The results indicate the effectiveness of these aquatic plants in reducing COD levels in wastewater. The percentage removal is calculated using Equation 2:

$$Percentage\ Removal\ (\%) = \left(\frac{CODinitial - CODfinal}{CODinitial}\right) \times 100 \tag{2}$$

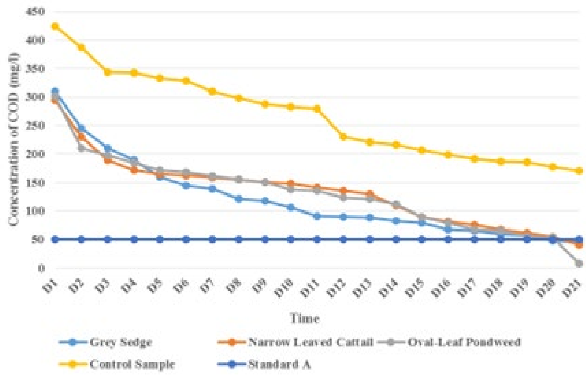

Figure 3. Chemical Oxygen Demand (COD) values for four different samples

5.3 Total Suspended Solids (TSS)

As shown in Figure 4, Lepironia articulata recorded the highest percentage of TSS removal at 92.32%, followed by Typha angustifolia and Monochoria vaginalis, with removal rates of 90.32% and 83.53%, respectively. The control tank showed only a 0.93% reduction in TSS. The blue line in Figure 4 represents Standard A for TSS, which is 50 mg/l as defined by the National Water Quality Standards for Malaysia. The study confirms the significant ability of the aquatic plants to reduce TSS in domestic wastewater. The percentage removal is calculated using Equation 3:

$$Percentage\ Removal\ (\%) = \left(\frac{Initial\ TSS\ Concentration - Final\ TSS\ Concentration}{Initial\ TSS\ Concentration}\right) \times 100 \tag{3}$$

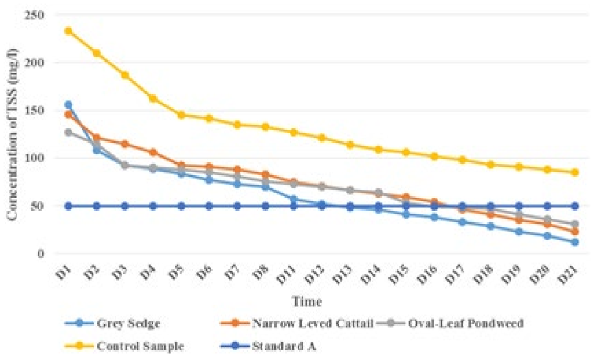

Figure 4. Total Suspended Solid (TSS) value for four different samples

5.4 Turbidity

Based on the results shown in Figure 5, Lepironia articulata recorded the highest turbidity removal efficiency at 97.34%. Monochoria vaginalis and Typha angustifolia followed with removal rates of 96.36% and 94.58%, respectively. The control sample exhibited only a 1.23% reduction in turbidity. The blue line in Figure 5 represents Standard A for turbidity, which is 5 NTU as defined by the National Water Quality Standards for Malaysia. These results indicate the high efficiency of the aquatic plants in improving water clarity by reducing turbidity levels. The percentage removal is calculated using Equation 4:

$$Percentage\ Removal\ (\%) = \left(\frac{Initial\,Turbidity - Final\,Turbidity}{Initial\,Turbidity}\right) \times 100 \tag{4}$$

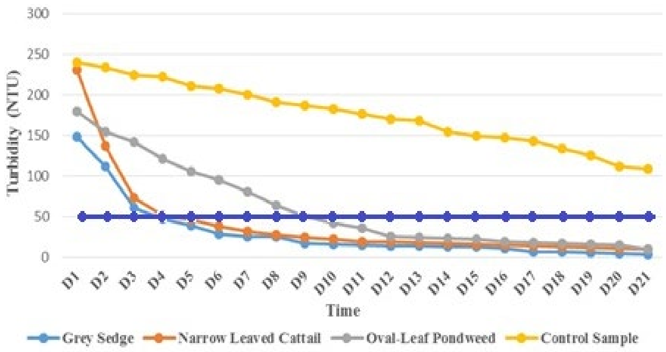

Figure 5. Turbidity value for four different samples

5.5 pH

The pH levels were measured weekly to ensure the water remained within a suitable range for the aquatic plants. As illustrated in Figure 6, all three aquatic plants maintained the pH of the wastewater within the neutral range (6.5-8.5) throughout the study. The control tank showed minor fluctuations in pH but remained within the acceptable range. The blue lines in Figure 6 represent the upper and lower limits of Standard A for pH, which are 6.5 and 8.5, respectively, as defined by the National Water Quality Standards for Malaysia.

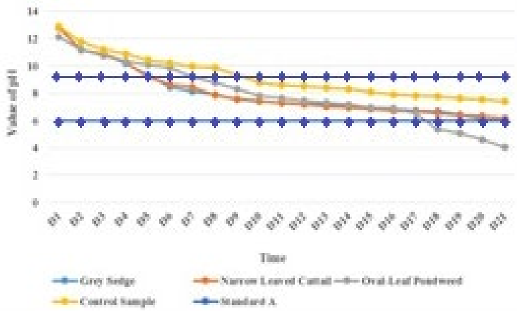

Figure 6. pH value for the four different samples

5.6 Copper (Cu)

As seen in Figure 7, the concentration of copper contaminants decreased significantly, with complete removal by week 3 for all three aquatic plants. The concentrations for Lepironia articulata, Typha angustifolia, and Monochoria vaginalis reached 0 mg/l, achieving a 100% success rate in copper remediation. The control sample, however, showed a slower decrease in copper concentration, reaching full removal only by week 6. The blue line in Figure 7 represents Standard A for copper, which is 0.05 mg/l as defined by the National Water Quality Standards for Malaysia.

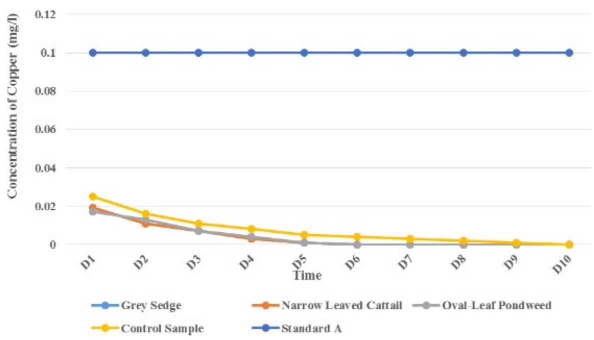

Figure 7. Concentration of copper values for four different samples

5.7 Chromium (Cr)

Figure 8 shows the decreasing concentrations of chromium over 11 weeks. Among the three plants, Monochoria vaginalis exhibited the highest chromium removal efficiency, with the concentration decreasing from 0.709 mg/l to 0.211 mg/l. Typha angustifolia and Lepironia articulata followed, showing reductions from 0.68 mg/l to 0.248 mg/l, and from 0.655 mg/l to 0.252 mg/l, respectively. The blue line in Figure 8 represents Standard A for chromium, which is 0.05 mg/l for Cr(VI) and 2.5 mg/l for Cr(III) as defined by the National Water Quality Standards for Malaysia. These results demonstrate that all three plants have significant potential for chromium removal.

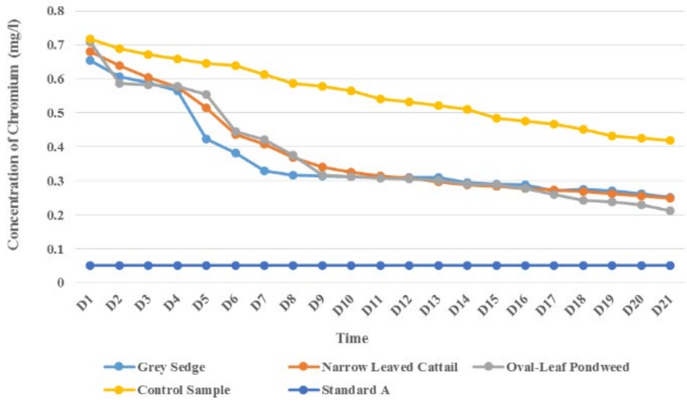

Figure 8. Concentration of chromium value for four different samples

5.8 Iron (Fe)

As shown in Figure 9, Monochoria vaginalis achieved the fastest iron removal, reducing the concentration from 1.345 mg/l to 0 mg/l. Lepironia articulata and Typha angustifolia also fully removed iron from the wastewater, though at different rates. The control sample showed a much slower reduction, with a final concentration of 0.890 mg/l, representing only a 43% reduction in iron content. The blue line in Figure 9 represents Standard A for iron, which is 1 mg/l as defined by the National Water Quality Standards for Malaysia.

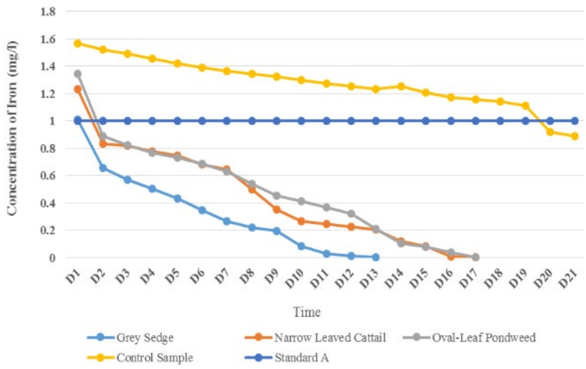

Figure 9. Concentration of iron value for four different samples

5.9 Lead (Pb)

Based on Figure 10, all three aquatic plants-Lepironia articulata, Monochoria vaginalis, and Typha angustifolia—successfully removed lead from the wastewater, with concentrations reaching 0 mg/l between Day 8 and Day 10. However, the initial lead concentrations in the wastewater samples were already below the Standard A limit. Therefore, while the plants demonstrated high removal efficiency, it is essential to note that the initial levels were already compliant with the standard, and the success of the plants should be evaluated based on their removal rates rather than just compliance. The blue line in Figure 9 represents Standard A for lead, which is 0.02 mg/l as defined by the National Water Quality Standards for Malaysia.

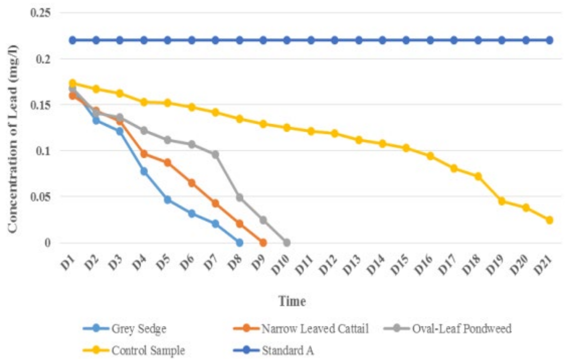

Figure 10. Concentration of Lead in four different samples

5.10 Zinc (Zn)

Figure 11 shows the lines that represent three selected aquatic plants and one control sample without any plants. All these samples are taken from domestic wastewater at Jalan Besi in Pasir Gudang, Johor. As shown in Figure 10, the concentration of zinc decreased for all samples. Among the aquatic plants, Lepironia articulata showed the highest reduction in zinc, from 0.310 mg/l to no detectable value. This is followed by Typha angustifolia and Monochoria vaginalis, with reductions from 0.370 mg/l to no detectable value and from 0.335 mg/l to no detectable value, respectively. The control sample showed a 77% success in removing zinc. The blue line in Figure 10 represents Standard A for zinc, which is 5 mg/l as defined by the National Water Quality Standards for Malaysia. All three aquatic plants achieved 100% removal, proving they are effective in zinc remediation [21].

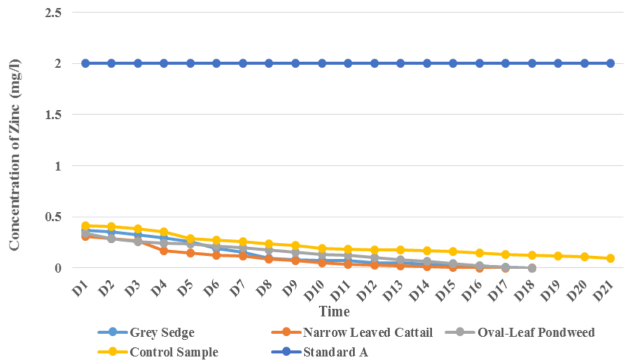

Figure 11. Concentration of Zinc in different four sample

The study confirms the potential of Monochoria vaginalis, Typha angustifolia, and Lepironia articulata as effective phytoremediation agents for domestic wastewater treatment, reducing environmental pollution. The efficacy of phytoremediation in removing heavy metals depends on various factors, including plant species selection, environmental conditions, and contaminant types. Our findings are consistent with the literature, suggesting that phytoremediation can be a viable solution for treating wastewater contaminated with heavy metals [14-15].

Table 1 provides the initial concentrations of various contaminants present in the wastewater before the application of phytoremediation. The concentrations are measured in milligrams per liter (mg/l) for heavy metals and in milligrams per liter (mg/l) or Nephelometric Turbidity Units (NTU) for other parameters.

Table 1. Initial concentration of heavy metal and other contaminants

Parameter	Concentration
Copper (Cu)	0.025 [mg/l]
Chromium (Cr)	0.718 [mg/l]
Iron (Fe)	1.568 [mg/l]
Lead (Pb)	0.173 [mg/l]
Zinc (Zn)	0.413 [mg/l]
BOD	39.70 [mg/l]
COD	425 [mg/l]
TSS	233 [mg/l]
Turbidity	240 [NTU]

Table 2 has shown successfully the percentage concentration of contaminants removal after using aquatic plants as phytoremediation agents. It has proven that Grey Sedge, Narrow Leaved Cattail and Oval-Leaf Pondweed are potential aquatic plants that are able to treat effluent domestic wastewater through phytoremediation process which involve the principle of ecology in rhizosphere bioremediation. All these three aquatic plants have the ability in accumulating contaminants especially the roots zone which is uniquely suitable as a model system that is used for screening plants and suitable for cleanup organic and inorganic pollutants. For Copper, Iron, Lead and Zinc removal, all three aquatic plants have 100% successful elimination within 11 weeks. For Chromium removal, Oval-Leaf Pondweed has the highest percentages removal of 70%. For BOD parameter, Grey Sedge has the highest percentages of removal with 85%. As for COD, Oval-Leaf Pondweed has shown the highest percentages removal with 97%. On the other hand, Grey Sedge was shown having the highest percentage in Total Suspended Solid parameter with 92%. In Turbidity parameter, Grey Sedge still shows the highest percentage with 97%.

Table 2. Percentage of removal of contaminants

Parameters	Grey Sedge	Narrow Leaved Cattail	Oval-Leaf Pondweed
Copper (Cu)	100	100	100
Chromium (Cr)	62	64	70
Iron (Fe)	100	100	100
Lead (Pb)	100	100	100
Zinc (Zn)	100	100	100
BOD	85	71	79
COD	85	86	97
TSS	92	84	76
Turbidity	97	96	95

6. CONCLUSION

This study demonstrates the potential of using aquatic plants, specifically *Monochoria vaginalis*, *Typha angustifolia*, and *Lepironia articulata*, for the phytoremediation of domestic wastewater contaminated with heavy metals and other pollutants. The results indicate that these plants were effective in reducing Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), turbidity, and the concentrations of heavy metals such as copper, chromium, iron, lead, and zinc. These findings are consistent with previous studies, which have highlighted the effectiveness of aquatic plants in pollutant removal [22-23]. Among the plants studied, *Lepironia articulata* showed the highest efficiency in removing BOD, TSS, and turbidity, while *Monochoria vaginalis* exhibited the highest removal efficiency for COD and chromium. Additionally, all three plants achieved significant removal rates for copper, iron, lead, and zinc, consistent with other research indicating the ability of aquatic plants to accumulate and detoxify heavy metals [24-25].

The concentrations mentioned in Table 1 reflect the initial levels of contaminants in the wastewater prior to treatment. The findings of this study affirm that phytoremediation, utilizing these specific plant species, is a promising green technology for improving water quality in domestic wastewater systems. Given the increasing global emphasis on sustainable and low-cost treatment technologies, this approach provides a viable alternative for regions with limited access to conventional treatment systems [26]. However, further research is needed to optimize the operational conditions for large-scale applications and to evaluate long-term performance in different environmental settings [6]. By contributing to the growing body of knowledge on the use of phytoremediation for wastewater treatment, this study supports the ongoing development of environmentally friendly solutions to water pollution, reinforcing the potential of phytoremediation as a sustainable option for water management.

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AUTHOR CONTRIBUTIONS

All authors contributed significantly to the research and manuscript preparation.

F. Ismail designed the study and conducted the experiments.

A.S. Abd Razak performed the data analysis and interpretation.

A. Z. A. Mohamad Termizi prepared the manuscript and was responsible for the literature review.

M. A. S. Nasarudin and S. Sulaiman also contributed to various aspects of the research and writing process. All authors reviewed and approved the final version of the manuscript.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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