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Comparative Study of Heavy Metal Uptake by Invasive Plant in Two Aquatic Environment

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Abstract

Water pollution resulting from agricultural runoff and urban activities has become a major environmental concern due to its adverse effects on surface water quality and aquatic ecosystems. Conventional water treatment methods are often costly and require intensive maintenance, highlighting the need for sustainable and nature-based alternatives. Phytofiltration using aquatic macrophytes offers a low-cost and environmentally friendly approach for improving water quality. This study investigates the phytofiltration potential of water lily (*Nymphaea sp.*) and water hyacinth (*Eichhornia crassipes*) in two different freshwater systems, namely Tasik Laguna at Universiti Tun Hussein Onn Malaysia (UTHM) and the Sawah Ring irrigation canal. A three-week experimental study was conducted with three trials per week for each plant and water system combination. Water quality parameters including aluminium (Al), nitrite (NO_2^-), nitrate (NO_3^-), ammonia (NH_3/NH_4^+), total hardness (THH), chloride (Cl^-), phosphate (PO_4^{3-}), copper (Cu), chlorophyll (CH) and pH were analysed before and after each treatment period to evaluate pollutant removal efficiency. The average weekly percentage removal was calculated to compare the phytofiltration performance of both aquatic plants under different hydrological conditions. The results showed that water hyacinth exhibited exceeding 60% removal efficiency for nutrients and selected heavy metals in the Sawah Ring canal, which is characterised by flowing water and higher pollutant loads. In contrast, water lily demonstrated more consistent performance in the relatively stagnant lake environment of Tasik Laguna, contributing to nutrient reduction and chlorophyll control through sediment interaction and surface shading. In conclusion, this study demonstrates that aquatic plant-based phytfiltration is an effective and sustainable method for improving surface water quality. The findings emphasise the importance of selecting appropriate plant species based on site conditions and support the application of nature-based solutions in water quality management. These results provide practical insights for local water management authorities and highlight the potential integration of phytofiltration into low-cost water remediation strategies.

1. Introduction

Water pollution has become a major environmental issue due to rapid urbanisation, agricultural intensification and increasing anthropogenic activities. Runoff from agricultural lands, industrial discharges and urban wastewater introduces excessive nutrients and heavy metals into surface water bodies, leading to eutrophication, degradation of aquatic ecosystems and risks to human health and biodiversity [1]. Elevated concentrations of nitrogen and phosphorus stimulate algal blooms and reduce dissolved oxygen levels, while heavy metal contamination poses long-term ecological and toxicological threats. Conventional water treatment technologies are often costly and require complex infrastructure, limiting their application in developing regions. Consequently, nature-based solutions such as phytoremediation have gained increasing attention as sustainable, low-cost and environmentally friendly alternatives for improving water quality.

Phytofiltration utilises plants and their associated microbial communities to remove, stabilise or transform pollutants through processes such as nutrient uptake, rhizofiltration and microbial-assisted degradation. Aquatic macrophytes are particularly effective in water treatment systems due to their high biomass production, extensive root systems and ability to support microbial biofilms [2]. Among these, water lily and water hyacinth are commonly found in Malaysia freshwater environments and have demonstrated strong pollutant removal capabilities. Previous studies have reported that water hyacinth can remove up to 60-80% of nitrogen and phosphorus from contaminated water while accumulating heavy metals within its tissues [3]. However, the efficiency of these plants is strongly influenced by site-specific conditions such as water flow, nutrient loading and sediment dynamics.

In Malaysia, freshwater systems exhibit diverse hydrological characteristics. Tasik Laguna at Universiti Tun Hussein Onn Malaysia (UTHM) is a semi-natural lake with relatively stagnant water, moderate nutrient input and existing water lily coverage that contributes to algal control through surface shading and sediment interaction. In contrast, the Sawah Ring irrigation canal is an agricultural water system exposed to direct runoff from paddy fields, resulting in high nutrient concentrations, sediment accumulation and fluctuating flow regimes. Water hyacinth is commonly observed in such polluted, flowing environments due to its rapid growth and high tolerance to adverse water quality conditions. Despite the natural presence of these aquatic plants, there is limited quantitative information comparing their phytofiltration performance under contrasting hydrological conditions.

Water pollution remains a critical global challenge, while invasive aquatic species are often regarded solely as ecological threats that require eradication due to their impacts on native biodiversity and ecosystem function [4]. This approach overlooks the potential of invasive plants as effective agents for phytofiltration. Although their pollutant-absorbing capabilities are well documented, limited studies have evaluated their application in controlled of semi-controlled systems such as floating treatment wetlands across different water quality conditions [5]. The lack of comparative data restricts the development of site-specific guidelines for plant selection and system design.

Therefore, this study evaluates and compares the phytofiltration performance of water lily and water hyacinth in two contrasting freshwater systems, namely Tasik Laguna (UTHM) and the Sawah Ring irrigation canal. The study focuses on assessing nutrient and selected pollutant removal under stagnant and flowing water conditions to identify the most suitable aquatic plant for different environmental settings. The findings are expected to provide scientific evidence supporting the application of aquatic macrophytes as cost-effective and sustainable solutions for water quality management, particularly in agricultural and campus environment while also contributing to the beneficial utilisation of invasive species within nature-based treatment systems.

2. Research Method

2.1 Site Selection

Two study sites with contrasting environmental conditions were selected to evaluate phytofiltration performance. Tasik Laguna represents a semi-stagnant urban lake influenced by runoff, organic matter accumulation and sediment deposition. In contrast, the Sawah Ring canal represents a flowing agricultural system with high nutrient inputs from fertiliser runoff and increased sediment loads from paddy field drainage. This site selection allows comparison of phytofiltration efficiency under typical urban and agricultural conditions.

Fig. 1 Tasik Laguna Pagoh, UTHM **(**2.1541° N, 102.7399° E.**)**

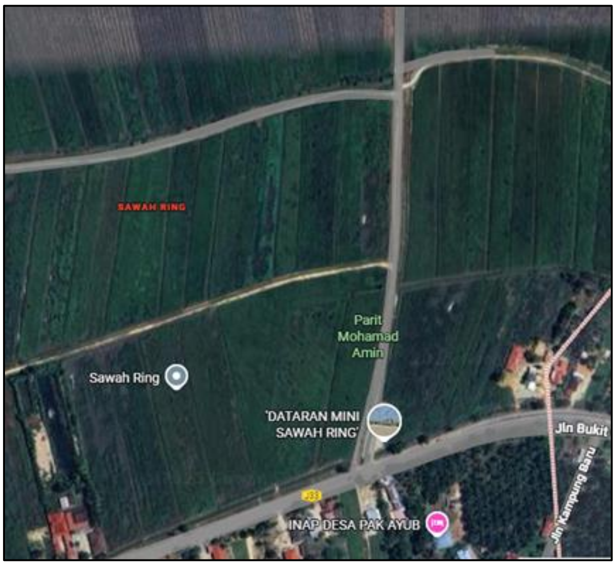

Fig. 2 Sawah Ring, Tangkak (2.226516° N, 102.682555° E.)

2.2 Plant Selection

The selection of aquatic plant species was based on ecological relevance, local availability and contrasting functional traits. Water lily (*Nymphaea* spp.) was selected to represent rooted, floating-leaved macrophytes commonly found in lake environments. Its rooted growth form allows direct interaction with sediments, making it suitable for stabilising bottom substrates and indirectly controlling algal growth through surface shading. Water hyacinth (*Eichhornia crassipes*), a free-floating macrophyte, was selected due to its well-documented capacity for rapid growth and high nutrient uptake. Its extensive fibrous root system provides a large surface area for adsorption of dissolved pollutants and attachment of microorganisms. The inclusion of both species enables comparison between different plant growth forms and their respective phytofiltration mechanisms.

2.3 Experimental Setup and Water Quality Assessment

The experiment was conducted over a three-week period to evaluate changes in water quality resulting from phytofiltration. Separate containers were prepared for each plant water combination. To maintain consistency, water samples were always collected from the same relative position in each container. Baseline water quality measurements were taken before plant introduction to establish reference conditions. The parameters analysed included selected nutrients, heavy metals, pH, chloride, hardness and chlorophyll. All measurements were carried out using a digital water testing instrument. For each measurement, water samples were collected and analysed according to the manufacturer's standard operating procedures. The same instrument was used throughout the study to ensure consistency in data collection and allow reliable comparison between pre- and post-treatment results. After baseline measurement, aquatic plants were introduced into the containers. The plants were allowed to interact naturally with the water for a one-week treatment period. During this time, pollutant removal occurred through nutrient uptake, particle adsorption and rhizosphere-related processes. Each plant water combination was tested in three independent trials to reduce variability and improve data reliability. This repeated-measures design enabled comparison of water quality changes across time, plant species and water body types.

2.4 Data Analysis and Percent Removal Calculation

Data obtained from before and after sampling were analysed to calculate pollutant removal efficiency using the percent removal formula. Mean removal efficiencies were calculated weekly and over the entire experimental period. Statistical trends were evaluated by examining temporal changes in removal efficiency across weeks and comparing mean values among plant species and water bodies. Consistent increases or decreases in nutrient, metal and chlorophyll removal efficiency were identifies to determine treatment performance.

2.5 Percentage Removal Efficiency Formula

$$\text{Removal (\%)} = \frac{C\ \textit{before} - C\ \textit{after}}{C\ \textit{before}} \times 100$$

Where

•C *before* = concentration of the water quality parameter before phytofiltration (mg/L)
•C *after* = concentration of the water quality parameter after phytofiltration (mg/L)

The percentage removal efficiency represents the effectiveness of the phytofiltration process in reducing pollutant concentrations by comparing initial and final values. A higher percentage removal indicates greater treatment efficiency, while lower values reflect limited pollutant reduction.

3. Result and Discussion

3.1 Percentage Removal Efficiency of Water Quality Parameters by Different Plant Species

Percentage removal efficiency analysis provides a quantitative comparison of phytofiltration performance among plant species. The results indicate that nitrogen-based pollutants achieved the highest removal efficiencies, followed by phosphate and heavy metals. Higher nitrogen removal efficiency is attributed to the combined effects of direct plant uptake and enhanced microbial activity within the rhizosphere [6]. Differences in removal efficiency among plant species may be explained by variations in root morphology, growth rate and nutrient demand. Plants with extensive root systems offer greater surface area for microbial colonisation and nutrient absorption [7]. Metal removal efficiencies were comparatively lower but showed stable trends, consistent with previous studies indicating that metal uptake in phytoremediation relies more on adsorption and sequestration rather than metabolic utilisation [8].

Table 1 Percentage Mean Concentration Removal Efficiency of Water Quality Parameters by Different Plant Species (%)

Week	Scenario	Al	NO_2	NO_3	NH_3/NH_4	THH	Cl	pH	PO_4	Cu	CH
1	Hyacinth_Sawah	25	29.93	30	29.88	10	9.99	0.31	29.94	24.71	30
1	Hyacinth_Tasik_sim	0	0	0	24.44	0	10.01	0.22	25	20.33	25
1	Lily_Sawah_sim	4	9.96	10	9.44	2	10.01	0.13	10	4.31	10
1	Lily_Tasik	0	0	0	11.05	0	10.01	0.05	11.88	5.07	12
2	Hyacinth_Sawah	25	30.1	30	29.33	10	9.99	0.21	30.18	26.42	30
2	Hyacinth_Tasik_sim	0	0	0	24.71	10	10.01	0.11	25	19.33	25
2	Lily_Sawah_sim	4	10.02	10	10.08	2	10	0.28	10.09	4.41	10
2	Lily_Tasik	0	0	0	10.98	0	10	0.34	12.18	5.31	12
3	Hyacinth_Sawah	25	30.06	30	29.3	10	9.99	0.1	30.06	25.02	30
3	Hyacinth_Tasik_sim	0	0	0	24.71	0	10	0.42	25.06	20.23	25
3	Lily_Sawah_sim	4	9.99	10	10.02	2	9.98	0.28	10.01	4.38	10
3	Lily_Tasik	0	0	0	10.25	0	10.03	0.33	11.92	5.18	12

The results show clear differences in water quality removal efficiency between plant species and water body types. Water hyacinth consistently showed higher removal efficiency for nutrients, particularly nitrate, ammonia/ammonium and phosphate, compared to water lily. This trend was most evident in the Sawah Ring canal, where flowing water conditions enhanced nutrient uptake and adsorption processes. The higher efficiency of water hyacinth is attributed to its rapid growth rate and well-developed root system, which promote effective nutrient assimilation and rhizosphere activity [11.]

In contrast, water lily demonstrated moderate but stable removal efficiency particularly in the lake environment of Tasik Laguna. Lower removal efficiencies observed in the lake for both plant species are likely related to reduced water movement and lower pollutant concentrations, which limit pollutant-root interactions. [12]. Removal of heavy metals such as copper was generally moderate, reflecting adsorption and immobilisation mechanisms rather than active uptake [13].

Overall, the findings confirm that phytofiltration performance is strongly influenced by plant species and hydrological conditions. Water hyacinth is more suitable for nutrient-rich, flowing systems, while water lily performs better under semi-stagnant conditions, highlighting the important of site-specific plant selection for effective phytofiltration applications.

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3.2 Comparison Between Plant Species and Water Bodies

Comparative analysis between plant species and water bodies revealed notable differences in phytofiltration effectiveness, indicating that both biological and environmental factors influence treatment performance. Water hyacinth consistently demonstrated higher removal efficiency, particularly for nutrients, suggesting strong adaptability and high pollutant uptake capacity. This may be attributed to its extensive fibrous root system, which provides a large surface area for nutrient absorption and microbial colonisation. These root-associated microorganisms further enhance nutrient transformation and removal processes.

Variations in removal efficiency between water bodies can be explained by differences in initial pollutant concentrations, hydrological conditions and surrounding land use activities. Nutrient-rich environments generally promote higher phytofiltration efficiency because greater pollutant availability increases the rate of plant uptake and microbial activity [9]. In contrast, lower pollutant concentrations may limit removal efficiency since fewer nutrients are available for assimilation. Water chemistry also plays an important role in determining phytofiltration performance. Parameters such as pH influence nutrient availability and metal solubility, which directly affect plant uptake efficiency [10]. For example, slightly acidic to neutral pH conditions often improve metal mobility, allowing easier absorption by plant roots. Hydrological conditions further contribute to performance differences, as flowing systems can enhance oxygenation and nutrient transport, whereas stagnant systems may rely more on sediment interaction and surface shading effects.

Table 2 Combined Comparison of Plant Species and Water Bodies

Plant Species	Water Body	Overall Performance/ Percentage Efficiency Removal (%)	Key Observation
Water Hyacinth	Tasik Laguna	Highest efficiency 65%	Optimal match of plant traits and nutrient-rich conditions
Water Hyacinth	Sawah Ring	Moderate high 55%	Performance reduced due to lower pollutant availability
Water Lily	Tasik Laguna	Moderate 45%	Effective but limited by plant uptake capacity
Water Lily	Sawah Ring	Lowest efficiency 30%	Less favourable plant-environmental interaction

Comparison between water bodies revealed that nutrient-rich environments supported higher removal efficiencies, particularly for nitrogen compounds. This suggests that pollutant availability plays a significant role in determining phytofiltration effectiveness. The combined comparison further highlights that optimal phytoremediation performance is achieved when suitable plant species are matched with favourable site conditions. Overall, the table-based analysis confirms that phytofiltration efficiency is governed by the interaction between plant physiological traits and environmental conditions. Floating macrophytes with rapid growth and dense root systems tend to perform better in nutrient-rich waters, while rooted plants contribute more to sediment-related pollutant control. This reinforces the importance of strategic plant selection and site-specific assessment when implementing phytofiltration systems to ensure optimal performance and long-term sustainability

3.3 Key Challenges

The primary challenge in this study was the variability in phytofiltration efficiency caused by differences in environmentaland hydrological conditions, which influenced plant performance and pollutant removal rates. Factors such as fluctuating nutrient loads, water flow conditions and sediment composition affected the consistency of pollutant uptake, particularly in flowing canal systems like the Sawah Ring canal. Additionally, the limited removal conservative ions and the moderate efficiency for heavy metals highlighted the constraints of phytofiltration when applied to pollutants that are not readily assimilated by plants.

Another key challenge involved the short experimental duration, which restricted the evaluation of long-term plant stability, biomass accumulation and potential nutrient re-release. This limitation may have led to underestimation or variability in removal efficiency, especially during the early acclimatisation phase of plant growth. Overall, these challenges emphasise the need for site-specific plant section, adequate treatment duration and integrated management strategies to optimise phytofiltration performance under real-world conditions

4. Conclusion

This study evaluated the effectiveness of phytofiltration using aquatic plant species in improving water quality across different freshwater environments over a three-week experimental period. The findings demonstrate that both water hyacinth and water lily contributed to the reduction of nutrient and selected heavy metal concentrations with removal efficiency influenced by plant species, water body type and hydrological condition. Water hyacinth showed comparatively higher efficiency in removing nitrogen-based pollutants, particularly ammonia/ammonium and nitrate, indicating its suitability for flowing canal systems. Water lily exhibited more stable performance in lake environments, reflecting its adaptability to low-flow conditions.

Temporal analysis revealed a progressive increase in removal efficiency over the experimental period, highlighting the role of plant acclimatisation and retention time in enhancing phytofiltration performance. Nutrient-rich conditions promoted higher uptake rates while the removal of conservative ions such as chloride remained limited. Moderate copper removal suggests that metal reduction occurred primarily though adsorption and immobilisation mechanism at the root-water interface.

Overall, the findings confirm that phytofiltration is a feasible nature-based approach for nutrient and metal reduction in freshwater systems. The comparative assessment provides technical insight int plant selection and site-specific application, supporting the implementation of phytofiltration as a sustainable water quality management strategy in agricultural and semi-urban environments.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Hurulain Silmina Hamdi, Furzani Pa'ee;* ***data collection:*** *Hurulain Silmina Hamdi, Haiqal Hazwan Mohd Hanafi, Muhammad Amirullah Mohd Rosli;* ***analysis and interpretation of results:*** *Hurulain Silmina Hamdi;* ***draft manuscript preparation:*** *Hurulain Silmina Hamdi, Furzani Pa'ee. All authors reviewed the results and approved the final version of the manuscript*

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