CONSTRUCTION
E-ISSN: 2785-8731
VOLUME 4, ISSUE 2, 2024, 156 – 164
DOI: https://doi.org/10.15282/construction.v4i2.10680

RESEARCH ARTICLE

The Performance of Pistia Stratiotes and Eichornia Crassipes for the Heavy Metal Removal during Backwash Water from WASRA System

F. Ismail, A.S. Abd Razak*, A.Z.A. Mohamad Termizi, M.A.S. Nasarudin, and S. Sulaiman

Faculty of Civil Engineering Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuhraya Tun Razak, 26300 Gambang, Kuantan, Pahang, Malaysia

ABSTRACT - This study was conducted to determine the ability of Phytoremediation technology in treating groundwater contaminated with high heavy metal content of waste water, which is known as backwash water, using WASRA. Two types of aquatic plants have been used as agents for the treatment of wastewater; water hyacinth (Eichhornia crassipes) and water lettuce (Pistia stratiotes). To absorb heavy metals from the wastewater, two tanks were used for placing the plants. All analyses on wastewater are based on the Standard Procedures issued by American Public Health Association (APHA, 2017). The study of plant morphology is also conducted, where the study uses FESEM/EDX methods to determine the type of heavy metals found in these plant parts. These plants were divided into three parts which are leaves, stems, and roots. Based on experiments, different species of plants have the ability to remove metals at different levels of effectiveness. Thus, the two species, used as agents of phytoremediation are successful in removing heavy metals, with a removal rate of 50.79% to 88.49%. Pistia stratiotes precedes absorption rates of various heavy metals in high rates in the root part. In conclusion, phytoremediation technology has a very high potential in removing pollutants from water.

ARTICLE HISTORY

Received	:	10th May 2024
Revised	:	20th June 2024
Accepted	:	09th July 2024
Published	:	15th Aug. 2024

KEYWORDS

Eichhornia crassipes
Pistia stratiotes
Heavy Metal
FESEM/EDX
Phytoremediation

1. INTRODUCTION

Water is a fundamental necessity for all living organisms, particularly humans. Its unique chemical properties, including polarity and hydrogen bonding, enable it to disperse, absorb, or suspend a wide range of compounds. Groundwater and surface water serve as vital sources of fresh water for both human consumption and maintaining the health of aquatic ecosystems. However, the interaction between these water sources presents various environmental concerns, such as aquifer contamination and the potential for surface water pollution due to waterborne contaminants, including heavy metals [1-2]. The presence of heavy metals in groundwater poses significant threats to the environment, marine life, and human well-being. In rural areas of Malaysia, water crises are not uncommon, primarily due to the logistical challenges of establishing conventional piped water systems. Many remote, underdeveloped regions with low population densities rely on local water sources, such as rivers, rainwater, and groundwater. Unfortunately, these sources are susceptible to contamination from nearby development activities, and water availability is highly dependent on weather conditions. To address this issue, a novel system known as the Water Supply System for Rural Areas (WASRA) has been introduced. WASRA aims to provide clean water to rural communities by treating rainwater and groundwater using natural raw materials and ultrafiltration membranes. WASRA effectively removes contaminants such as heavy metals, organic and inorganic substances, and harmful microorganisms, safeguarding the health of these communities.

Among the various processes involved in the WASRA system, this study focuses on the backwash process, a vital component in water filtration systems that helps maintain filter longevity and water quality. It is important to note that the backwash water often contains heavy metals, including fluoride, iron, zinc, aluminium, copper, and manganese. To address this challenge, this study explores the potential of phytoremediation as a solution. Phytoremediation is a cost-effective and environmentally friendly technology that has been proven effective in removing contaminants, making it highly relevant for developing countries [3-4]. This method leverages the unique ability of aquatic plants to absorb nutrients and heavy metals from water. To enhance the removal of heavy metals from backwash water, two types of aquatic macrophytes, namely water lettuce (Pistia stratiotes) and water hyacinth (Eichornia crassipes), are utilized. The use of these plants facilitates the removal of heavy metals from the backwash water, ensuring compliance with environmental regulations.

2. METHOD AND MATERIALS

For this project, samples of backwash water were taken from the WASRA pump system. The treatment of backwash water will be conducted using a phytoremediation system in the same area. The phytoremediation system is divided into two zones: extreme zones and polishing zones. In this study, water samples are concentrated in the polishing zones that use two types of plants: Eichhornia crassipes (water hyacinth) and Pistia stratiotes (water lettuce). The plants will be

***CORRESPONDING AUTHOR | A. S. Abdul Razak** | ✉ syukor@umpsa.edu.my

specifically arranged in the phytoremediation system before the treatment starts. The polishing zones in the phytoremediation system have two batches: the first batch consists of water hyacinths, while the second batch consists of water lettuces. Samples of water flowing in and out through each plant species will be taken once a week for 8 weeks during the study period. For each sampling period, three samples from each treatment batch will be collected for further evaluation. The water samples will be analysed based on the following parameters: Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), Turbidity, and the concentrations of heavy metals such as manganese (Mn), zinc (Zn), iron (Fe), copper (Cu), and lead (Pb).

For heavy metal analysis, an atomic absorption spectrophotometer (AAS) will be used. Additionally, Field Emission Scanning Electron Microscopy/Energy Dispersive X-Ray (FESEM/EDX) will be employed to determine the amount of heavy metal in the plant tissues, including the leaves, stems, and roots. The sampling method will follow the standard methods for the examination of water and wastewater by the American Public Health Association (APHA, 2005)[5]. Moreover, the quality of the backwash water before and after treatment will be assessed based on the Water Quality Act (WQA, 1975) under the Environmental Quality (Industrial Effluent) Regulations, 2009[6]. The analysis of the parameters will be conducted weekly. This procedure is essential to evaluate the effectiveness of phytoremediation technology in removing heavy metal contaminants from backwash water. Specifically, samples were preserved using specified procedures to ensure data quality. For the BOD test, samples should ideally be analysed on the same day as sampling. If not possible, they should be stored at 4°C and can be preserved for up to 48 hours. For heavy metal testing, samples must be preserved using nitric acid, adjusting the pH to less than 2. These preservation steps are crucial to prevent inaccuracies in the results.

Most of the parameters will be measured using a DR-5000 spectrophotometer following APHA (2005) guidelines. Heavy metal analysis will be performed using an AAS to determine the heavy metal concentrations in each sample. In studying heavy metal removal, the plants will be analysed to determine the amount and type of heavy metals in the plants and their impact on the plants. The FESEM/EDX method will be used for this analysis. Plant samples will be cut into small parts and placed at ambient temperature for 24 hours before analysis. The data from each sample point will be analysed using Microsoft Excel. This approach will help determine if there are differences between the two types of plants in the phytoremediation treatment over time. Thus, Microsoft Excel will be used to obtain the results.

The water quality parameters chosen for these study COD, BOD, TSS, Turbidity, and heavy metal concentrations are critical indicators of water pollution and overall water quality. COD and BOD are essential for understanding the organic load and the oxygen demand in the water, which are crucial for assessing the potential impact on aquatic life and the overall ecosystem. TSS and Turbidity provide insights into the presence of particulate matter, which can affect water clarity and quality. The selected heavy metals (Mn, Zn, Fe, Cu, Pb) are common pollutants that pose significant health risks to humans and the environment, making their monitoring vital for ensuring compliance with environmental regulations such as the Environmental Quality (Industrial Effluent) Regulations, 2009[6]. Figure 1 illustrates the flow of backwash water from the WASRA system through the phytoremediation process, highlighting the different zones and plant batches used for treatment.

2.1 WASRA Pump System:

The process begins with the WASRA pump system, which is the source of backwash water.

a) Phytoremediation System:

The backwash water from the WASRA pump system is directed into the phytoremediation system, which is designed to treat the water.

b) Extreme Zone:

Within the phytoremediation system, the water first passes through the extreme zone. This zone includes a pre-treatment area where initial filtration and sedimentation take place. This step helps to remove larger particles and some contaminants, preparing the water for further treatment.

c) Polishing Zones:

After the extreme zone, the partially treated water flows into the polishing zones, which consist of two separate batches:

- Batch 1: This batch contains water hyacinths (*Eichhornia crassipes*). These plants are known for their ability to absorb and remove heavy metals and other contaminants from the water.
- Batch 2: This batch contains water lettuces (*Pistia stratiotes*). Similar to the water hyacinths, water lettuces also play a crucial role in absorbing and removing contaminants from the water.

d) Treated Water:

After passing through the polishing zones, the now-treated water exits the phytoremediation system. This clean water is then ready for supply to the rural community, ensuring they have access to safe and clean water.

The combination of the WASRA system and the phytoremediation system, including the extreme zone and polishing zones, provides a comprehensive approach to treating backwash water. By leveraging the natural abilities of water hyacinths and water lettuces, this system effectively removes heavy metals and other contaminants, making the water safe for use.

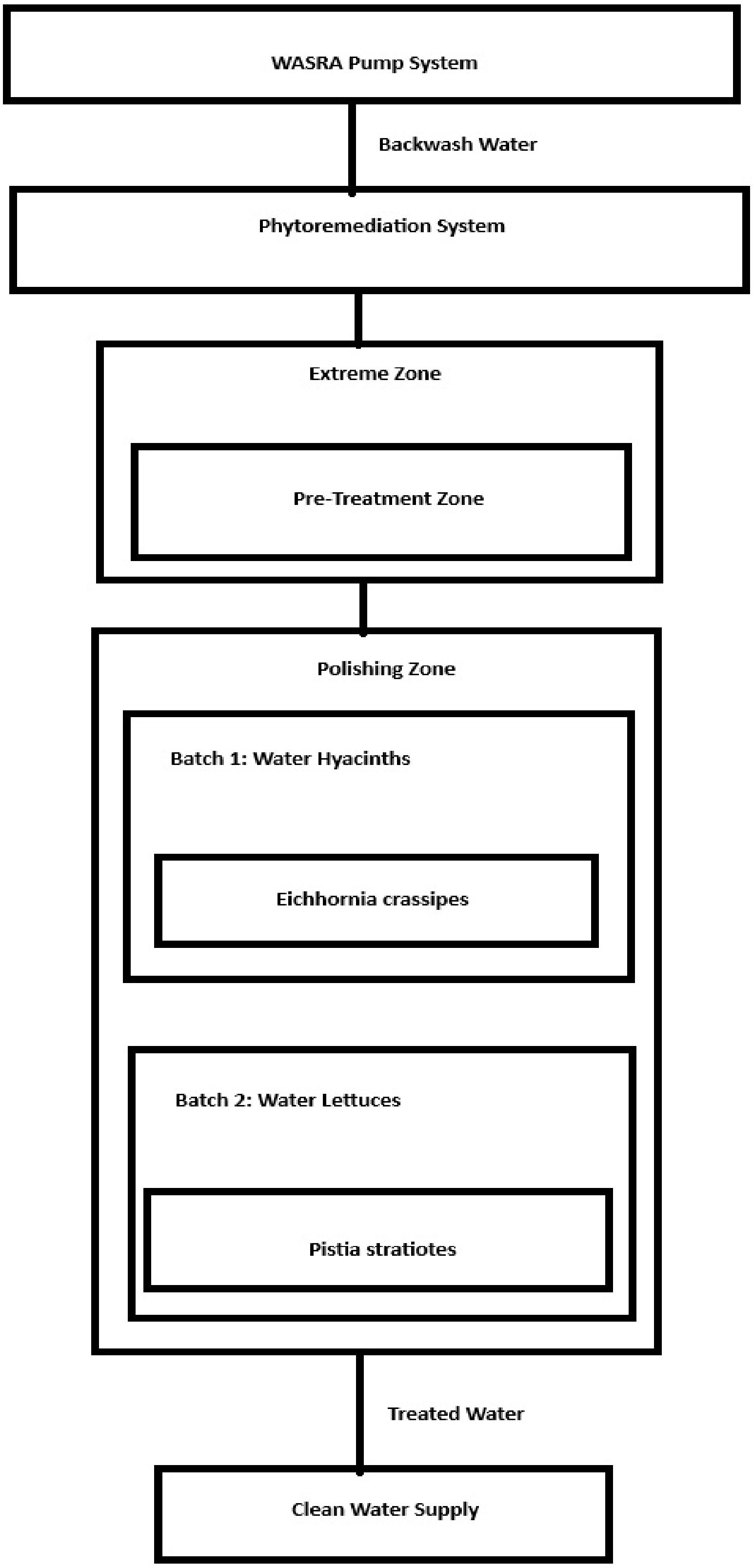

Figure 1. WASRA pump system

3. RESULTS AND DISCUSSION

In order to determine the removal efficiency of the plants used on the parameters studied, the data obtained will be used accordingly. The formula to calculate the removal efficiency for each plant is as follow in Eq.1.

$$\text{Removal efficiency} = (\text{Inlet Concentration-Outlet concentration})/ (\text{Inlet concentration}) \times 100\% \quad (1)$$

The Inlet Concentration and Outlet Concentration were measured considering the retention time of the water in the phytoremediation system. The retention time was determined to be 24 hours, which is the duration it takes for water to travel from the inlet to the outlet. Therefore, the Inlet Concentration was measured at the beginning of this period, and the Outlet Concentration was measured 24 hours later. This ensures that the removal efficiency calculation accurately reflects the treatment process. Based on data for 15 samples, the average value will be calculated and finally percentage removal efficiency for all parameters was obtained. The analysis also was carried out using FESEM/EDX where the parts of the plant are analyzed and data of physiology at each part will be produced. Subsequent discussions will be based on results obtained.

3.1 Removal Efficiency of Two Types of Plant

As shown in Figure 2, the removal efficiency for Eichhornia crassipes is 45.44% and stands at the highest rank compared to the Pistia stratiotes. The removal efficiency for Pistia stratiotes is only 42.67%. This finding is in line with expected performance for water hyacinth pond [3]. This condition happens due to the capability of Eichhornia crassipes to support medium for microbial degradation to take place in the contaminated water [7-8]. The data presented in this study indicates that both water hyacinths and water lettuces are effective in removing heavy metals from the backwash water. However, Eichhornia crassipes shows a higher removal efficiency compared to Pistia stratiotes. This could be attributed to its higher biomass production and faster growth rate, which enhance its ability to absorb and accumulate heavy metals [9].

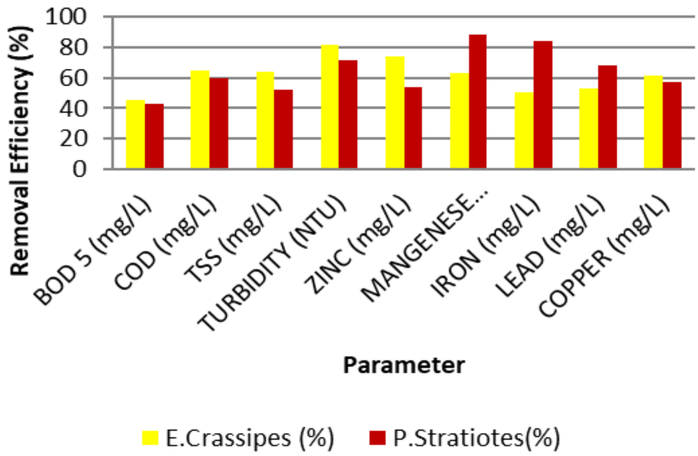

Figure 2. Graph on removal efficiency two type of plants

3.2 Chemical Oxygen Demand (COD)

The COD removal efficiency using Eichhornia crassipes was higher compared to Pistia stratiotes as shown in Figure 2. For Eichhornia crassipes, the COD reduction is 61.32% while Pistia stratiotes recorded a COD reduction of 58.93%. This can be attributed to the higher biomass production in Eichhornia crassipes, which results in higher organic matter uptake and COD reduction. This result is consistent with findings from other studies indicating the higher efficacy of Eichhornia crassipes in reducing organic pollutants [10-11].

3.3 Biochemical Oxygen Demand (BOD)

The BOD removal efficiency using Eichhornia crassipes was higher compared to Pistia stratiotes as shown in Figure 2. For Eichhornia crassipes, the BOD reduction is 49.23% while Pistia stratiotes recorded a BOD reduction of 46.78%. This could be due to the higher metabolic activity and greater root surface area of Eichhornia crassipes, which enhances microbial degradation of organic matter, leading to higher BOD removal [12-13].

3.4 Total Suspended Solids (TSS)

The TSS removal efficiency using Eichhornia crassipes was higher compared to Pistia stratiotes as shown in Figure 2. For Eichhornia crassipes, the TSS reduction is 57.80% while Pistia stratiotes recorded a TSS reduction of 53.90%. This may be due to the dense root structure of Eichhornia crassipes, which effectively traps and settles suspended particles, resulting in higher TSS removal [14-15].

3.5 Turbidity

The turbidity removal efficiency using Eichhornia crassipes was higher compared to Pistia stratiotes as shown in Figure 2. For Eichhornia crassipes, the turbidity reduction is 59.40% while Pistia stratiotes recorded a turbidity reduction of 55.60%. This result aligns with the higher TSS removal efficiency observed in Eichhornia crassipes, as turbidity is often correlated with the presence of suspended particles in water [16-17].

3.6 Heavy Metal Content in Two Types of Plant Parts

Aquatic plants can absorb and accumulate metals within particles in contaminated water. In this study, to detect heavy metals such as zinc, manganese, iron, lead, and copper in aquatic plants, FESEM together with EDX was used. To analyse these two types of aquatic plants, they were divided into three parts: leaves, stems, and roots for Eichhornia crassipes, and leaves and roots for Pistia stratiotes. The results for each part of the plants are discussed in the following section.

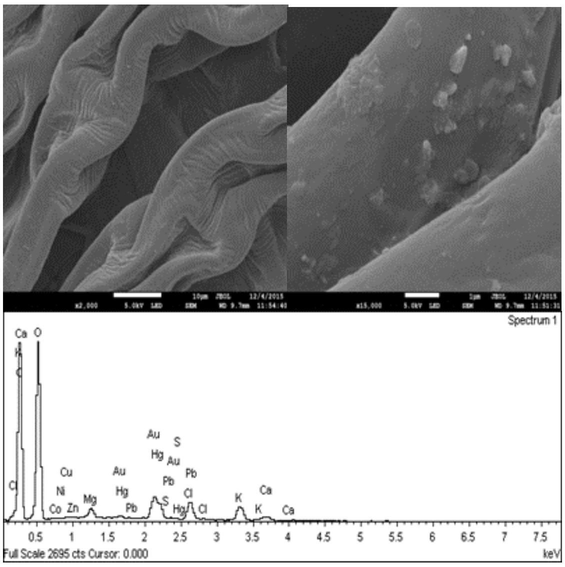

Figure 3. FESEM micrographs and EDX spectra in leaves area of Eichhornia Crassipes

Table 1. Weight of heavy metal in leaf area of Eichhornia Crassipes

Heavy Metal	Weight (%)
Lead	0.27
Iron	0.26

The percentages in Table 1 were obtained by analysing the EDX spectra, which measure the relative abundance of elements in the sample. The weight percentage represents the proportion of the total detected elements that is attributable to each specific heavy metal. Only a small amount of heavy metals for iron and lead can be detected in the leaves section in Eichhornia crassipes (Figure 3), where it can be related with the upward translocation of iron and lead through xylem. In Table 1, it is found that the amount of weight for lead is more than the amount of weight for iron. The value of weight for lead is 0.27%, while for iron is 0.26%. The leaves consist of lead concentration, but no more than in roots and stems [12]. In addition, the spectra of Eichhornia crassipes did not find other heavy metals due to the lower internal concentration of metals in the leaf's cells.

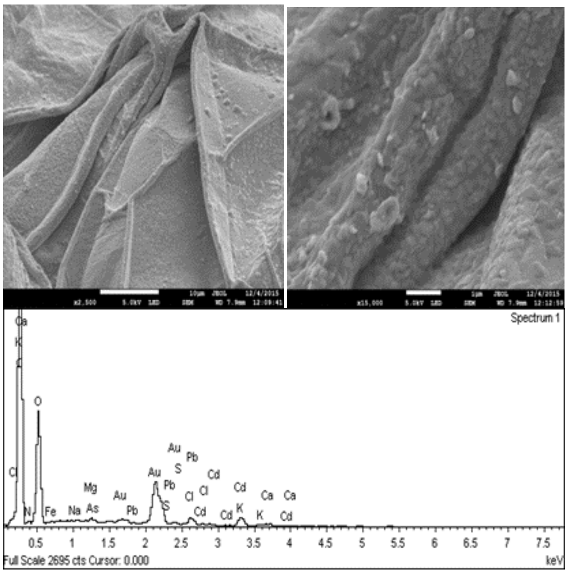

Figure 4. FESEM micrographs and EDX spectra in stem area of Eichhornia Crassipes

The percentages in Table 2 were obtained by analysing the EDX spectra, which measure the relative abundance of elements in the sample. The weight percentage represents the proportion of the total detected elements that is attributable to each specific heavy metal. The heavy metals detected in stem of Eichhornia crassipes is copper, zinc and lead are located inside the cells in the vascular tissues, especially in xylem tissues (Figure 4). In Table 2, the value of weight on lead is 0.81%, while value for copper and zinc is 0.23% and 0.14%. The Eichhornia crassipes stated that the concentration of copper was slightly absorbed by this plant [13]. In addition, if concentration of copper supplied increased, the level of copper uptake in the plant tissue was decreased.

Table 2. Weight of heavy metal in stem area of Eichhornia Crassipes

Heavy Metal	Weight (%)
Lead	0.81
Zinc	0.14
Copper	0.23

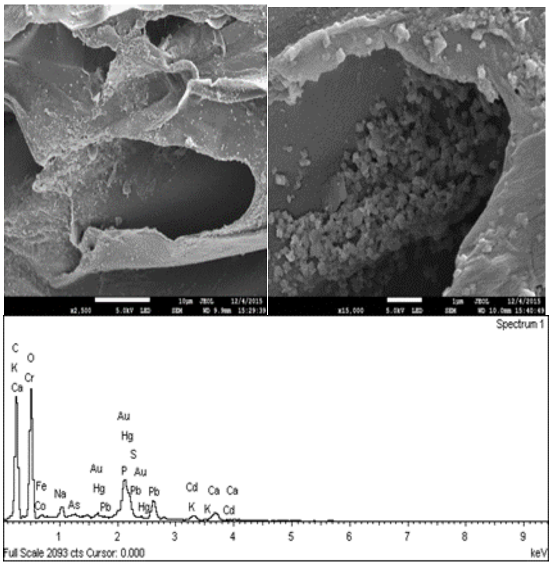

Figure 5. FESEM micrographs and EDX spectra in root area of Eichhornia Crassipes

The percentages in Table 3 were obtained by analysing the EDX spectra, which measure the relative abundance of elements in the sample. The weight percentage represents the proportion of the total detected elements that is attributable to each specific heavy metal. In the roots (Figure 5), iron, lead, copper, and zinc were detected in the xylem tissue. The value of weight for iron is 1.14%, the highest in cell walls. For lead and zinc, the value of weight is less than the value of weight for iron, which is 0.21% and 0.10%, respectively. The value of weight for copper in the root shows the lower value of 0.04%. The greater proportion of metal absorbed remained in the root system rather than being translocated to other plant parts [14]. The greater proportion of metal absorbed remained in the root system rather than being translocated to other plant parts [15].

Table 3. Weight of heavy metal in root area of Eichhornia Crassipes

Heavy Metal	Weight (%)
Lead	0.21
Zinc	0.10
Copper	0.04
Iron	1.14

The percentages in Table 4 were obtained by analysing the EDX spectra, which measure the relative abundance of elements in the sample. The weight percentage represents the proportion of the total detected elements that is attributable to each specific heavy metal. Only iron and lead can be detected in the leaves section (Figure 6), and this can be related to the upward translocation of iron and lead through xylem. As shown in Table 4, the total weight of heavy metals for iron is 3.38% compare to amount weight of lead which is 2.96%. The presence of lead in Pistia stratiotes leaf tissues could interfere with the initial steps of chlorophyll synthesis [17]. The total heavy metal absorbed in leaf is still lower than the total heavy metal in root.

Table 4. Weight of heavy metal in leaf area of Pistia stratiotes

Heavy Metal	Weight (%)
Lead	2.96
Iron	3.38

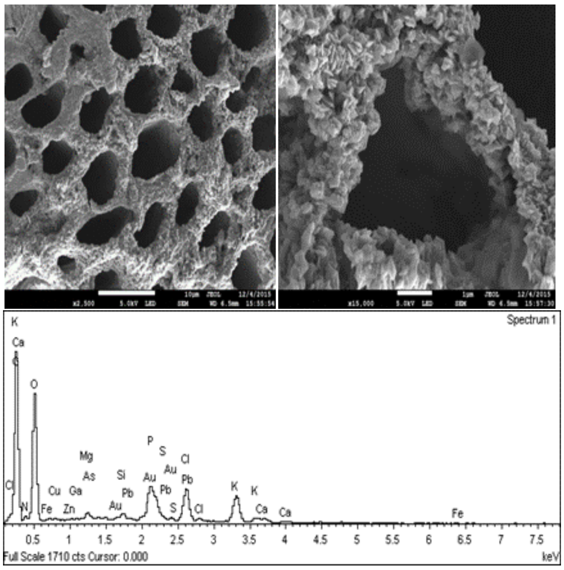

Figure 6. FESEM micrographs and EDX spectra in leaf area of Pistia Stratiotes

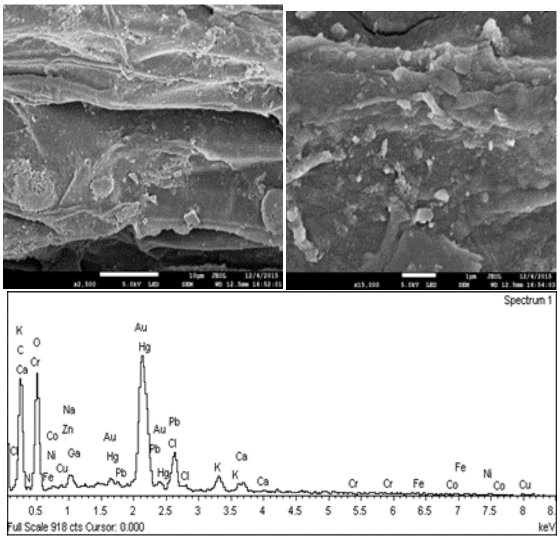

Figure 7. FESEM micrographs and EDX spectra in root area of Pistia Stratiotes

Table 5. Weight of heavy metal in root area of Pistia stratiotes

Heavy Metal	Weight (%)
Lead	2.11
Zinc	0.44
Copper	0.03
Iron	0.56

The percentages in Table 5 were obtained by analysing the EDX spectra, which measure the relative abundance of elements in the sample. The weight percentage represents the proportion of the total detected elements that is attributable to each specific heavy metal. In the root (Figure 7), the amount of iron, lead, copper, and zinc can be detected in the xylem tissue of concentration root. The value of weight for lead is 2.11% highest in cell walls. The iron and zinc value of weight were less than the value of weight for lead which is 0.56% and 0.44%. The value of weight for copper in the root shows the lower value which is only 0.03%. Pistia stratiotes is an aquatic plant that grows rapidly and is a high biomass crop with an extensive root system that is able to enhance the heavy metal removal. Pistia stratiotes exhibited different pattern to lead removal although accumulated at high concentration mainly in the root system [19-20].

4. CONCLUSION

The laboratory results of the phytoremediation system using Eichhornia crassipes and Pistia stratiotes demonstrate an effective method to reduce heavy metals in backwash water. From the study, it can be derived that different types of plants have varying preferences for specific types of metals. These plants are effective in absorbing different levels of heavy metals from contaminated water. In this study, Pistia stratiotes emerged as the most effective plant species in removing heavy metals from contaminated backwash water. This species showed the highest removal efficiency for manganese, iron, lead, and aluminum, with efficiencies of 88.49%, 83.94%, 68.15%, and 71.12%, respectively. On the other hand, Eichhornia crassipes showed less absorption for most metals but was effective in accumulating zinc and copper, removing 73.72% of zinc and 61.19% of copper from backwash water.

The method used to determine the type of heavy metals accumulated in the physiology of Eichhornia crassipes and Pistia stratiotes was FESEM/EDX. The analysis revealed that low levels of heavy metals from backwash water were detected in the leaves of both plants, specifically iron and lead. In the stems of Eichhornia crassipes, heavy metals detected included copper, zinc, and lead, while in Pistia stratiotes, the stem contained manganese in addition to lead and copper. In the roots, both plants absorbed lead, copper, zinc, and iron. In essence, the application of the phytoremediation system provides a medium to treat heavy metal-contaminated backwash water. The implementation of this system successfully depolluted the backwash water and ensured that the final discharge met the standard discharge limits set by DOE Malaysia. The use of Eichhornia crassipes and Pistia stratiotes in this system demonstrated their ability to absorb various heavy metals present in backwash water. The data obtained were verified with supporting literature, facts, and statistical evidence Principal Component Analysis (PSO), and Bivariate Hypothesis Testing (BH).

ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Civil Engineering Technology for providing the experimental facilities and to all technicians at Highway and Traffic Engineering Laboratory.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

AUTHOR CONTRIBUTION

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.

REFERENCES

[1] U.S. Geological Survey (USGS). *What is Groundwater?* 2021. Retrieved from https://groundwater.org/what-is-groundwater/.

[2] S. Singh, "Phytoremediation: A sustainable alternative for environmental challenges," *International Journal of Green and Herbal Chemistry*, vol. 1, pp. 133–139, 2012.

[3] Tchobanoglous, G., & Burton, F. L. (1991). *Wastewater Engineering: Treatment, Disposal and Reuse*. McGraw-Hill, McGraw-Hill Series in Water Resources and Environmental Engineering, New York, USA, 1991.

[4] M. Darshan, M. Rizwana, and D. Nilesh, "Phytoremediation of textile waste water using potential wetland plant: Eco sustainable approach," *International journal of interdisciplinary and Multidisciplinary Studies*, vol. 4, no. 1, pp. 130-138, 2014.

[5] B.D. Tripathi and S.C. Shukla, "Biological treatment of wastewater by selected aquatic plants," *Environmental Pollution*, vol. 69, no. 1, pp. 69-78, 1991.

[6] V.K. Mishra, and B.D. Tripathi, “Concurrent removal and accumulation of heavy metals by three aquatic macrophytes,” *Bioresource Technology*, vol. 99, no. 15, pp. 7091-7097, 2008.

[7] S. Bunluesin, M. Kruatrachue, P. Pokethitiyook, G.R. Lanza, E.S. Upatham, and V. Soonthornsarathool, “Plant screening and comparison of Ceratophyllum demersum and Hydrilla verticillata for cadmium accumulation,” *Bulletin of Environmental Contamination & Toxicology*, vol. 73, no. 3, pp. 591-598, 2004.

[8] A.S. El-Gendy, N. Biswas, and J.K. Bewtra, “A floating aquatic system employing water hyacinth for municipal landfill leachate treatment: Effect of leachate characteristics on the plant growth,” *Journal of Environmental Engineering and Science*, vol. 4, no. 4, pp. 227-240, 2005.

[9] U. Majeed, I. Ahmad, M. Hassan, and A. Mohammad, “Phytoremedial potential of aquatic plants for heavy metals contaminated industrial effluent,” *European Academic Research*, vol. 2, pp. 7038-7968, 2014.

[10] T. Ajayi, and A. Ogunbayo, “Achieving environmental sustainability in wastewater treatment by phytoremediation with water hyacinth (eichhornia crassipes),” *Journal of Sustainable Development*, vol. 5, no. 7, p. 80, 2012.

[11] C. Keith, S.V. Borazjani, H. Diehl, Y. Su, and B.S. Baldwin, “Removal of copper, chromium, and arsenic by water hyacinths,” In *36th Annual Mississippi Water Resources Conference, Mississippi State University*, pp. 15-19, 2006.

[12] Fathunnisa and Indah Rachmatiah, “Content of heavy metals in the water and water hyacinth (eichhornia crassipes) in water bodies receiving wastewater from textile industry, *The Third Joint Seminar of Japan and Indonesia Environmental Sustainability and Disaster Prevention*, Institut Teknologi Bandung, Indonesia – November 25th, 2015.

[13] A.W. Aini Syuhaida, S.I. Sharifah Norkhadijah, S.M. Praveena and A. Suriyani, “The comparison of phytoremediation abilities of water mimosa and water hyacinth,” *ARPN Journal of Science and Technology*, vol. 4, no. 12, 2014.

[14] J.B. Harborne, *Metals and Micronutrients: Uptake and Utilisation by Plants*. In D.A. Robb and W.S. Pierpoint (Eds.), Phytochemical Society of Europe Symposia Series No. 21. Academic Press, London. 341 pages, Phytochemistry, 1984.

[15] Y.M. Nor, “The absorption of metal ions by Eichhornia crassipes,” *Chemical Speciation & Bioavailability*, vol. 2, no. 2, pp. 85-91, 1990.

[16] R.S. Espinosa, “Lead uptake and growth responses in Pistia Stratiotes Linn,” *Manila Journal of Science*, vol. 4, no. 1, 2001.

[17] D. Singh, A. Tiwari, and R. Gupta, “Phytoremediation of lead from wastewater using aquatic plants,” *Journal of Sustainable Development*, vol. 5, no. 7, pp. 80-86, 2012.

[18] X. Xu, Y. Liu, X. Cao, and L. Zhao, “Comparison of the characteristics of activated carbons from lignin, cellulose, and wood,” *Journal of Materials Chemistry A*, vol. 1, no. 46, pp. 13803-13811, 2013.

[19] W. Zhang, and C.H. Huang, “Phytoremediation of heavy metal-contaminated soils by a hybrid floating treatment wetland. *Water*, vol. 11, no, 4, p. 639, 2019.

[20] Y. Zhou, Y., et al. “Application of phytoremediation to soil polluted by heavy metals: A review,” *Environmental Science and Pollution Research*, vol. 26, no. 19, pp. 19052-19060, 2019.