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HEAVY METALS AND NUTRIENTS REMOVAL FROM SEWAGE WATER USING WATER HYACINTH, EICHHORNIA CRASSIPES

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ABSTRACT

Water pollution is a serious health problem and the amount of industrial and domestic waste increases continuously in recent times. Phytoremediation is one effective methods to remove heavy metals and nutrients from the wastewater by Eichhornia crassipes. In this study, macrophytes were surveyed from the contaminated freshwater system and characterized macrophytes for phytoremediation. A total of twelve macrophytes were identified from the coir contamination pond and Eichhornia crassipes significantly improved water quality than other macrophytes ($p<0.01$). Water hyacinth (Eichhornia crassipes) is a rapidly growing, free-floating aquatic macrophyte. It is capable of assimilating large quantities of heavy metals and nutrients. Experiments were conducted and the uptake of arsenic, cadmium, lead, copper and zinc from the aqueous medium for five different concentrations ranging from 5 mg/L to 25 mg/L was evaluated. The uptake of heavy metal was analyzed and the efficacy was determined every week. The selected macrophyte was healthy, young and acclimatized in sewage water. Results revealed that at a 10 mg/L concentration of heavy metals, the removal efficiency was greater and plant growth was normal. The heavy metal removal efficiency was checked for water hyacinth. The heavy metal removal efficiency was between 45 and 97%. Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased total dissolved solids, total suspended solids, sulphate, chloride, calcium, magnesium and iron level. E. crassipes treated coir retting wastewater showed decreased phenol levels. The mean initial phenol level was 450 ± 10.2 mg/L before treatment. The percentage removal of phenol was 58% after 10 days and the percentage of phenol removal increased after 20 days of treatment (92.88%) ($p<0.001$). It was concluded that by using macrophytes, heavy metals and nutrients could be effectively removed from waste water.

Keywords: Water Hyacinth, Bioaccumulation, Nutrients, Assimilation, Heavy Metal, Removal

1. INTRODUCTION

Water pollution is a serious problem for well-developed and developing countries. The amount of industrial and domestic waste increases continuously in recent times. The amount of effluent from the houses, and industrial units are increasing exponentially, however, the present treatment system is not effective to manage this large amount of pollutants from the manufacturing units. The heavy metal pollution, including, copper (Cu), zinc (Zn), lead

(Pb), and arsenic (As) cause serious problemsfor the public health and the environment (Khan et al., 2023). Traditionally, physical and chemical methods were used to treat wastewater pollutants, including, heavy metals, and most of these processes are highly complex, highly expensive and need high technical specificity. Wastewater treatment using aquatic plants were used to remove various pollutants, which has several advantages of easy operation, low costs, and high pollution treatment ability (Reena Mol and Murugesan, 2022a; Reena Mol and Murugesan, 2022b). This method is useful to treat wastewater in environmentally friendly and natural conditions while improving the landscape and increasing biodiversity, and local ecosystems (Zhou et al., 2023; Khan et al., 2023).

Phytoremediation is a modern technology that involves using living plant species to eliminate pollutants in air, soil, and water, and it was increasingly used for wastewater purification for its lower cost, eco-friendly compared with traditional physic-chemical methods, and energy-saving properties (Vaz et al., 2023). The selection of water plants for the degradation of pollutants requires various considerations. First, the sensitivity and tolerance of various plants to contaminants can vary. Second, an increasing nutrient and pollutant removal potency requires water plants with rapid growth rates, maximum biomass, and easy harvest and management (Rezania et al., 2015; Singh et al., 2022). Third, native plant species are highly preferred for phytoremediation because exotic or non-native species hinder the restoration of various natural areas and may cause ecosystem damage. Fourth, the sudden climatic changes and destruction of water plants not only cause huge secondary pollution but also disrupt the potential of bioremediation (Wareen et al., 2023; Galgali et al., 2023). Hence, the selection of suitable plants is an important factor in improving the potential of biodegradation (Xia and Ma, 2006). The phytoremediation potential of various plant species has been studied (Chen et al., 2023). Most of these water plants have been shown to have maximum efficacy in removing nutrients, heavy metals and pollutants from the environment. The main objective of the study is to analyze heavy metal removal from the wastewater by water hyacinth, E. crassipes.

2. MATERIALS AND METHODS

2.1. COIR RETTING EFFLUENT COLLECTION AND ANALYSIS

Coir retting wastewater was collected from the discharged point of the coir retting plant at Tirunelloor, Cherthala, Alappuzha District, Kerala State, India. The area map of the coir retting pond was illustrated in Fig. 1. The amount of phosphate, pH, turbidity, TDS, TH, sulphate, chloride, fluoride, iron, and ammonia were analyzed as described earlier (APHA, 1995). The suspended solid was separated using filter paper. The polyphenol content of the sample was determined as described previously by APHA (2005). Heavy metals such as nickel, zinc, lead, chromium and mercury were analyzed by atomic absorption spectroscopy (Ogunfowokan et al., 2019).

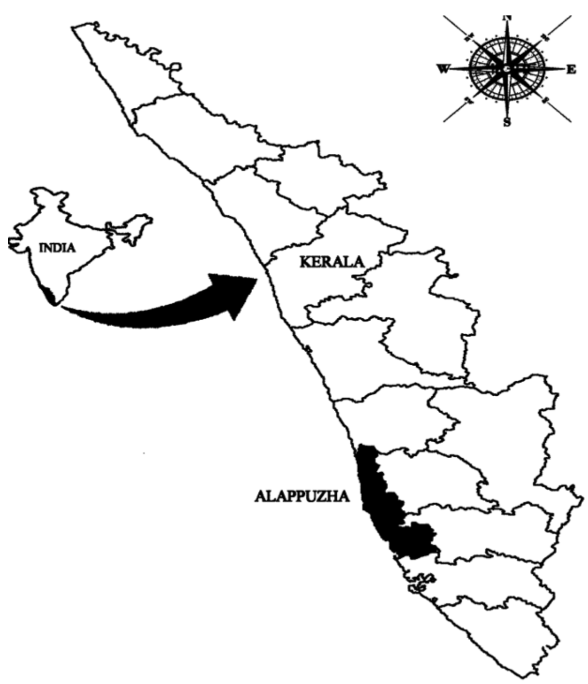


Figure 1 Coir retting effluent collection point at Tirunelloor, Cherthala, Alappuzha District, Kerala State

2.2. AQUATIC MACROPHYTES

Aquatic macrophytes were collected from the pond contaminated with coir retting effluent. The field trips were performed once a month for six months to determine macrophytes in this pond. The growth of macrophytes and other plants was seen at the collection point of the pond (Fig. 2).

Figure 2 Tirunelloor pond with dense macrophytes

Macrophytes were directly collected from the pond by hand, or using a long handled hook net and washed several times with tap water. The washed macrophytes were dried under filter paper and identification was performed. Morphological characters were analyzed and identified as described previously by Gamble and Fischer (1921-1935), and Cook (1990).

2.3. ASSESSMENT OF AQUATIC MACROPHYTES FOR THE TREATMENT OF RETTING WASTEWATER

The experiment was performed in round plastic containers. The collected macrophytes were washed with tap water and maintained for 10 days. Retting wastewater was filled in the containers (15 L) and macrophyte (10 numbers) was introduced. A total of twelve macrophytes (Salvinia natans L., Anabaena spiroides Klebahn, Marsilea quadrifolia L., Ipomoea aquatic L., Eichhornia crassipes (Mart.) Solms, Colocasia esculentum (L.) Schott, Scirpus lacustris (L.), Spirodela polyhiza (L.) Schleid, Typha lotifolia L., Bacopa monnieri (L.) Pennell, and Lemna minor L.) characterized from the pond was used for analysis. To the control, macrophyte was not introduced. The experiment was performed in laboratory conditions as described previously (Xia and Ma, 2006). A triplicate experiment was performed and the mean value was taken into consideration. The reduction of TSS, phosphate, TDS, TH, sulphate, polyphenol and ammonia was analyzed after one week and the percentage (%) removal was calculated.

2.4. HEAVY METAL STOCK PREPARATION

Standard solutions of arsenic, cadmium, lead, copper and zinc were prepared at 100 µg/mL concentration. All chemicals used were obtained from Hi-media, Mumbai, India. All stock solutions were made using double distilled water or Millipore water. All other chemicals used were ACS grade or analytical grade.

2.5. HEAVY METAL BIOSORPTION BY E. CRASSIPES IN THE LABORATORY

The experiment was performed for 30 days and 100 g of water hyacinth was used in the experimental tank. The experimental heavy metal concentration was 5 mg/L, 10 mg/L, 15 mg/L, 20 mg/L and 25 mg/L. Water hyacinth was grown in sewage water containing heavy metals. The heavy metals (arsenic, cadmium, lead, copper and zinc) in the plants were evaluated using an Atomic Absorption Spectrophotometer after 5 to 25 days.For further experiments, 10 mg/L stock solution was prepared for analysis. For the control tank, metal solution was not established. All experiments were performed in triplicates and the mean value was considered for analysis.

2.6. ANALYSIS OF HEAVY METALS

The experiment and sampling period started on 10 June 2019. The heavy metal content (arsenic, cadmium, lead, copper and zinc) was monitored after 5 – 30 days, to observe the heavy metal content removal by water hyacinth. The heavy metals (arsenic, cadmium, lead, copper and zinc) in the water samples were evaluated using an Atomic Absorption Spectrophotometer.

2.7. ANALYSIS OF NUTRIENT PARAMETERS

E. crassipes was used in this study to analyze the efficacy of removing TSS, TDS, nitrite, nitrate, sulphate, chloride, calcium, magnesium, and iron from the treated wastewater. The selection of macrophytes was based on rapid growth rate and phytoremediation potential. The polyphenol content of the sample was determined as described previously by APHA (2005).

3. RESULTS AND DISCUSSION

3.1. IDENTIFICATION OF AQUATIC MACROPHYTES FROM THE POND

A total of twelve macrophytes were identified during the study period. These were, S. natans, A. spiroides, M. quadrifolia, I. aquatic, E. crassipes, C. esculentum, S. lacustris, S. polyhiza, T. lotifolia, B. monnieri, and L. minor.

3.2. PHYSICOCHEMICAL ANALYSIS OF COIR RETTING EFFLUENT

The physico-chemical factors of retting wastewater were analyzed and the mean ± standard deviation was used for analysis. The TSS value was 19760 ± 400 mg/L and an increased level of nitrate was observed (5.82 ±0.42 mg/L). An increased level of sulphate, phosphate, calcium, iron and phenol was detected. Alkaline pH was observed and an increased magnesium level (187.5 ± 10.4 mg/L) was observed (Table 1).

Table 1 Physicochemical analysis of coir retting effluent collected near the outlet of the open coir retting unit.

Sl. No	Parameters	Result
1	Total dissolved solids	1438 ± 120
2	Total suspended solids	19760 ±400
3	Nitrite	2.41 ± 0.05
4	Nitrate	5.82 ±0.42
5	Sulphate	82.4 ±8.3
6	Chloride	348 ± 10.3
7	Chemical oxygen demand	10184 ±263.2
8	Biological oxygen demand	5028.2 ±409.4
9	Calcium	492.4 ±24.2
10	Magnesium	187.5 ± 10.4
11	Sulphate	138.4 ±5.5
12	Iron	3.19 ± 0.32
13	Phenol	450 ± 10.2
14	pH	9.72 0.1

3.3. PHYTOREMEDIATION POTENTIAL OF AQUATIC MACROPHYTES

The phytoremediation potential of twelve aquatic macrophytes is described in Table 2. In the initial experiment, aquatic macrophytes were treated for seven days and phytodegradation potential was analyzed. I. aquatica removed 51.2% phosphate and 56.2% total hardness. E. crassipes Removed 69% TSS, 74.5% TDS, 48.2% phosphate, 50.1% total hardness, 65.4% sulphate, 87.2% ammonia and 60.7% polyphenol from the wastewater. After seven days of treatment, the colour reduction was observed and all plants were stable and contributed to the degradation of coir retting effluent (Table 2).

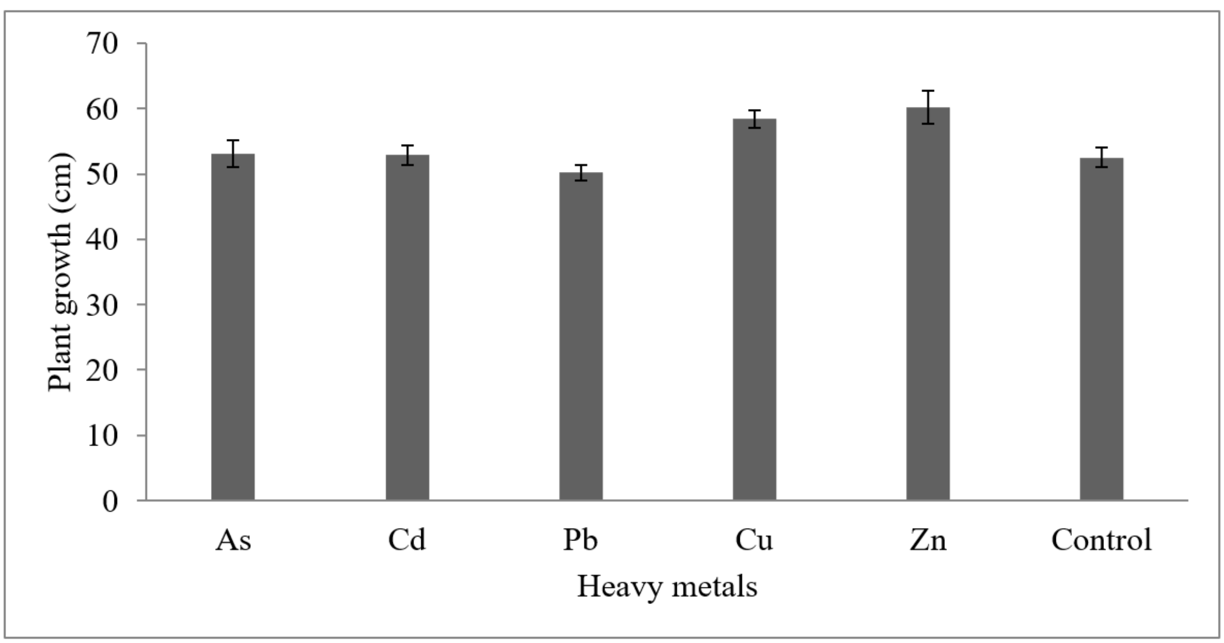
Table 2 Influence of macrophytes on the removal of nutrients and polyphenol from the retting effluent.

Macrophytes	% removal						
	TSS	TDS	Phosphate	TH	Sulphate	Ammonia	Polyphenol
S. natans	30.2	10.4	0.51	49.1	40.5	10.4	0.5
A. spiroides	14.1	18.1	4.2	37.2	50.2	7.6	14.2
M. quadrifolia	28.4	15.2	3.1	40.3	53.5	8.5	0.02
I. aquatica	46.3	49.2	51.2	56.2	60.2	76.1	35.4
E. crassipes	69	74.5	48.4	50.1	65.4	87.2	60.7
C. esculentum	50.2	15.2	18.4	39.5	46.1	16.7	19.3
S. lacustris	5.2	1.6	10.6	4.8	5.2	1.5	0.2
S. polyhiza	37.8	30.1	42.3	17.8	38.5	16.2	5.8
T. lotifolia	1.9	19.6	10.1	4.6	1.72	0.51	0.01
B. monnieri	40.7	56.3	8.6	6.1	39.5	1.02	14.2
L. minor	35.3	28.5	2.2	38.4	15.4	14.9	0.81
J. repens	18.5	15.3	0.53	47.1	28.3	1.9	1.59

3.4. GROWTH PROFILE ANALYSIS

The growth of the water hyacinth after one month was analyzed. Plant growth is associated with the process of increasing the height, mass, and size of cells or cell organelles. Growth can also represent the development and reproduction of a plant. Height is one of the important indicators for assessing thegrowth of plants containing different environmental heavy metals. In addition to the dependence of height on the genetic characteristics of a variety, it alsodepends on external conditions such as climate, temperature, oxygen, mineral nutrition,fertilizer, water, etc. (Saha et al., 2017; Kamboj and Tiwari, 2022). The growth of plants in polluted water is important for theabsorption and accumulation of heavy metals in plants. The height results for the waterhyacinths are depicted in Fig. 3A. There was a significant difference in plant height forthis plant with $p < 0.05$, which could validly explain their differences in plant growth (Kabeer et al., 2022). Heavy metal affected plant biomass and was statistically significant ($p<0.05$). In the control plant, plant biomass was 42.8 ± 3.3. g, and Pb significantly affected the plant biomass (26.4 ± 3.2 g) (Fig. 3B).

A



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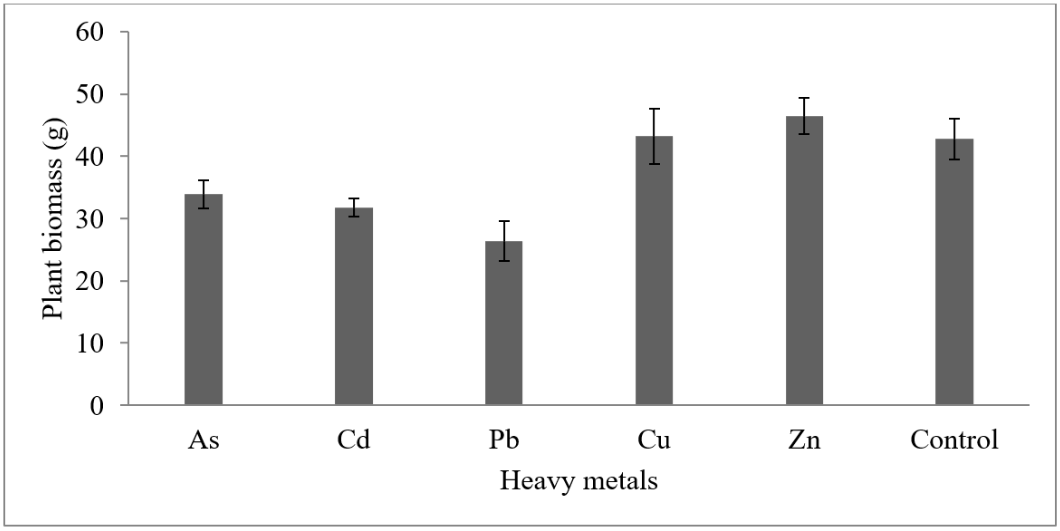

Figure 3 Effects of heavy metal concentrations on the growth of water hyacinth after one month. The growth was measured in cm (A) and the plant biomass was expressed as gram

The height of the water hyacinth in each pot was considered as height growth. As water hyacinth is a wild plant, it grows very well under natural conditions. However, the height growth of the water hyacinth differed depending on the different metals; someplants even withered, died, and did not develop young plants. The biomass of the pot wasthen significantly reduced. Phytoremediation refers to the use of plants to partially or substantially remediateselected contaminants in contaminated soil, sludge, sediment, groundwater, surface water, and wastewater.

3.5. PHYTOREMEDIATION OF HEAVY METALS FROM THE WASTE WATER

Phytoremediation is popular because of its cost-effectiveness, and long-term applicability.The objective of utilizing water hyacinth in phytoremediation technique testing wasto assess its efficiency for heavy metal treatment. Therefore, after being planted, the samplewas monitored and the heavy metal content in the water was analyzed three times, after one month, to observe the metal content in water treated with water hyacinth overtime. There is an urgent need to develop suitable green method for the removal of pollutants from wastewater. Moreover, certain water plants with potential phytoremediation activity were restricted in a certain environments. Water hyacinth is the fastest growing water plant, and has a lot of potential to remove varieties of heavy metals from water bodies. The application of water plants to treat heavy metals is restricted in Southern Hemisphere countries.Rezania (2015) applied water hyacinth and achieved >80% removal of pollutants from the wastewater. The physiological response of water plants in the removal of cadmium was reported by Das et al. (2015).Gupta and Balomajunder (2015) reported the removal of chromium from wastewater. Singh et al. (2015) used a rotary drum reactor and reported the removal of heavy metals such as Cd, Pb, Ni, Fe, Mn, Cu and Zn from the wastewater using water hyacinth and this method was economically viable. Many earlier investigations used single aquatic plants in the removal of single metal pollutants. The present study assesses the removal of various pollutants from the wastewater using water hyacinth. The removal efficiency percentage for the plants' ability to absorb heavy metals such as arsenic, cadmium, lead, copper and zinc in the water over time is shown in Fig. 2 – 6. The treatment efficiencies of water hyacinth for arsenic, cadmium, lead, copper and zinc over the 30 days of the experiment were 65.2±3.2%, 2.5±0.31%, 0.9±0.006%, 90.5±1.7%, and 97.1±0, respectively. By theend of the one-month experimental period, the cleaning rates of the water hyacinths for all heavymetals were mostly high (50-70%) (Fig. 4a-e).

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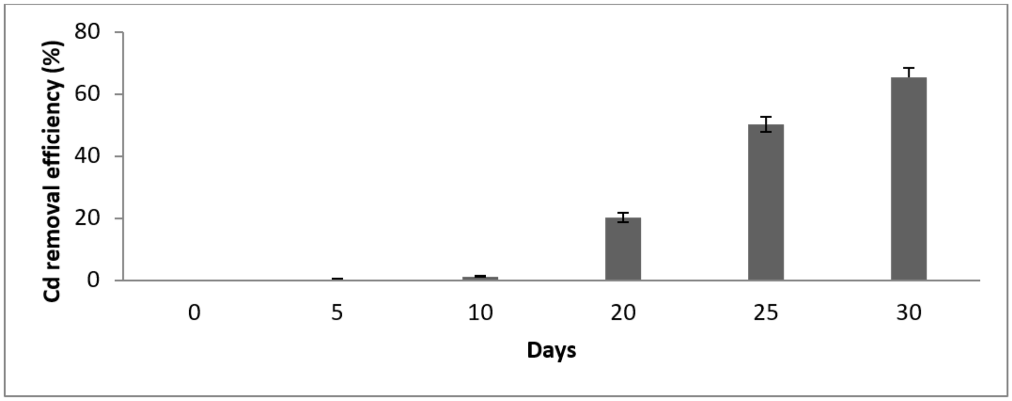
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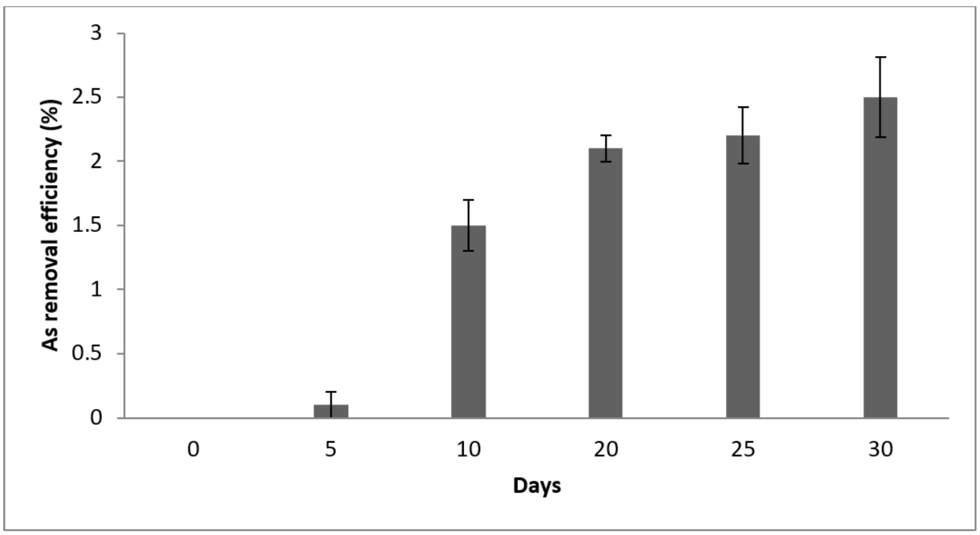
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As removal efficiency (%)
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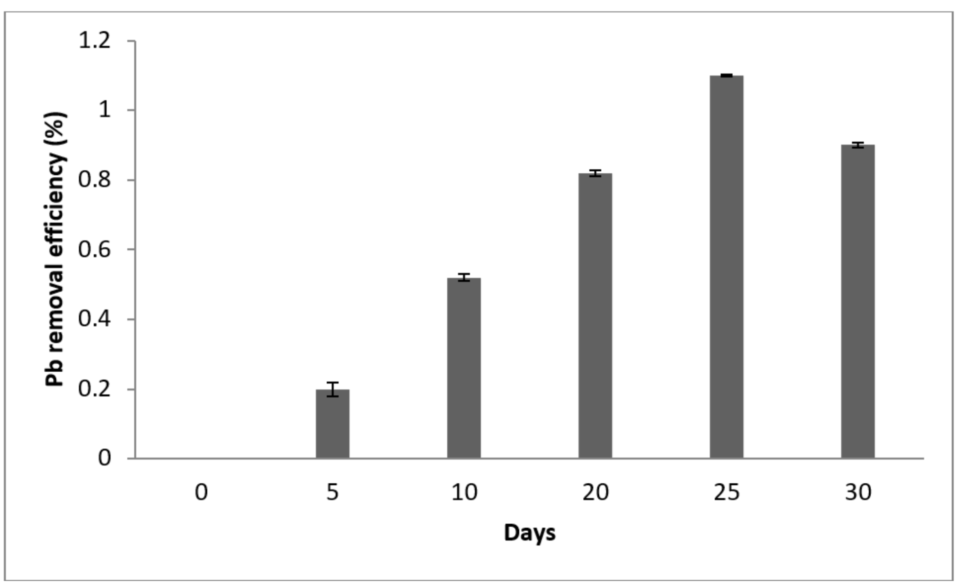
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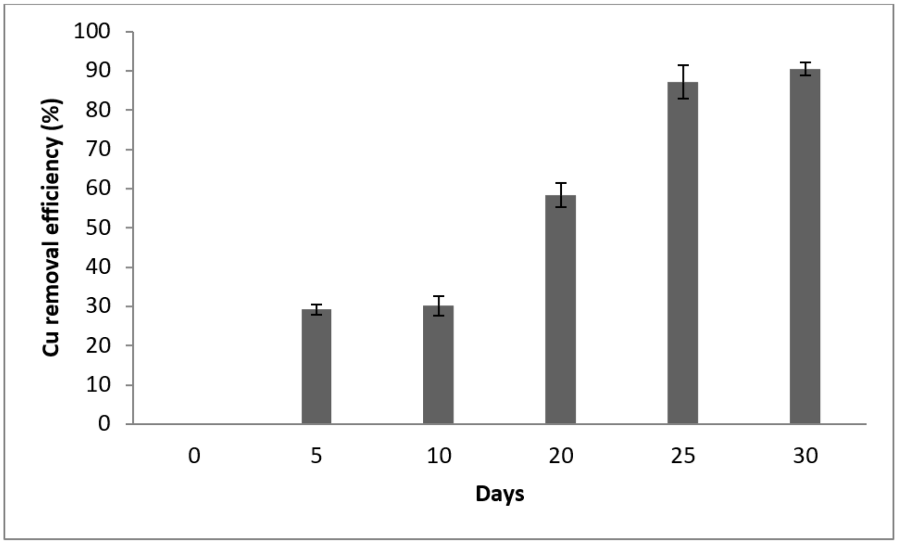

E

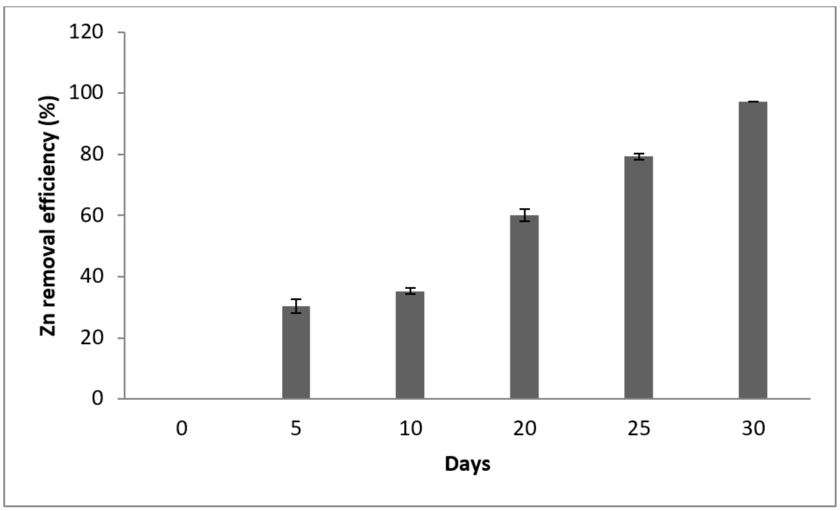

Figure 4 The concentration of cadmium (A), arsenic (B), lead (C), copper (D), and zinc (E) in the wastewater treated with hyacinth for 30 days.

The results show that the remaining heavy metal content in the water treated with waterhyacinths decreased significantly after one compared to the original concentrations.The remaining percentage of heavy metals in sewage water is very less (Ajayi and Ogunbayo, 2012). The findings of the pot trials reveal that this plant has the potential to absorb heavyelements such as cadmium, arsenic, lead, zinc, and copper from wastewater. When theplants were added to the pots, the cadmium, arsenic, lead, zinc, and copper concentrationsin the pots with the plants were significantly reduced. As a result, we can conclude thatevaporation and settlement caused very little loss. The results show that water hyacinth isan effective plant capable of removing heavy metals from wastewater (Jayaweera and Kasturiarachchi, 2004).

Specifically, removal efficiency increased with increasing culture time. Similarly, previous studies have reported a decrease in heavy metal concentrations in the remaining aqueous solution with increasing the culture time of the experiment. Previous research states that substantial heavy metal removal can be achieved in a short time by Eichhornia crassipes (Naz et al., 2022). Moreover, Eichhornia crassipes can effectively remove appreciable quantities of heavy metals from fresh water, especially at low concentrations. The plants exhibited a certain tolerance to heavy metals; however, they became withered, yellow, and necrotic when the concentrations of heavy metals in the water exceeded the plant's maximum tolerated concentration to heavy metals. The initial concentrations of heavy metals in an aqueous solution had a significant effect on the removal efficiency of Eichhornia crassipes; i.e., high concentrations of heavy metals required more active absorption sites for removal. Thus, removal was low when the initial concentrations of heavy metals were low because the active sites of Eichhornia crassipes were not effectively utilized (Ting et al., 2018; Fox et al., 2008; Newete and Byrne, 2016). The active sites became gradually occupied with an increase in the initial concentrations of heavy metals until reaching equilibrium. If additional heavy metals were added after the equilibrium stage, the concentrations in heavy metals in the solution would correspondingly increase, thus leading to a decrease of the removal efficiency. The cell walls of the roots and their large surface area enhance the adaptability of Eichhornia crassipes to aquatic environments and help improve water quality (Endgaw, 2020).

3.6. REMOVAL NUTRIENTS FROM THE WASTEWATER BY E. CRASSIPES

Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased TSS levels. The mean initial TSS level was 19760 ± 400 mg/L before treatment. On the second day of treatment, the TSS value was significantly reduced (12100 ± 150 mg/L) ($p<0.001$). On day 20, the TSS value was 603 ± 10 mg/L and the reduction of TSS was mainly due to the fibrous root system of the macrophyte. The percentage of removal of TSS was 49% after 4 days and the percentage of TSS removal increased after 20 days of treatment (3.02%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased TDS levels. The mean initial TDS level was 1438 ± 120 mg/L. On Day 4 of treatment, the TDS value was significantly reduced (1092 ± 22 mg/L). The percentage of removal of TDS was 58.4% after 10 days and the percentage of TDS removal increased significantly after 20 days of treatment (95.4%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased nitrite levels. The mean initial nitrite level was 2.41 ± 0.05 mg/L before treatment. On the second day of treatment, the nitrate value was reduced marginally (2.34 ± 0.14 mg/L). On day 20, the nitrite value was 0.14 ± 0.09 mg/L. The percentage of removal of nitrite was 41% after 6 days and the percentage of nitrite removal increased significantly after 20 days of treatment (98%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased nitrate levels. The mean initial nitrate level was 5.82 ± 0.42 mg/L before treatment. On the second day of treatment, the nitrate value was significantly reduced (3.29 ± 0.17 mg/L). On day 10, the nitrate value was 0.87 ± 0.014 mg/L and the reduction of nitrate. The percentage removal of nitrate was 85% after 10 days and the percentage of nitrate removal significantly increased after 16 days of treatment (93.3%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased sulphate levels. The mean initial sulphate level was 82.4 ± 8.3 mg/L before treatment. On the second day of treatment, the sulphate content was significantly reduced (75.3 ± 7.2 mg/L). On day 10, the sulphate value was 40.5 ± 1.5 mg/L. The percentage of removal of sulphate was 51% after 10 days and the percentage of sulphate removal significantly increased after 20 days of treatment (90.7%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased chloride levels. The mean initial chloride level was 348 ± 10.3 mg/L before treatment. On the second day of treatment, the chloride value was significantly reduced (264 ± 14.2 mg/L). On day 10, the chloride level was 139 ± 20.4 mg/L. The percentage of removal of chloride was 60.1% after 10 days and the percentage of chloride removal increased after 20 days of treatment (82.8%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased calcium levels. The mean initial calcium level was 492.4 ± 24.2 mg/L before treatment. On the second day of treatment, the calcium value was 387.2 ± 30.5 mg/L. On day 10, the calcium value was 10.4 ± 0.5 mg/L. The percentage of removal of calcium was 97.08% after 10 days and the percentage of calcium removal increased after 20 days of treatment (99.3%) ($p<0.001$). The mean initial magnesium level was 187.5 ± 10.4 mg/L before treatment. On the second day of treatment, the magnesium value was 160.4 ± 20.2 mg/L. On day 20, the magnesium value was further decreased (25.3 ± 3.67 mg/L). The percentage removal of magnesium was 49.49% after 10 days and the percentage of magnesium removal increased after 20 days of treatment (86.6%) ($p<0.001$). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased sulphate levels. The mean initial sulphate level was 138.4 ± 5.5 mg/L before treatment. On the second day of treatment, the sulphate content was significantly reduced (114.7 ± 4.6 mg/L). On day 10, the sulphate content was 87.5 ± 1.5 mg/L and decreased as 27.2 ± 3.7 mg/L after 20 days ($p<0.001$). The percentage of removal of sulphate was 37% after 10 days and the percentage of sulphate removal increased after 20 days of treatment (81.4%). Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased iron levels. The mean initial iron level was 3.19 ± 0.32 mg/L before treatment. On day 10, the iron value was significantly reduced (0.972 ± 0.12 mg/L). On day 20, the iron value was 0.36 ± 0.08 mg/L ($p<0.001$). The percentage of removal of iron was 30.5% after 10 days and the percentage of iron removal increased after 20 days of treatment (81.3%). The continuous exposure of macrophytes to various inorganic or organic matter results in sequestration or rapid uptake followed by degradation or transformation, which can be oxidative, revealing in the development of metabolites, which get assimilated by covalent binding to macrophytes (Valadi et al., 2019). Macrophytes present in constructed and natural wetlands also show the potential to remove inorganic matter such as phosphorus and nitrogen from effluent (Uysal, 2013). Aquatic plant species such as Potamogeton crispus, Ceratophyllum demersum, Elodea nuttallii, Elodea canadensis and Eichhornia crassipes removed excessive phosphorus, and nitrogen from the wastewater from hydroponic systems. In macrophytes, nitrogen removal ability occurs mainly in the form of nitrate and ammonia (Umar et al., 2015). Moreover, in submerged macrophytes, the leaves and root system significantly contributed to improved nutrient uptake (Rahman et al., 2008). In constructed wetland system, macrophytes such as Elodea sp., Myriophyllum sp., Eichhornia crassipes, Lemna sp., Azolla sp., Scirpus robustus, Scirpus maritimus, Typha latifolia, Typha latifolia, and Juncus xiphioides were characterized (Pang et al., 2016). Aquatic macrophytes possess hardness, ease of handling, maximum productivity, tolerance to survive adverse climatic conditions, rapid growth and bioaccumulation ability establishing them as an unavoidable source in the field of phytoremediation.

3.7. REMOVAL OF POLYPHENOL

Phytoremediation treatment of coir retting wastewater using E. crassipes showed decreased phenol levels. The mean initial phenol level was 450 ± 10.2 mg/L before treatment. On day2, the phenol value was reduced slowly (438.4 ± 20.1 mg/L). On day 10, the phenol value was 187.4 ± 10.1 mg/L. The percentage removal of phenol was 58% after 10 days and the percentage of phenol removal increased after 20 days of treatment (92.88%) ($p<0.001$) (Fig. 5). Eichhornia crassipes has the potential to remove colour from the wastewater (Lagos et al., 2009). The present finding was corroborated with previous findings. It removed phenol and cyanide from synthetic/simulated wastewater (Singh and Balomajumder, 2021). Ali et al. (2019) used activated carbon from Eichhronia crassipes plant as adsorbent for the removal of phenol from aqueous solution.

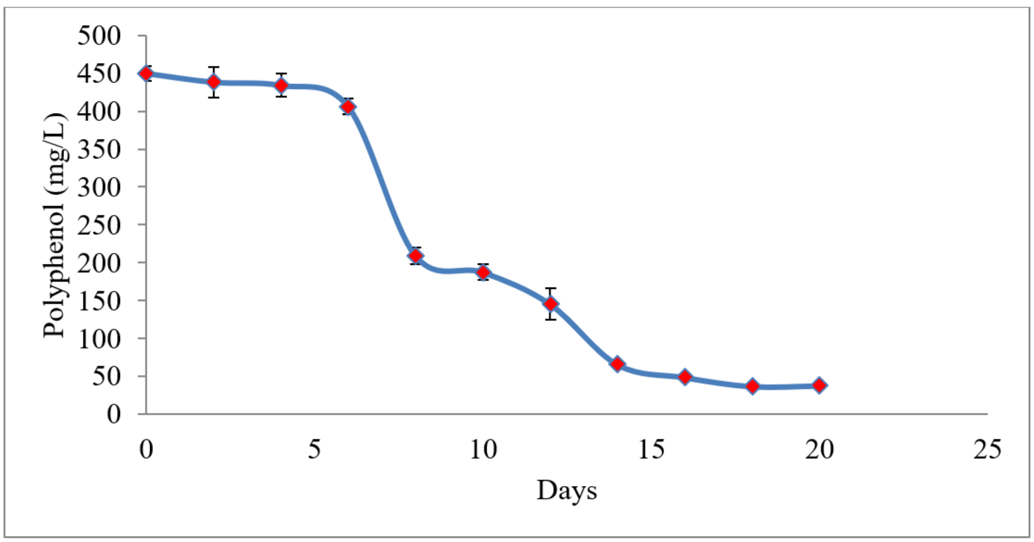

Figure 5 Phytoremediation of phenol in the water hyacinth treatment systems (n=3). The phenol value represents an average value for three different experiments.

4. CONCLUSIONS

This study presents research on the removal of heavy metals, nutrients from aqueous environments using biological processes and makes a significant contribution to the multi-component analysis of toxic metal removal from sewage water by Eichhornia crassipes plants. Specifically, this study evaluated the use of Eichhornia crassipes as a mitigation technique for the remediation of sewage water contaminated by heavy metals and nutrients. The results provide several important insights into the timing and efficiency of heavy metal removal in both single heavy metal and multi-component heavy metal systems, as well as the removal of nutrients. The evidence from our study strongly suggests that the macrophyte, E. crassipes may be used as an efficient phytoremediation material for the uptake of heavy metals and nutrients from waste water.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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