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Evaluation of Pennisetum setaceum Biomass for Phytoremediation of Industrial Heavy Metals in Sudan

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Abstract

This study assessed the effectiveness of *Pennisetum setaceum* leaf powder, collected from Sudan, as a low-cost biosorbent for removing Pb(II), Cd(II), Ni(II), and Cr(III) from industrial wastewater. Biomass was oven-dried, ground into fine powder, and applied in batch adsorption experiments using wastewater obtained from a steel processing facility in Khartoum. Pre- and post-treatment metal concentrations were quantified using Atomic Absorption Spectrophotometry. Adsorption tests were performed at constant pH and contact time while varying biosorbent dosage and initial metal concentrations.The biosorbent achieved **removal efficiencies above 80% for all metals**, with maximum removal observed for **Cr (III) (98.3%)**, followed by **Pb(II) (92%)**, **Ni(II) (86%)**, and **Cd(II) (81%)**. Increasing biosorbent dosage consistently improved metal uptake, indicating enhanced mass transfer and greater availability of active binding sites. The removal efficiency order **Cr(III) > Pb(II) > Ni(II) > Cd(II)** suggests differing affinities of surface functional groups for each metal ion.These results demonstrate that *P. setaceum* leaf powder is a sustainable and efficient biosorbent for treating heavy-metal-contaminated wastewater, particularly for Cr(III) and Pb(II). Further studies involving adsorption isotherms, kinetic modeling, and surface characterization are recommended to optimize its integration into practical wastewater treatment systems.

Keywords: Heavy metals, low-cost treatment, atomic absorption spectrophotometry (AAS), sustainable biosorbent, *Pennisetum setaceum*

INTRODUCTION

Pennisetum setaceum (fountain grass) is a perennial species native to tropical Africa, southwestern Asia, and the Arabian Peninsula, characterized by its feathery spikelets (POWO, 2025). In Sudan, it is distributed across regions such as the Nile Land and Red Sea Province and is occasionally used as coarse livestock forage (eFlora of India, 2024).

Industrial wastewater generated from mining, textile production, and chemical processing contains a range of pollutants, including toxic and persistent heavy metals (Spellman, 2017; Tchobanoglous *et al*., 2014). Although methods such as coagulation–flocculation, membrane filtration, adsorption, and advanced oxidation can effectively reduce metal concentrations, they are often financially and technically demanding for low-income regions (Fu and Wang, 2011). Metals such as Pb, Cd, Cr, and Ni pose particular concern due to their toxicity, environmental persistence, and bioaccumulation potential (Ali, Khan and Ilahi, 2019). Their health impacts from neurotoxicity to carcinogenicity are well documented (Jaishankar *et al*., 2014; Tchounwou *et al*., 2012; Zhitkovich, 2011; Jarup and Akesson, 2009; Costa *et al*., 2005; WHO, 2019; Flora, Gupta and Tiwari, 2012).

In Sudan, industries including leather tanning, metallurgy, and battery recycling discharge inadequately treated effluents, aggravating heavy metal contamination, while the high cost of conventional remediation limits practical implementation. Phytoremediation offers a low-cost and sustainable alternative; however, **the phytoremediation or biosorption potential of** *P. setaceum* **for heavy metal removal from industrial wastewater has not been previously assessed**, despite its abundance, resilience, and ecological adaptability.

This study addresses this gap by evaluating the capacity of *P. setaceum* leaf biomass to remove Pb (II), Cd (II), Ni (II), and Cr (III) from industrial wastewater, providing insight into its suitability as a locally available biosorbent for use in Sudan and similar arid regions.

MATERIALS AND METHODS

Materials

All chemicals used in this study were of analytical reagent (AR) grade and of the highest available purity. These included hydrochloric acid (HCl), sodium hydroxide (NaOH), deionized water, and standard stock solutions of lead(II), cadmium(II), nickel(II), and chromium(III).

Plant Sample Collection

Leaves of *Pennisetum setaceum* were collected in November 2022 from the western bank of the Nile River in Omdurman City, Sudan. The plant species was taxonomically identified and authenticated at the Botany Laboratory, Faculty of Science and Technology, Omdurman Islamic University, Omdurman, Sudan.

Industrial Wastewater Sample Collection

Industrial wastewater samples were obtained from the effluent of a steel processing plant located in Khartoum, Sudan. The samples were collected in 1000 mL glass bottles and stored in a cool, dark environment to preserve their original chemical characteristics. No preliminary filtration was performed. Heavy metal concentrations in the wastewater were determined using Atomic Absorption Spectrophotometry (AAS).

Preparation of *Pennisetum setaceum* Leaf Powder as Adsorbent

Approximately 500 g of *P. setaceum* leaves were thoroughly washed with distilled water to remove surface impurities, then oven-dried at 80 °C for 24 hours. The dried biomass was ground into a fine powder using a mechanical grinder and stored in a clean, airtight glass container for subsequent use.

FTIR Analysis

To identify the functional groups responsible for metal binding, the powdered biomass was characterized using Fourier Transform Infrared Spectroscopy (FTIR). Spectra were recorded in the range of 4000–400 cm^{-1}, and the major absorption bands were analyzed to determine the presence of hydroxyl, carboxyl, carbonyl, and other functional groups associated with biosorption activity.

Preparation of Industrial Wastewater Sample

Fifty milliliters of the collected industrial wastewater were diluted with deionized water in a 100 mL volumetric flask. The diluted samples were homogenized prior to analysis, and the concentrations of the target heavy metal ions were quantified using AAS.

Preparation of Standard Metal Solutions

Standard solutions of Pb(II), Cd(II), and Ni(II) were prepared at concentrations of 0.01, 0.1, 0.2, and 1 ppm. Standard solutions of Cr(III) were prepared at concentrations of 0.001, 0.002, 0.01, and 0.1 ppm from the corresponding stock solutions, following the procedure described by Doorn *et al*. (1997).

Adsorption Experiments

Adsorption Capacity Assessment of *Pennisetum setaceum* Leaf Powder

To evaluate the adsorption capacity of *Pennisetum setaceum* leaf powder, 1.00 g of the prepared biosorbent was added to 100 mL of standard aqueous solutions of Pb(II), Cd(II), Ni(II), and Cr(III), each at initial concentrations of 10 ppm and 50 ppm. The experiments were conducted in separate 250 mL Erlenmeyer flasks. The pH of each solution was adjusted to 5.0 using dilute hydrochloric acid (HCl) or sodium hydroxide (NaOH) to optimize metal ion binding. The mixtures were then

stirred continuously for 2 hours at ambient temperature (25 ± 5 °C) to ensure equilibrium adsorption. Following treatment, the solutions were filtered, and the residual metal ion concentrations were measured using Atomic Absorption Spectrophotometry (AAS) to determine the adsorption efficiency of the biosorbent.

Effect of Adsorbent Dosage

The effect of biosorbent dosage was evaluated by conducting batch adsorption experiments using *P. setaceum* leaf powder at five dosage levels: 1.0, 1.5, 2.0, 2.5, and 3.0 g. For each dosage, identical experimental conditions were maintained (constant pH, contact time, temperature, and initial metal concentration). **Each dosage treatment was performed in triplicate** to ensure reproducibility and allow statistical comparison.

Determination of Metal Ion Concentrations

Concentrations of Pb(II), Cd(II), Ni(II), and Cr(III) in both untreated and treated wastewater, as well as in standard solutions, were quantified using Atomic Absorption Spectrophotometry (AAS). All AAS measurements were also conducted in triplicate to ensure analytical precision.

Instrumentation and Calibration

Prior to analysis, the atomic absorption spectrophotometer was calibrated using deionized water as a blank. Standard calibration curves for each metal ion were constructed from the prepared standard solutions. The absorbance of each sample was automatically recorded by the instrument, and the corresponding metal concentrations were calculated directly based on the calibration data.

Results and Discussion

The potential of dry biomass from *P. setaceum leaves* to remove selected heavy metals from industrial wastewater was assessed through a series of batch adsorption experiments. The study aimed to evaluate the efficiency of this plant material in reducing concentrations of heavy metal ions, providing insight into its suitability for phyto-remediation applications. The results obtained allowed for the analysis of adsorption behavior under varying conditions, including metal concentration and dry biomass dosage.

The percentage yield of dry *P. setaceum* leaves is shown in **Table 1**.

Table 1. Yield (%) of dry *P. setaceum* leaves

Initial fresh weight (g)	Dry weight (g)	Yield (% g/g)
500	180.64	36.85

The dry biomass output from 500 g of *Pennisetum setaceum* leaf powder, as seen in **Table 1**, was 180.64 g, which translates to a 36.85% yield. Under comparable drying circumstances, Milad and Ezeldin (2017) recorded a lower percentage, indicating a greater yield. **Figure 1** shows a comparison between the yields of the current research and those of Milad and Ezeldin.

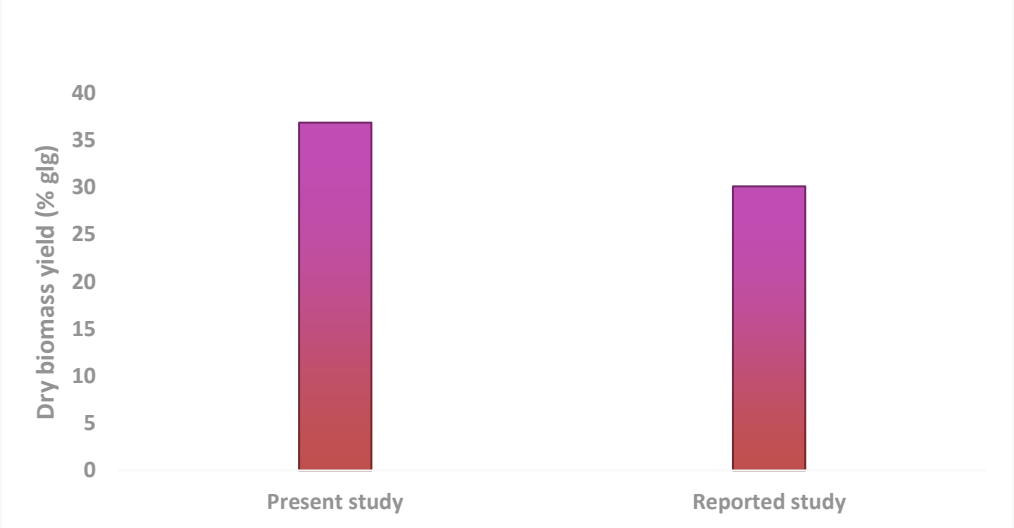


Figure 1. Dry Biomass Yield Comparison Between the Present Study and Milad & Ezeldin (2017)

The results presented in **Table 2,** clearly demonstrate the strong metal-removal capacity of *Pennisetum setaceum* leaf powder when applied to raw petroleum wastewater. Substantial reductions were observed for all four metals, confirming the biosorbent's effectiveness under real wastewater conditions rather than synthetic laboratory solutions. Lead (II) concentration decreased from 0.089 mg/L to 0.011 mg/L (87.6% removal), while cadmium (II) was reduced from 0.073 mg/L to 0.015 mg/L (79.5%). Nickel (II) showed an 82.2% decline, and chromium (III) exhibited the highest removal efficiency of 97.3%, dropping from 0.943 mg/L to 0.025 mg/L. The outstanding performance observed for Cr(III) is consistent with earlier experimental results, which indicated preferential adsorption of trivalent ions due to their higher charge density and stronger electrostatic interactions with negatively charged binding sites on the biomass.

These findings align well with previous studies using plant-based biosorbents. For instance, Pennisetum purpureum, *Typha latifolia*, and *Agave sisalana* fibers have been reported to remove Pb(II), Cd(II), and Ni(II) with efficiencies typically ranging between 70% and 90%, depending on biosorbent dosage and solution conditions. The removal efficiencies observed in the current study—particularly for Pb(II) and Ni(II)—fall within or above these ranges, indicating that *P. setaceum* performs comparably or even superiorly to other commonly investigated low-cost adsorbents. Moreover, the exceptionally high Cr(III) removal (over 97%) surpasses many reported values for untreated lignocellulosic biomasses, which often range between 60% and 90%. This suggests that the functional groups present in *P. setaceum* leaves (likely hydroxyl, carboxyl, and phenolic groups) exhibit strong affinity toward trivalent chromium, enhancing binding efficiency.
The results are also consistent with earlier studies that highlight how biosorbents derived from grasses or invasive plant species can achieve high metal uptake even without chemical modification. Similar trends have been noted for *Eichhornia crassipes* and *Lemna minor*, which demonstrate particularly strong performance for Pb(II) and Cr(III). This reinforces the potential of *P. setaceum* an abundant and often invasive species—as a sustainable, low-cost resource for wastewater remediation.

Overall, the comparison with previous research underscores that *P. setaceum* leaf powder is not only effective but also highly competitive with other natural biosorbents. Its ability to achieve removal efficiencies above 80% for all tested metals, coupled with its remarkable affinity for Cr(III), positions it as a promising alternative for use in industrial wastewater treatment, particularly in petroleum-contaminated systems where mixed-metal pollution is common.

Table 2. ***Heavy Metal Concentrations in Industrial Wastewater Before and After Biosorption Treatment with Pennisetum setaceum Leaf Powder***

Heavy Metal	Concentration Before Treatment (mg/L)	Concentration After Treatment (mg/L)
Lead (II)	0.089	0.011
Cadmium(II)	0.073	0.015
Nickel(II)	0.045	0.008
Chromium(III)	0.943	0.025

Chromium (III) exhibiting the greatest removal efficiency, followed by lead (II), nickel (II), and cadmium (II), these results indicated that the leaf powder of *P. setaceum* has a high adsorption capacity for heavy metals. The possibility of utilizing this plant-based biosorbent as a cost-effective and environmentally acceptable alternative for the treatment of industrial wastewater was

highlighted by its high metal removal efficiencies. The findings indicated that *P. setaceum* leaf powder had a strong adsorption capacity for lead, cadmium, nickel, and chromium ions in industrial wastewater. After treatment with the leaf media, the concentrations of lead and copper were found to be below the limits established by the American Society for Testing and Materials (ASTM). **Figure 2** compares the concentrations of lead (II), cadmium (II), nickel (II), and chromium (III) in industrial wastewater before and after treatment with *P. setaceum* leaf powder.

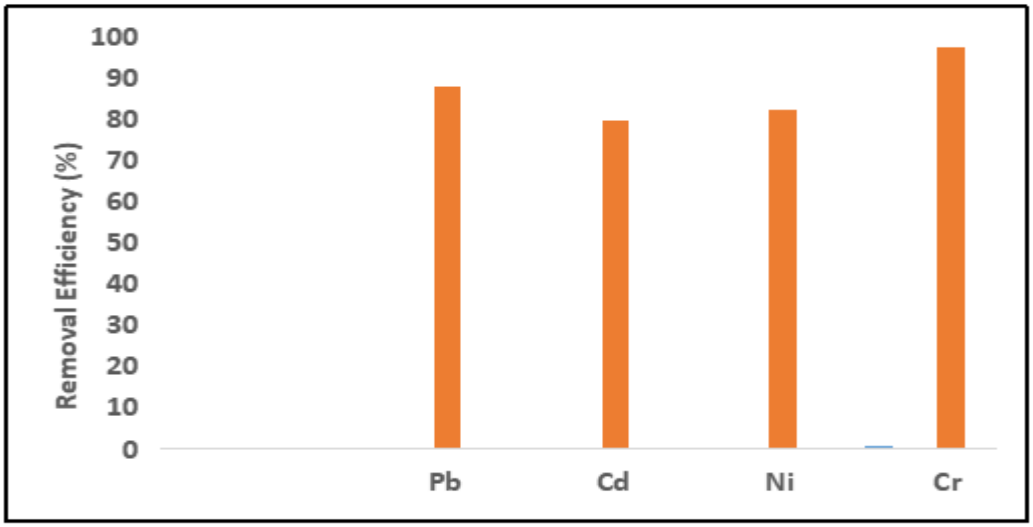


Figure 2. ***Heavy Metal Concentrations in Industrial Wastewater Before and After Treatment with Pennisetum setaceum Leaf Powder and the Corresponding Removal Efficiencies***

The influence of *Pennisetum setaceum* leaf powder dosage on the removal efficiencies of Pb(II), Cd(II), Ni(II), and Cr(III) from industrial wastewater is summarized in **Table 3**.

Table 3. ***Effect of Pennisetum setaceum Leaf Powder Dosage on the Removal Efficiency of Selected Heavy Metals from Industrial Wastewater***

Heavy Metal Ion	Weight of *P. setaceum* Leaf Powder (g)	Removal Efficiency (% w/w)
Pb(II)	0.50	85.60
	1.00	87.80
	1.50	90.30
	2.00	92.70
	2.50	95.20
Cd(II)	0.50	77.40
	1.00	79.80
	1.50	82.30
	2.00	84.80
	2.50	87.60
Ni(II)	0.50	80.80
	1.00	83.30
	1.50	85.50
	2.00	87.80
	2.50	90.20
Cr(III)	0.50	94.30
	1.00	95.20
	1.50	96.30
	2.00	97.40
	2.50	98.30

Overall, the results reveal a clear positive correlation between biosorbent dosage and metal removal efficiency for most tested ions. This trend reflects the fundamental principle of biosorption: increasing the amount of biomass generally enhances the availability of active binding sites, thus improving metal uptake. For Pb(II), removal efficiency increased steadily from 85.60% at 0.50 g to 95.20% at 2.50 g. The consistently high performance across all dosage levels indicates a strong affinity of *P. setaceum* biomass for lead ions. This behavior is likely linked to the presence of carboxyl, hydroxyl, and phenolic groups in the leaf powder, which facilitate ion-exchange and complexation reactions. Similar observations have been reported for other lignocellulosic biosorbents such as *Eichhornia crassipes*, *Moringa oleifera*, and *Pennisetum purpureum*, where Pb(II) removal efficiencies typically increase with biomass dosage and often exceed 80%. The values obtained in the present study fall within the upper range of these reports, suggesting that *P. setaceum* is a competitively effective biosorbent for lead removal. Cd(II) followed a similar trend, with removal increasing from 77.40% at 0.50 g to 87.60% at 2.50 g. The slight reduction in efficiency at the highest dosage can be attributed to particle aggregation, which reduces the

effective surface area and consequently limits metal–biosorbent interactions.This phenomenon is commonly documented in biosorption studies, including those using banana peels, rice husks, and sugarcane bagasse, where overly high biosorbent loads can create diffusion limitations and partial shielding of active sites. Despite this minor decline, the overall Cd(II) removal remained within ranges previously reported for many plant-based biosorbents (60–85%), reaffirming the moderate yet reliable performance of *P. setaceum* biomass for cadmium adsorption. Ni(II) also showed a progressive increase in removal efficiency with increasing dosage, rising from 80.80% at 0.50 g to 90.20% at 2.50 g. This pattern aligns with studies involving similar biomaterials, such as *Typha latifolia* and *Cocos nucifera* fibers, which typically report Ni(II) removal between 70% and 90% depending on dosage and solution characteristics. The results indicate that Ni(II) ions interact favorably with the functional groups of *P. setaceum*, suggesting strong biosorption kinetics and potential for practical use in treating nickel-contaminated industrial effluents. Cr(III) exhibited the highest removal efficiency among the tested metals. Even at the lowest dosage (0.50 g), removal achieved 94.30%, increasing to 98.30% at 2.50 g. This near-complete removal underscores the strong affinity of *P. setaceum* for trivalent chromium. The superior performance is likely due to the higher charge density of Cr(III), which enhances electrostatic attraction and forms more stable complexes with negatively charged active sites. Comparable trends have been observed with biosorbents such as *Lemna minor*, bamboo-derived materials, and untreated agricultural residues, though Cr(III) removal rarely exceeds 95% without chemical modification. Thus, the exceptionally high efficiencies recorded here indicate that *P. setaceum* leaf powder is particularly suited for chromium remediation.

Overall, the order of metal removal efficiency **Cr(III) > Pb(II) > Ni(II) > Cd(II)** is consistent with known differences in ionic radius, charge, hydration energy, and binding affinity. Trivalent ions typically show stronger binding than divalent ones, which explains the superior performance for Cr(III). The relatively lower removal of Cd(II) has also been widely reported in biosorption studies, often attributed to weaker complexation tendencies and competition with more strongly adsorbing ions.

The linearity curves presented in Figure 3, further support the dosage efficiency relationship, showing a generally proportional increase in removal efficiency with increasing biosorbent mass. This dose-dependent behavior reflects the robust biosorptive capacity of *Pennisetum setaceum* leaf powder and reinforces its potential as an eco-friendly, low-cost, and effective biosorbent for heavy metal removal from industrial wastewater.

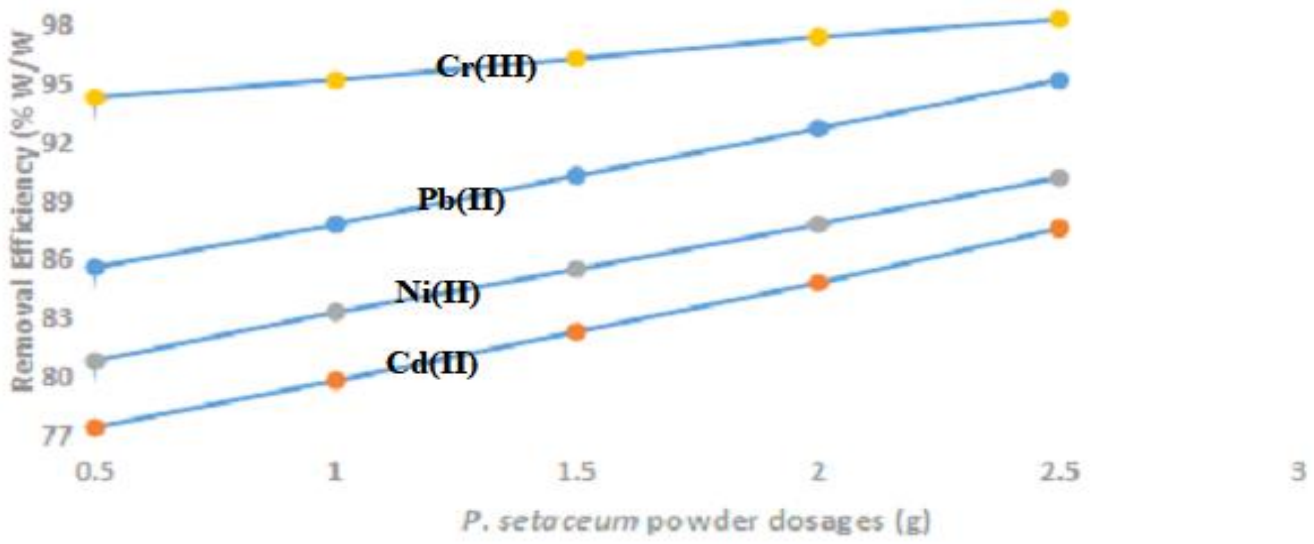


Fig 3.The Leaner Curves Between Removal Efficiency Percentages (% w/w) and *P. setaceum* leaf powder weights (g) for Pb(II), Cd(II), Ni(II) and Cr(III) ions

Figure 3 illustrates the linear relationship between the removal efficiencies (% w/w) of the selected metal ions and the corresponding dosages of *P. setaceum* leaf powder. The observed variations in removal efficiencies among the metals may be attributed to their differing affinities for the functional groups on the biosorbent, as well as variations in ionic radii and hydration energies.

The observed trends confirm that increasing the biosorbent dosage enhances the availability of active binding sites, thereby improving metal ion adsorption. The linear nature of the curves suggests that the adsorption process may follow first-order kinetics with respect to biosorbent dosage within the tested range. Overall, the data support the potential application of *P. setaceum* leaf powder as an effective, low-cost biosorbent for the removal of heavy metals from aqueous solutions, particularly for Cr(III) and Pb(II) ions.

The effect of initial heavy metal ion concentration on the removal efficiency of *Pennisetum setaceum* leaf powder was investigated, with results presented in **Table 4** and **Figure 4**.

Table 4. ***Effect of Initial Heavy Metal Ion Concentration on the Removal Efficiency of Pennisetum setaceum Leaf Powder***

Heavy Metal Ion	Concentration (ppm)	Removal Efficiency (%)
Pb(II)	10	88.30
Cd(II)	10	80.60
Ni(II)	10	86.40
Cr(III)	10	90.20
Pb(II)	50	94.30
Cd(II)	50	84.80
Ni(II)	50	90.60
Cr(III)	50	96.70

The removal efficiencies of four heavy metal ions (Pb(II), Cd(II), Ni(II), and Cr(III)) at two initial concentrations (10 ppm and 50 ppm) were evaluated and are presented in **Table 4**. Overall, the data demonstrated that the adsorption system exhibited high removal performance across all tested metal ions, with efficiencies ranging from 80.6% to 96.7%. At the lower initial concentration of 10 ppm, Cr(III) showed the highest removal efficiency (90.2%), followed closely by Pb(II) (88.3%) and Ni(II) (86.4%). Cd(II) exhibited the lowest removal efficiency among the tested ions at this concentration, with a value of 80.6%. The relatively lower adsorption of Cd(II) might have been attributed to its weaker interaction with the adsorbent surface or competitive binding effects. When the initial concentration was increased to 50 ppm, the removal efficiencies improved for all metal ions. Cr(III) again exhibited the highest efficiency (96.7%), indicating a strong affinity between Cr(III) ions and the adsorbent, even at higher loading. Pb(II) also demonstrated a notable increase in removal efficiency, reaching 94.3%. Similarly, Ni(II) and Cd(II) showed enhanced removal performances, with efficiencies of 90.6% and 84.8%, respectively. The increase in removal efficiency at higher metal concentrations could have been due to a higher driving force for mass transfer, which facilitated more effective interaction between the metal ions and the active sites of the adsorbent. Moreover, the consistent trend in performance is Cr(III) > Pb(II) > Ni(II) > Cd(II), at both concentration levels as shown in **Fig 4**. The consistent increase in removal efficiency and eventual plateauing behavior supports this interpretation. The selectivity pattern observed for selected heavy metals,also suggests that surface binding energies play a key role, consistent with the *Langmuir* model's concept of finite, energetically similar binding sites.

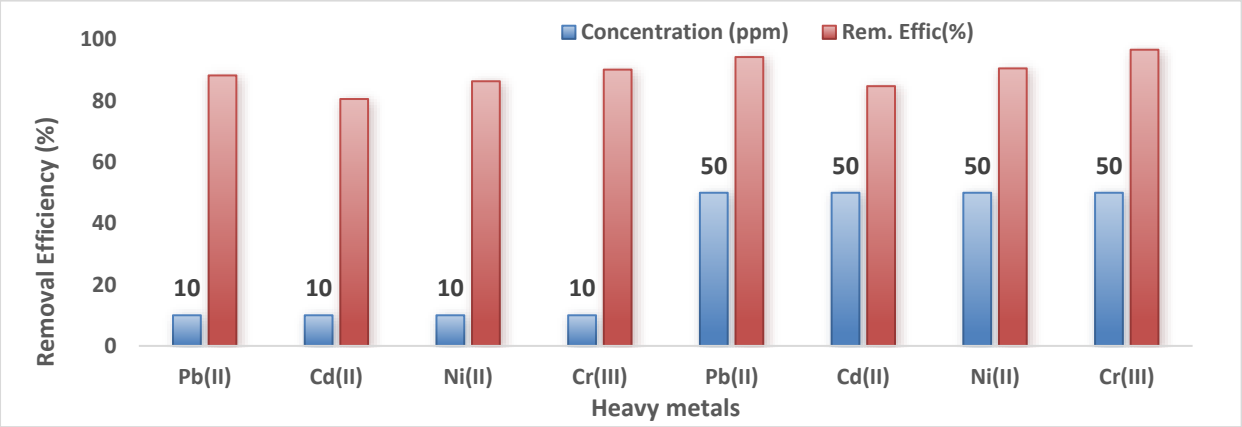


Figure 4. ***Comparison of Initial and Final Heavy Metal Concentrations and Their Corresponding Removal Efficiencies Following Treatment with Pennisetum setaceum Leaf Powder***

As shown in **Table 4** and **Figure 4,** the results indicated that the adsorbent exhibited varying affinities for different metal ions, likely influenced by their physicochemical properties, such as ionic radius, electronegativity, and hydration energy. These findings confirmed the effectiveness of the adsorbent in treating water contaminated with heavy metals and suggested a potential selectivity toward certain ions, particularly Cr(III) and Pb(II). Further investigations involving isotherm modeling, kinetic studies, and surface characterization were recommended to elucidate the underlying adsorption mechanisms.

Conclusion

The experimental findings demonstrated that *Pennisetum setaceum* leaf powder was an effective biosorbent for the removal of Pb(II), Cd(II), Ni(II), and Cr(III) ions from industrial wastewater. The dry biomass consistently achieved removal efficiencies exceeding 80% for all tested metals, with Cr(III) showing the highest adsorption performance across varying biosorbent dosages and initial metal concentrations. Increased biosorbent dosage enhanced removal efficiency, likely due to the greater availability of active binding sites. Similarly, higher initial metal concentrations appeared to facilitate improved mass transfer and adsorption dynamics. Overall, *P. setaceum* leaf powder proved to be a promising, low-cost, and sustainable biosorbent, particularly effective for the remediation of Cr(III) and Pb(II) in contaminated wastewater. Industrial wastewater often contains a mixture of metals and organic pollutants. The study used solutions with individual metal ions, which may not fully represent competitive adsorption behavior under real wastewater conditions. Conduct life-cycle assessment and cost–benefit analysis to determine large-scale feasibility and environmental sustainability compared to conventional wastewater treatment technologies.

References

Ali, H., Khan, E. & Ilahi, I., 2019. Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. *Journal of Chemistry*, 2019(1), pp.1–14.

Cervantes, C., Campos-García, J., Devars, S., Gutiérrez-Corona, F., Loza-Tavera, H., Torres-Guzmán, J.C. & Moreno-Sánchez, R., 2001. Interactions of chromium with microorganisms and plants. *FEMS Microbiology Reviews*, 25(3), pp.335–347.

Costa, M., Davidson, T.L., Chen, H., Ke, Q. & Zhang, P., 2005. Nickel carcinogenesis. *Mutation Research: Fundamental and Molecular Mechanisms of Mutagenesis*, 592(1–2), pp.1–11.

Doorn, M.R.J., Strait, R., Barnard, W. & Eklund, B., 1997. *Estimate of global greenhouse gas emissions from industrial and domestic wastewater treatment: Final report*. United States Environmental Protection Agency, Research Triangle Park, NC, USA.

eFlora of India, 2024. *Pennisetum setaceum*. Botanical Survey of India. Available at: [Accessed 10 Aug. 2025].

Flora, G., Gupta, D. & Tiwari, A., 2012. Toxicity of lead: A review with recent updates. *Interdisciplinary Toxicology*, 5(2), pp.47–58.

Fu, F. & Wang, Q., 2011. Removal of heavy metal ions from wastewaters: A review. *Journal of Environmental Management*, 92(3), pp.407–418.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B. & Beeregowda, K.N., 2014. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology*, 7(2), pp.60–72.

Jarup, L. & Akesson, A., 2009. Current status of cadmium as an environmental health problem. *Toxicology and Applied Pharmacology*, 238(3), pp.201–208.

Kotaś, J. & Stasicka, Z., 2000. Chromium occurrence in the environment and methods of its speciation. *Environmental Pollution*, 107(3), pp.263–273.

Milad, S. & Ezeldin, M., 2017. Eco-friendly removing of some heavy metals via *Morus nigra* leaves. *American Journal of Chemical Engineering*, 5(6), pp.147–153.

Needleman, H., 2004. Lead poisoning. *Annual Review of Medicine*, 55, pp.209–222.

Plants of the World Online (POWO), 2025. *Pennisetum setaceum*. Royal Botanic Gardens, Kew. Available at: [Accessed 10 Aug. 2025].

Spellman, F.R., 2017. *Handbook of Water and Wastewater Treatment Plant Operations*. 3rd ed. Boca Raton, FL: CRC Press.

Tchobanoglous, G., Stensel, H.D., Tsuchihashi, R. & Burton, F.L., 2014. *Wastewater Engineering: Treatment and Resource Recovery*. 5th ed. New York: McGraw-Hill Education.

Tchounwou, P.B., Yedjou, C.G., Patlolla, A.K. & Sutton, D.J., 2012. Heavy metal toxicity and the environment. *EXS*, 101, pp.133–164.

World Health Organization (WHO), 2010. *Exposure to cadmium: A major public health concern*. Geneva: WHO.

World Health Organization (WHO), 2019. *Lead poisoning and health*. Geneva: WHO. Available at: [Accessed 10 Aug. 2025].

Zhitkovich, A., 2011. Chromium in drinking water: Sources, metabolism, and cancer risks. *Chemical Research in Toxicology*, 24(10), pp.1617–1629.