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Research Article

Assessment of the lead, cadmium, mercury, and arsenic adsorption capacities of EDTA-modified and umodified cellulose fibres from elephant grass *(Pennisetum purpureum)*

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Abstract

Heavy metal pollution of water caused by various anthropogenic activities remains a significant global challenge, threatening the supply of clean water. Conventional water remediation approaches are costly with potential environmental risks. Thus, the development of cost-effective and biodegradable remediation methods is imperative. This study assessed the heavy metal adsorption capacities of native and EDTA-modified elephant grass (*Pennisetum purpureum*) cellulose. Elephant grass was collected from Enugu, Nigeria. The samples were washed and shade-dried. Cellulose was extracted via alkali treatment and bleaching, and then modified with EDTA to enhance its adsorptive properties. Batch adsorption experiments were designed to evaluate the capacities of unmodified and modified cellulose fibers to adsorb heavy metals from aqueous solutions under controlled conditions. The metal ion concentrations before and after adsorption were measured using flame atomic absorption spectrophotometry, and the adsorption capacities were calculated. The unmodified and modified cellulose exhibited the highest affinity for Hg(II) and Cd(II), respectively. Both types effectively removed ~70% of the Hg and Cd ions from solution. These results indicated that the unmodified cellulose was particularly effective for Hg removal, while the modified cellulose excelled in adsorbing Cd. They suggest the potential of these materials for the targeted remediation of specific contaminants and also identify them as cost-effective and biodegradable solutions for remediating heavy metal pollution.

Özet

Çeşitli antropojenik faaliyetler sonucu ağır metallerin neden olduğu su kirliliği, temiz su kaynaklarını tehdit eden önemli bir küresel sorun olmaya devam etmektedir. Geleneksel su arıtma yöntemleri maliyetli olup, potansiyel çevresel dezavantajları da bulunmaktadır. Bu nedenle, uygun maliyetli ve biyolojik olarak parçalanabilir arıtma tekniklerinin geliştirilmesi zorunludur. Bu çalışmada, sudan ağır metallerin uzaklaştırılması için fil otundan (*Pennisetum purpureum*) elde edilen modifiye edilmemiş ve EDTA ile modifiye edilmiş selülozun adsorpsiyon kapasiteleri değerlendirilmiştir. Fil otu Enugu, Nijerya'dan toplanmıştır. Örnekler yıkanmış ve gölgede kurutulmuştur. Alkali işlem ve ağartma yoluyla selüloz ekstraksiyonu yapılan selüloz, adsorpsiyon özelliklerini geliştirmek için EDTA ile modifiye edilmiştir. Modifiye edilmemiş ve EDTA ile modifiye edilmiş selüloz liflerinin sulu çözeltilerden ağır metalleri adsorbe etme kapasitelerini değerlendirmek için kontrollü koşullar altında toplu adsorpsiyon deneyleri gerçekleştirilmiştir. Adsorpsiyon öncesi ve sonrası metal iyon konsantrasyonları alev atom absorpsiyon spektrofotometresi kullanılarak ölçülmüş ve adsorpsiyon kapasiteleri buna göre hesaplanmıştır. Modifiye edilmemiş ve edilmiş selüloz en yüksek afiniteyi sırasıyla Hg(II) ve Cd(II) için göstermiştir. Her iki selüloz tipi çözeltilerden yaklaşık %70 oranında Hg ve Cd iyonlarını etkili bir şekilde uzaklaştırmıştır. Bulgular, modifiye edilmemiş selülozun Hg gideriminde özellikle etkili olduğunu, modifiye selülozun ise Cd adsorpsiyonunda üstün olduğunu göstermiştir. Bu sonuçlar, her iki tip selülozun belirli kirleticilere karşı hedefli arıtma potansiyeline sahip olduğunu düşündürmektedir. Sonuçlar bu maddelerin ağır metal arıtımı için uygun maliyetli ve biyolojik olarak parçalanabilir çözümler olarak ele alınabileceklerine işaret etmektedir.

Keywords: cellulose, heavy metals, biodegradable, remediation, adsorption

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Introduction

Groundwater, a crucial natural resource supporting human health and socio-economic development, as well as ecosystems, has recently faced escalating contamination issues. The global reliance on groundwater for drinking needs has grown significantly, with ~2.5 billion people depending solely on this resource (Grönwall et al., 2020). Water, as an indispensable element for sustaining life on Earth, plays a pivotal role in socio-economic growth and sustainable development (Okudo et al., 2023). The impacts of water resource mismanagement are further compounded by a range of human activities, posing a severe threat to water quality worldwide (Ighalo & Adeniyi, 2020; Akhtar et al., 2021).

The contamination of water resources by heavy metals, originating from natural sources and human activities, has emerged as a global concern of prominence (Egbueri et al., 2020). Heavy metal pollution of water is a significant environmental issue due to its potential ecological and human health-associated repercussions. Heavy metals, characterized by high atomic weights and densities, can cause toxicity even at low concentrations due to their environmental persistence and cumulative nature (Kumar et al., 2021). These metals, including lead (Pb), mercury (Hg), cadmium (Cd), chromium (Cr), arsenic (As), and nickel (Ni), common in industrial effluents, can disrupt aquatic ecosystems and bioaccumulate in the food chain, thereby threatening aquatic organisms and humans (Ali et al., 2020; Abd Elnabi et al., 2023; Pugazhendhi, 2024).

The water bodies are contaminated by heavy metals from diverse sources, including industrial discharge, agricultural runoff, and geological processes (Aziz et al., 2023). They exert detrimental effects on environmental stability and human well-being, potentially leading to physical, muscular, and neurological disorders (Saha et al., 2019; Ali et al., 2020). Consequently, an in-depth understanding of the quality and evolution of groundwater, as well as the associated drivers, is imperative for ensuring long-term water sustainability (Obasi et al., 2020).

The remediation of polluted water involves a process that aims to restore water quality by removing or neutralizing undesirable elements (Hashim et al., 2011). Various techniques and strategies with a focus on mitigating the adverse environmental and health issues stemming from water pollution have been employed (Asefon, 2025). These methods comprise a spectrum of approaches, encompassing physical, chemical, and biological treatments, as well as engineered technologies, all applied together to enhance the safety and quality of water (Trifirò & Zanirato, 2024). Heavy metals, a prominent type of wastewater-derived contaminants, can be effectively eliminated through established techniques such as adsorption, nanofiltration, reverse osmosis, solvent extraction, chemical precipitation, flotation, coagulation, flocculation, membrane filtration, and ion exchange (Gupta et al., 2015). These encompass renewable and non-renewable sources, are adaptable, and utilize a range of chemicals, synthetic and biomaterials, as well as their modified forms (Biswal & Balasubramanian, 2023). Conventional water remediation methods often pose high costs and potential environmental drawbacks (Elbasiouny et al., 2021). Chemical water treatment, though effective, may lead to hazardous leaching (Srivastava, 2021). Especially, biomaterials exhibit considerable potential applicability across various domains, including energy generation, material production, and waste treatment (Chowdhury et al., 2025). In particular, they hold promise for use in environmentally friendly wastewater treatment methods, like adsorption. Agricultural by-products and plant biomass, either modified or not, have demonstrated significant efficacy when harnessed for adsorption. Emerging biosorbents hold potential for metal recovery, cost-effectivity, and minimal secondary waste generation (Bilal et al., 2021). Various materials of crop origin, such as hemicelluloses, cellulose (modified or unmodified), pectin, lignin, and proteins, possess adsorption capabilities, particularly cellulose (Fomina et al., 2014). While certain operational challenges arise with these materials, their modification can overcome such limitations, increasing their adsorption capacity and mitigating issues such as color leaching (Aziz et al., 2024). Therefore, the demand for non-toxic, degradable, cost-efficient, and highly efficient biomaterials has grown, positioning cellulose as a superior alternative (Oyewo et al., 2020). Cellulose, a biodegradable and non-toxic polysaccharide prevalent in various natural resources and agricultural residues, demonstrates applicability in varied water treatment techniques, particularly in removing toxic metals and dyes (Rehman et al., 2020).

Elephant grass (*Pennisetum purpureum*) is a rapidly growing and high-biomass source of cellulose (Yuan et al., 2024). This study investigated the adsorption capacity of unmodified and EDTA-modified cellulose from elephant grass for different concentrations of lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) under constant temperature and pH. The objectives were (i) to extract cellulose from elephant grass and chemically modify it with EDTA to improve its heavy metal adsorption capacity; (ii) to investigate and quantify the adsorption capacities of both unmodified and modified cellulose for Pb, Cd, As, and Hg, using batch experiments; (iii) to compare the metal adsorption efficiencies of the unmodified and modified cellulose samples and determine if EDTA modification yields statistically significant improvements in absortion capacity; (iv) evaluate the degree of heavy metal extraction achieved by both forms of cellulose; and (v) assess the overall effect of EDTA modification on their metal-binding performance.

Materials and Methods

Collection of Grass Samples

The elephant grass used was obtained from the Lomalinda Estate, Enugu, Nigeria, where it grows widely during the dry season. The samples were collected by cutting the stems near the base with scissors (Lailaty et al., 2024). Their identity was confirmed by Prof. C. S. Eze of the Department of Applied Biology, Enugu State University, Nigeria. The samples were washed repeatedly with water to remove the extraneous impurities. Subsequently, they were shade-dried to reduce the moisture content, a step that is crucial for preserving cellulose fiber quality (Kaur et al., 2018).

Cellulose Extraction

The dried elephant grass samples were ground; 114 g of each was soaked in 5% NaOH and mechanically stirred for 2 h at 70°C. Then, the suspension was filtered, and the solid fraction was rinsed with water until a neutral pH was achieved. It was then dried at 100°C for 12 h and bleached by manual stirring with 30% H_2O_2 for 1 h at 90°C. The solid obtained after bleaching was rinsed and dried for 12 h at 100°C (de Morais Teixeira et al., 2011).

EDTA Modification

The cellulose fibres were divided into two portions, and one was EDTA-modified (Igwe et al., 2005). For this, 17 g of the fibres was refluxed in a mixture of 300 mL pyridine and 56.7 g EDTA for 3 h at 70°C. The mixture was cooled, diluted with 300 mL of deionized water, and filtered. The filtered and EDTA-modified fibres were washed copiously with deionized water and dried at 50°C for 12 h. The dried and modified adsorbent was then analyzed. The other portion was left unmodified and also analyzed.

Batch Adsorption Experiments

Equilibrium sorption of selected metal ions onto the cellulose fibres was assessed using 100 mL of each metal ion solution with concentrations varying from 200–1000 mg/L. A constant metal ion–substrate contact period of 1 h, at 29°C, and a pH of 6.7 was applied. Then, 0.2 g samples of the cellulose fiber were added to 20 mL of each solution with a specific concentration of metal ions. The setup was arranged in a rotary shaker at a moderate speed to equilibrate the mixture. After the allotted time, the mixture was rapidly filtered. The metal ion concentration of the filtrate was determined with a flame atomic absorption spectrophotometer. The difference between the initial and final ion concentrations of the solutions was considered the quantity of metal ions adsorbed by the fibres, both unmodified and modified ones.

The heavy metal adsorption capacity of cellulose was determined using Equation 1.

$$\text{Adsorption Capacity (q)} = \frac{(C_0 - C_f) \text{ x } V}{m} \qquad \text{(Equation 1)}$$

Where: C_0 = Initial concentration of metal ions in solution before adsorption, C_f = Final concentration of metal ions in solution after adsorption, V = Volume of the metal ion solution, and m = Mass of the cellulose used. The adsorption capacity is typically expressed in mg/g or µg/g, indicating the amount of metal ions adsorbed per unit mass of cellulose.

$$\text{Fraction of amount adsorbed} = \frac{C_t}{C_0} \qquad \text{(Equation 2)}$$

Where, C_t is the amount of metal ions adsorbed at any time "t;" $C_t = C_0 - C_f$.

The degree of extraction "α" was determined as follows (Nikiforova et al., 2023).

$$\alpha = \frac{C_0 - C_f}{C_0} \text{ x } 100\% \qquad \text{(Equation 3)}$$

Statistical Analysis

The statistical significance of the findings was comprehensively assessed using Excel 2016 (Microsoft, WA, USA) and Matplotlib 3.7.0 (https://matplotlib.org/3.7.0/) on Jupyter Notebook 6.5.4 (https://jupyter-notebook.readthedocs.io/en/v6.5.4/). Mean and standard deviations were computed as descriptive statistics for all the measured parameters.

Method Validation

A standard was spiked, run as a sample, and the resulting concentration was determined. The % recovery was then calculated, with values > 90% confirming equipment accuracy, thereby validating the results obtained (Table 1).

$$\% \text{ recovery} = \text{spiked - unspiked} \times 10 \qquad \text{(Equation 4)}$$

Results

Heavy Metal Adsorption Capacity of the Unmodified and Modified Cellulose

The average adsorption capacity of the unmodified cellulose was highest with Hg, followed by Pb, Cd, and As; that of the modified cellulose was highest with Cd, followed by Hg, Pb, and As (Table 2).

Table 1. % recovery calculated using calibration.

Samples	As (ppm)		Hg (ppm)		Lead (ppm)		Cd (ppm)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Spike sample (ppm)	9.09	9.08	9.07	9.07	9.28	9.47	10.67	10.72
Unspike sample (ppm)	0.24	0.29	0.22	0.25	0.298	0.280	0.987	0.955
Original conc spiked (ppm)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
% recovery	88.5	87.9	88.5	88.2	89.82	91.9	96.83	97.65

Amount injected (standard). All the tested metal ions fell within acceptable recovery limits, indicating that flame atomic absorption spectrophotometer could accurately quantify the heavy metals analyzed.

Table 2. Heavy metal adsorption capacities of the unmodified and modified cellulose.

Metal	Mean adsorption capacity (mg/g) ± standard deviation		
	Unmodified cellulose	Modified cellulose	*p*-value
Pb	42.40 ± 1.31	39.93 ± 16.46	0.754
Cd	35.50 ± 28.03	46.27 ± 19.16	0.436
As	19.77 ± 13.98	18.37 ± 7.73	0.828
Hg	53.63 ± 5.92	44.67 ± 11.14	0.165

No statistically significant differences were observed in the heavy metal adsorption capacities of the modified and unmodified cellulose. However, modification may still benefit other properties, such as improving physical stability or increasing the adsorption capacity for non-heavy metals. Though the mean adsorption capacity for Pb slightly decreased with modification, the large standard deviation in the capacities between the modified and unmodified samples suggests high variability in Pb uptake between the two. EDTA modification resulted in a higher average adsorption capacity for Cd, but a reduction in variability. However, very little difference was observed between the unmodiafied and modified cellulose in terms of As adsorption capacity. The unmodified cellulose performed better than EDTA-modified cellulose with Hg(II), having a greater mean adsorption and lower variability.

Fractions of Heavy Metals Adsorbed by the Unmodified and Modified Cellulose

The unmodified cellulose had the highest fraction of adsorbed Hg at 1000 mg/L, while the modified one had the maximal fraction of adsorbed Cd at 2000 mg/L.

There was no statistically significant difference in metal adsorption ability between the modified and unmodified cellulose for most of the heavy metals and concentrations tested. However, the *p*-value for 1500 mg/L Cd was marginally significant at 0.051, suggesting that modification might influence Cd adsorption at this concentration. EDTA modification did not consistently improve Pb adsorption, unlike Cd, especially at 1500 mg/L. The adsorption of As varied inconsistently with modification. Unmodified cellulose demonstrated better Hg adsorption, especially at lower concentrations.

Fraction of Pb Adsorbed by the Unmodified and Modified Cellulose

Figure 1 suggests that the highest fraction of Pb adsorbed was by the modified cellulose, but not the unmodified one.

Fraction of Cd Adsorbed by the Unmodified and Modified Cellulose

Figure 2 indicates that the greatest fraction of Cd adsorbed was by the modified cellulose rather than the unmodified one.

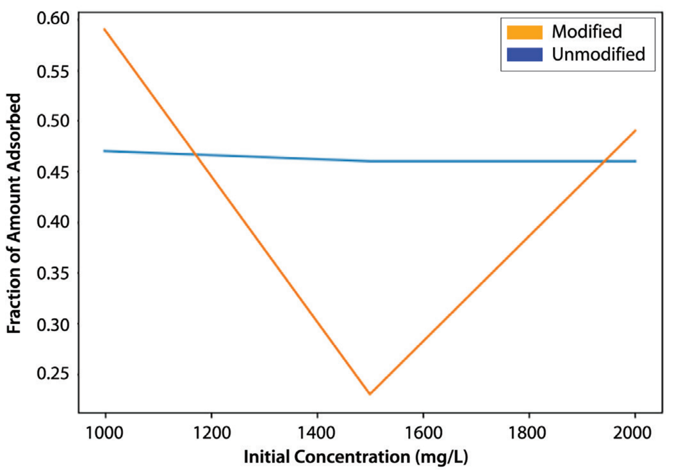

Figure 1. Fraction of Pb adsorbed by the unmodified and modified cellulose.

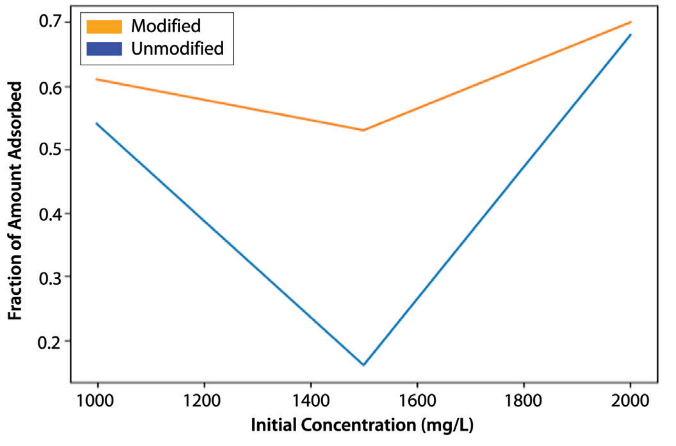

Figure 2. Fraction of the amounts of Cd adsorbed by the unmodified and modified cellulose.

Fraction of As Adsorbed by the Unmodified and Modified Cellulose

Figure 3 suggests that the highest fraction of As adsorbed was by the modified cellulose, but not by the unmodified one.

Fraction of Hg Adsorbed by the Unmodified and Modified Cellulose

Figure 4 shows that the highest fraction of Hg adsorbed was by the unmodified cellulose rather than the modified one.

Degree of Heavy Metal Extraction by the Unmodified and Modified Cellulose

The highest percentage of heavy metals extracted by the unmodified cellulose was with Hg, while that by the modified cellulose was with Cd (Table 4).

Statistically significant variations in heavy metal adsorption capabilities of the modified and unmodified cellulose were observed for Pb at 1500 mg/L, Cd at 1500 mg/L, and As at 2000 mg/L. These results suggest that cellulose modification may have a metal-type and concentration-dependent effect on the adsorptive ability. At 1500 mg/L, Pb adsorption dropped from 46% (unmodified) to 23 % (modified), with a marked p-value of 0.046. However, at 1000 and 2000 mg/L, the differences were statistically insignificant, indicating no consistent enhancement with modification. At 1500 mg/L, Cd adsorption improved remarkably from 16% to 53% ($p = 0.027$), but not at 1000 and 2000 mg/L, which may be due to a saturation or equilibrium effect at higher doses. At 2000 mg/L, As adsorption declined significantly from 57% (unmodified) to 3% (modified) ($p = 0.043$), but increased insignificantly from 9% to 27% at 1500 mg/L. However, a general trend toward improved adsorption was observed, suggesting concentration sensitivity. E.g., unmodified cellulose demonstrated higher Hg adsorption consistently across all concentrations.

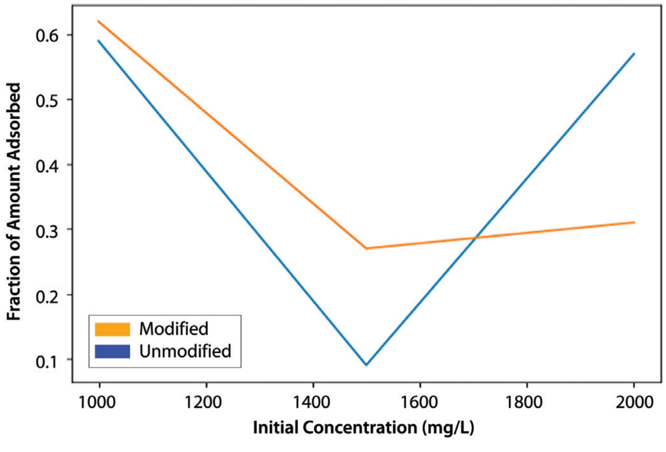

Figure 3. Fraction of As adsorbed by the unmodified and modified cellulose.

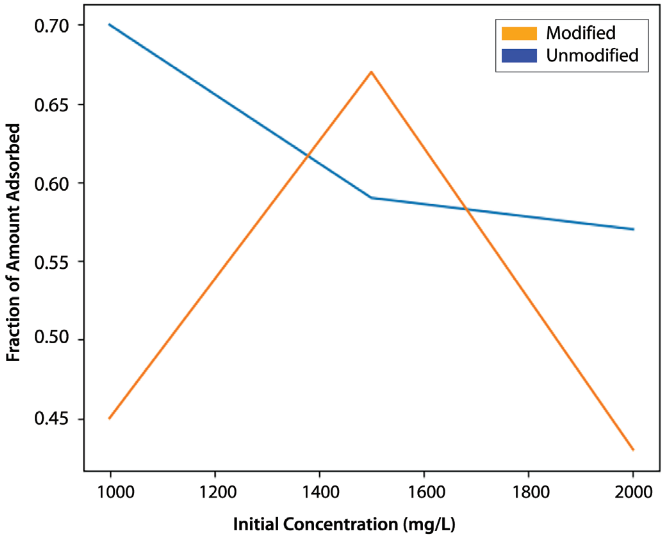

Figure 4. Fraction of Hg adsorbed by the unmodified and modified cellulose.

Table 3. Fractions of heavy metals adsorbed by the unmodified and modified cellulose.

Metal	Fraction of adsorbed amount		p-value
	Unmodified	Modified	
Pb			
1000 mg/L	0.466	0.589	0.345
1500 mg/L	0.456	0.229	0.151
2000 mg/L	0.463	0.491	0.836
Cd			
1000 mg/L	0.544	0.609	0.636
1500 mg/L	0.159	0.528	0.051
2000 mg/L	0.680	0.697	0.851
As			
1000 mg/L	0.585	0.615	0.834
1500 mg/L	0.085	0.269	0.272
2000 mg/L	0.574	0.308	0.144
Hg			
1000 mg/L	0.702	0.453	0.234
1500 mg/L	0.593	0.667	0.624
2000 mg/L	0.572	0.434	0.432

Table 4. Degree of heavy metal extraction by unmodified and modified cellulose.

Metal	Degree of extraction (%)		p-value
	Unmodified	Modified	
Pb			
1000 mg/L	47	59	0.345
1500 mg/L	46	23	0.046
2000 mg/L	46	49	0.836
Cd			
1000 mg/L	54	61	0.636
1500 mg/L	16	53	0.027
2000 mg/L	68	70	0.851
As			
1000 mg/L	59	62	0.834
1500 mg/L	9	27	0.161
2000 mg/L	57	31	0.043
Hg			
1000 mg/L	70	45	0.057
1500 mg/L	59	67	0.524
2000 mg/L	57	43	0.176

Discussion

The mean adsorption capacities indicated that modified cellulose adsorbed Cd the highest, but As the least, across all concentrations. In contrast, unmodified cellulose had the maximum adsorption capacity for Hg, while the least for As at all concentrations (Table 2). EDTA modification of the cellulose fibers modestly enhanced the Cd adsorption capacity, supporting the role of the chelating groups of cellulose in improving Cd(II) uptake (Fujita et al., 2025). The adsorption of Pb and As was not markedly affected by the modification, suggesting that these metals may interact equally well with both native and functionalized cellulose (Motloung et al., 2023). Conversely, Hg adsorption capacity was greater in the unmodified cellulose, indicating that EDTA modification may introduce functional groups that are less favorable to Hg(II) binding (Riccardi et al., 2013). The adsorption mechanisms of cellulosic materials could explain these patterns. Intrinsic adsorption and columbic interaction are the two primary concepts that may be used to describe the adsorption of metal ions on cellulosic materials (Darmenbayeva et al., 2024). The electrostatic energy of the bonds between the adsorbents and adsorbates produces Coulombic interactions. The interaction intensity mostly depends on the charge of each substrate. The surface areas of the materials dictate intrinsic adsorption. Additionally, surface and microporous adsorptions can be simultaneous (Shi et al., 2022).

The variations in Pb, Cd, As, and Hg ion adsorption are represented as fractions of the adsorbed amount (C_t) vs. the initial concentration (C_o). C_t represents the quantity of metal ions adsorbed at any given time "t." Modified cellulose demonstrated the highest adsorption capacity for Pb, Cd, and As ions, indicating that EDTA modification improved adsorption. The adsorption fractions demonstrate an enhancement in Cd uptake by the EDTA-modified cellulose, particularly at 1500 mg/L Cd, indicating effective chelation (Table 3). Pb and As absorption showed inconsistent responses, with EDTA-functionalization reducing the adsorption efficiency of cellulose with certain concentrations of ions. Hg exhibited a stronger affinity for the unmodified cellulose, suggesting that EDTA ligands may not offer favorable coordination sites for the Hg(II) ions. These findings underscore the importance of matching adsorbent functional groups to the specific chemistry of each metal ion. An enhancement in the adsorption capacity of cellulose post-modification was reported by Kaur et al. (2022), who comprehensively reviewed modified cellulose adsorbents—including EDTA functionalized ones, and their adsorption capacities for Pb, Cd, and Cu. They noted that chemical modifications, like adding EDTA groups, significantly enhanced the adsorption capacity and binding affinity of the unmodified cellulose.

The adsorption abilities revealed a clear metal- and concentration-dependent behavior of cellulose modification (Table 4). EDTA-functionalization significantly improved the removal of Cd at 1500 mg/L, most likely due to robust chelation, while reducing the adsorption of Pb and As at specific concentrations, possibly due to steric effects or changes in surface chemistry. Hg showed a higher affinity for unmodified cellulose, which may be due to the metal-binding limitations of EDTA. These findings signify that certain modifications of adsorbents are suitable for specific contaminants and their expected concentrations. A comparison of Figures 1–4 suggested that modified cellulose had the maximum adsorption capacity for Cd ions, followed by Hg, As, and Pb. In general, this result indicates that Cd(II) > Hg(II) > As(III) > Pb(II) is the pattern of adsorption onto the modified cellulose. A comparison of the adsorption capabilities of unmodified cellulose for various concentrations of heavy metals indicated a maximum adsorption for Hg(II) at 1000 mg/L. Furthermore, Figures 1–4 demonstrate that unmodified cellulose had the maximum adsorption capacity for Hg ions, followed by those of Cd, As, and Pb. Thus, the general trend of adsorption onto unmodified cellulose is Hg(II) > Cd(II) > As(III) > Pb(II). Gupta et al. (2021) reported a similar trend in their review. In contrast, Kenawy et al. (2018) demonstrated a different trend: Cu(II) > Zn(II) > Cd (II) > Pb > Hg, which was consistent with both the modified and unmodified maize husks.

These findings demonstrate that the type of metal ion, the concentration of the metal ion in solution, and the type of adsorbent modification affect the amounts of metal ions bound by cellulose (Chen et al., 2019). The nature and distribution of the substrate active groups, the type of metal ion–substrate interaction, and size differences in the metal ions can explain the variations in their uptake levels (Wang et al., 2023). The ionic radii were As^{3+}: 0.46 Å, Cd^{2+}: 0.97 Å, Hg^{2+}: 1.02 Å, and Pb^{2+}: 1.20 Å. The adsorption rate is inversely proportional to the ionic diameter (Sasan et al., 2023). Similarly, in this study, the ion with the largest radius, Pb(II), had the lowest adsorption. However, the next in size, As(III), went against the trend. This inconsistency can be explained by the surface adsorption of component groups on substrates being more vital for adsorption capacity than microporous adsorption in such cases, which is especially true for Cd(II) and Hg(II) than As(III) ions (Abdelhamid & Mathew, 2021; Aguayo-Villarreal et al., 2024). As a result, compared to As(III), the adsorption of Cd(II) and Hg(II) ions was greater. Statistical analyses unraveled key trends in the adsorption behavior of the unmodified and EDTA-modified cellulose fibers toward heavy metals. While there were no statistically significant differences in the adsorption capacities for Pb, Cd, As, and Hg between the two cellulose types, EDTA modification enhanced Cd adsorption, particularly at its high concentrations. These results suggest that EDTA modification enhances Cd extraction, especially at 1500 mg/L, but may hinder that of Pb and As at certain concentrations. Hg was consistently adsorbed more by unmodified cellulose, indicating unfavorable interactions with the donor O_2 atoms of EDTA.

Conclusion

This study investigated the adsorption capacities of unmodified and EDTA-modified cellulose fibres derived from elephant grass for four toxic heavy metals—Pb, Cd, Hg, and As—from aqueous solutions. The results indicated that both cellulose types possessed considerable potential as biosorbents. However, their affinities varied based on the metal ion involved and the type of chemical modification. The unmodified cellulose demonstrated the highest adsorption capacity for Hg, particularly at its lower concentrations, suggesting a strong inherent affinity for Hg(II) ions. In contrast, EDTA-modified cellulose exhibited significantly improved adsorption for Cd, indicating that EDTA functionalization increased metal binding, especially for Cd(II). These findings support the hypothesis that EDTA grafting introduces functional groups that facilitate chelation and complexation with specific metal ions. Although the differences in adsorption capacities were not always statistically significant at $p < 0.05$, modification did enhance the average adsorption and extraction percentages for certain metals—especially Cd at higher concentrations. The adsorption trends observed were Hg(II) > Cd(II) > As(III) > Pb(II) and Cd(II) > Hg(II) > As(III) > Pb(II) for the unmodified and modified cellulose, respectively. The results also suggest that surface adsorption by functional groups may play a more major role than microporous adsorption, particularly for Cd(II) and Hg(II) ions.

In conclusion, both unmodified and modified elephant grass cellulose fibres present biodegradable, cost-effective, and environmentally friendly options for the remediation of heavy metal-contaminated water. In particular, EDTA-modified and unmodified cellulose show promise for the targeted removal of Cd and Hg, respectively.

Ethics

Ethics Committee Approval: Since the article does not contain any studies with human or animal subject, its approval to the ethics committee was not required.

Data Sharing Statement: All data are available within the study.

Footnotes

Author Contributions: Conceptualization: I.I.U., O.N.A., and E.O.N.; Design/methodology: I.I.U., O.N.A., and E.O.N.; Execution/investigation: I.I.U., O.N.A., and E.O.N.; Resources/materials: I.I.U., O.N.A., and E.O.N.; Data acquisition: I.I.U., O.N.A., and E.O.N.; Data analysis/interpretation: I.I.U., O.N.A., and E.O.N.; Writing – original draft: I.I.U., O.N.A., and E.O.N.; Writing – review & editing/critical revision: I.I.U., O.N.A., and E.O.N.

Conflict of Interest: The authors have no conflicts of interest to declare.

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