Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268 (Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 24 No. 2 Article ID B4239 2025

Original Research Paper https://doi.org/10.46488/NEPT.2025.v24i02.B4239 Open Access Journal

Investigating the Effectiveness of Peanut Hull as Biosorbent of Lead (Pb) from Water

Mehak Verma† and Sarita Sachdeva
Department of Biotechnology, Manav Rachna International Institute of Research and Studies, Sector 43, Faridabad, Haryana, India
†Corresponding author: Mehak Verma; mehakverma2829@gmail.com

Abbreviation: Nat. Env. & Poll. Technol.
Website: www.neptjournal.com

Received: 09-07-2024
Revised: 21-08-2024
Accepted: 26-08-2024

Key Words:

Biosorption
Heavy metals
Lead
Peanut hull
SDG-6
SDG-12

Citation for the Paper:

Verma, M. and Sachdeva, S., 2025. Investigating the effectiveness of peanut hull as biosorbent of lead (Pb) from water. *Nature Environment and Pollution Technology*, 24(2), p. B4239. https://doi.org/10.46488/NEPT.2025.v24i02.B4239

Note: From year 2025, the journal uses Article ID instead of page numbers in citation of the published articles.

ABSTRACT

Lead contamination poses a major threat to health and environmental well-being. The remediation of this heavy metal from water sources is essential to safeguard health and ensure access to clean water. In this study, Peanut hull was used as a biosorbent for lead (Pb) removal from water. It focuses on optimizing various parameters important for lead removal. Statistical analysis, such as the Kruskal-Wallis test, was done to assess the significance of these parameters on lead biosorption, and an inverse variance weighting technique was employed to derive the weighted contribution of each variable for fixed Pb removal categories in the range of 80-100% and 80% (below). On analysis, it was found that factors such as pH and biomass dosage played major roles in lead removal. Furthermore, Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray Spectroscopy (EDS), were done to find out changes in the structural and elemental characteristics of peanut hull after lead sequestration. Overall, this study highlights the potential of peanut hull as a promising biosorbent for lead removal from water, thereby offering a sustainable solution to water contamination with heavy metals.

INTRODUCTION

Water is one of the most essential resources required for the survival of living beings on earth. It plays a crucial role in physiological functions such as digestion, circulation, regulation of temperature, and waste removal. Beyond its biological importance, water also plays an important role in hydration, agriculture, sanitation, and industry, but access to clean and safe water is a cornerstone of public health, reducing the spread of diseases and improving the quality of life, along with very survival of lifeform on this planet. However, when it comes to water contamination with heavy metals, Lead contributes to significant health risks. When ingested through contaminated water, lead can accumulate in the body, leading to a range of health problems, such as developmental delays in children, neurological damage, kidney damage, and high blood pressure (Prabha & Udayashankara 2014, Tewari et al. 2023). Even low levels of lead exposure can be harmful, making it crucial to ensure that water sources are free from such contaminants. The United States Environment Protection Agency (USEPA) sets maximum permissible limits for lead (II) in drinking water at 0.015 $mg.L^{-1}$ and in wastewater at 0.1 $mg.L^{-1}$ respectively (Tanase et al. 2020).

Therefore, to address the removal of lead contamination in water, biosorption has emerged as an effective technique. This technique utilizes biological materials to adsorb and eliminate a pollutant, also offering a promising solution to mitigate Pb poisoning (Apori et al. 2018).

From the various materials used in the past, Peanut hull, the outer covering of peanut, also known as ground nut, consisting of cellulose, hemicellulose, and lignin, has proved to be a novel bioadsorbent as it is very porous and has a large surface area which makes it a good bioadsorbent. Though these hulls have no nutritional benefits, they do have health benefits as they have antioxidants such as polyphenols, amino acids, and flavonoids (Adhikari et al. 2019). They also contain Carotene, Luteolin, and Isosaponaretin (Yu et al. 2014). Peanut hulls not only exhibit antimicrobial activities, which can help reduce harmful bacteria in water, but also demonstrate inhibitory effects against pest attacks (Wee et al. 2007, Adhikari et al. 2019). These benefits are being explored in the scientific world for the benefit of humans. In addition to this, they also show good adsorbent properties in the removal of metals and dyes from water (Sattar et al. 2019, Panchal et al. 2020). In recent times, new regulations have been introduced to bolster the protection of our environment, majorly focusing on the depollution and recycling of heavy metals. These regulations emphasize the need for eco-friendly depollution methods. Plant-based materials for the treatment of water are highly encouraged because of their eco-friendly and non-toxicity nature (Dharsana & Arul Jose 2022). Among the various approaches, using low-cost natural adsorbents for the adsorption process stands out as an effective and sustainable solution for heavy metal remediation (Olabanji & Oluyemi 2021, Kali et al. 2024, Sudan et al. 2024). Therefore, peanut hull fits best as a bioadsorbent for the removal of heavy metals such as lead from water. It is environmentally friendly and cost-effective and works great in removing toxic metals and contaminants. It contains functional groups like hydroxyl, carboxyl, and amino, which enable the biosorption process (Gong et al. 2005).

In this study, Peanut hull is used as a biosorbent for the removal of Lead from water. The impact of parameters such as pH, contact time, temperature, metal concentration, particle size, and biomass dose on the adsorption efficiency of lead from water was investigated in light of the presence of lead in raw drinking water in Faridabad district, Haryana, as observed in previous study undertaken. Also, In alignment with the United Nations Sustainable Development Goals (SDGs), Goal 6 (Clean Water and Sanitation) and Goal 12 (Responsible Consumption and Production) supports the utilization of peanut hulls as biosorbents in sustainable water management and promote the efficient use of natural resources.

MATERIALS AND METHODS

Preparation of Biosorbent

Peanut hull was selected as biomaterials. It was sourced from a local market and thoroughly washed with water to remove any impurities. Afterward, it was air-dried for three days. The dried husks were then ground using a grinder machine and sieved through meshes of sizes (100, 150, 200, 250, and 300 mm) to obtain particles of varying sizes. These biomass particles were stored in airtight pouches to preserve their quality and were subsequently utilized in batch experiments.

Preparation of Metallic ion Solution

A lead standard solution ($Pb(NO_3)_2$) in HNO_3 at 0.5 $moL.L^{-1}$ of 1000 ppm) was purchased from Sigma Aldrich. Stock solutions of 50, 100, 150, 200, and 250 ppm were prepared using the standard solutions. pH of the samples was maintained by adding 0.1M NaOH solution or by adding 0.1M HCl solution.

Design of Sorption Experiments

Adsorption studies were conducted by considering six major factors as operational variables. The effects of pH levels (4-8), temperature (20-40°C), particle size (100-300 mm), biomass dose (1-5 $g.L^{-1}$), initial metal concentration (50-250 ppm), and metal exposure time (30-240 min) were investigated to determine the optimal conditions for Pb removal. The experiment was designed on Minitab 17 using the Taguchi method with six variables at five levels. A 25-run experiment was designed using the software. Each run was carried out in triplicate with a specific range for each variable. A 50 mL water sample was taken, and the peanut hull biomaterial was added along with a synthetic metal solution of Lead, and the experiments were performed as shown in Fig. 1. The experiments were conducted in a 250 mL flask containing the lead synthetic solution in different concentrations containing the desired level of peanut hull biomass at the beginning of each experiment. The flasks were kept in the incubator and were agitated at 125 rpm and then centrifuged at 5000 rpm for 5 min to separate the solid from the liquid phase. The samples were filtered and the concentrations of metal in the samples were estimated by Atomic Absorption Spectroscopy (Model No. AAS429).

Characterization

Scanning Electron Microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were undertaken to analyze the sorption of lead on the biomaterial. The air-dried samples of the peanut hull, before and after biosorption, were used. The samples were coated with a thin layer of gold before conducting morphological studies to ensure clear imaging and prevent charging effects. The elemental compositions of the samples were analyzed using energy-dispersive X-ray spectroscopy (EDS) integrated with the scanning electron microscope (SEM) at bar lengths of 10 µm and a voltage

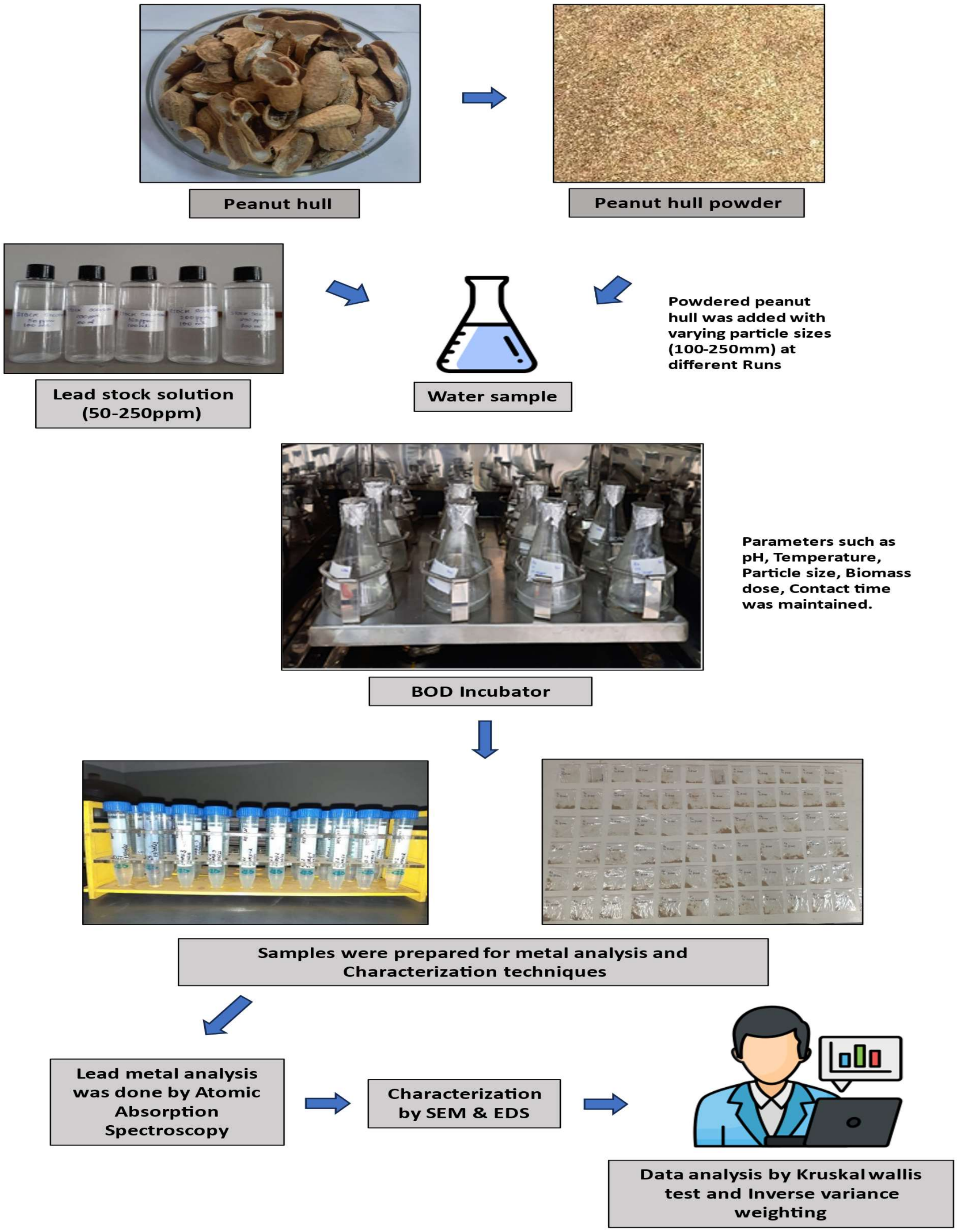


Fig. 1: Schematic diagram depicting the process of biosorption study with lead metal.

of 20 kV at 1500 magnification was recorded on a JEOL JSM-6610LV SEM.

Statistical Analysis

Statistical analysis was conducted using Python 3.11.4 (by Anaconda) and R software. The Kruskal–Wallis test was used to determine the significance of the adsorption parameters on metal removal. The inverse variance weighting method was used to determine the weight percent contribution of each variable towards the removal of the Lead metal. In this method, the weights of each variable are calculated as the inverse of the variance of the variable when taking multiple measurements with varying values of the variables. In this study, several variables, each contributing towards the removal of lead, and to calculate the weighted contribution of each variable, first, the total percentage removal was fixed into two categories, namely 80-100% and below 80%, to obtain the significant number of data points. Given the percentage removal in each category, the variance (var) of the values of the contributing variables was calculated using the R statistical software. The inverse of this variance (1/var) was regarded as the weight. To calculate the weight percent, all these weights were summed up for all the variables, and the percentage was calculated as weight/sum * 100. The assumptions include that the variables are independent and their values are expressed in their respective standard units (Team 2024).

To determine the optimum conditions, adsorption efficiency was calculated using Eq.1 -

$$\text{Adsorption efficiency (\%)} = C_O - C_F \times 100/C_O \quad \ldots(1)$$

Where C_O is the initial concentration (ppm) and C_F is the Final concentration (ppm) of the metal.

RESULTS AND DISCUSSION

Effect of pH

The potential of hydrogen (pH) plays an important role in influencing the process of biosorption. The biosorption of lead (Pb) on the sorbent was investigated across a pH range of 4 to 8, considering various factors such as temperature, particle size, biomass dosage, metal concentrations, and contact time. The influence of pH on metal removal was investigated across varying concentrations (50, 100, 150, 200 and 250 ppm). As seen in Fig. 2, Average maximum removal was observed at pH 5, i.e. 91.51%. Also, out of the experiments conducted, under varying variables, at an initial concentration of 150 ppm, pH 5, lead removal (100%) was observed, which indicates the efficiency of peanut hull as a biosorbent. Hence, results reveal that pH is one of the crucial factors. The competitiveness of metallic ions, the activity of the functional groups in the biomass, and the solution chemistry of the metals are all impacted by pH (Verma & Suthar 2015).

Furthermore, the Kruskal Wallis test statistically shows significant removal of Pb across all the variables. The inverse variance weighting approach gives the weighted contribution of each variable across the percentage ranges of 80-100% and below 80%. The result reveals that pH is one of the most important factors among all the adsorption parameters, with % weights ranging from 47.52-50.40%.

Effect of Temperature

The effect of this parameter on the metal removal was investigated in the temperature range between 20-40°C. Temperature significantly impacts the adsorption capacity, kinetics, and thermodynamic properties of peanut hulls in the removal of lead (Pb) metal (Aranda-García & Cristiani-Urbina 2018). Further, temperature variations can alter the efficiency of adsorption, affect the rate at which adsorption occurs, and influence the overall thermodynamic feasibility of the process (Znad et al. 2022). The maximum average removal, i.e., 87.65% at 20°C. With the increase

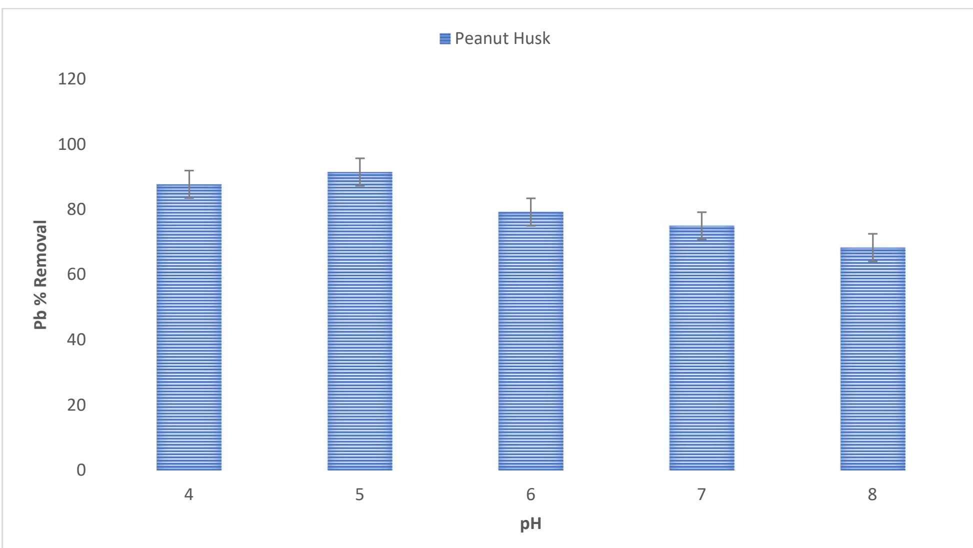


Fig. 2: Effect of pH on Lead adsorption efficiency.

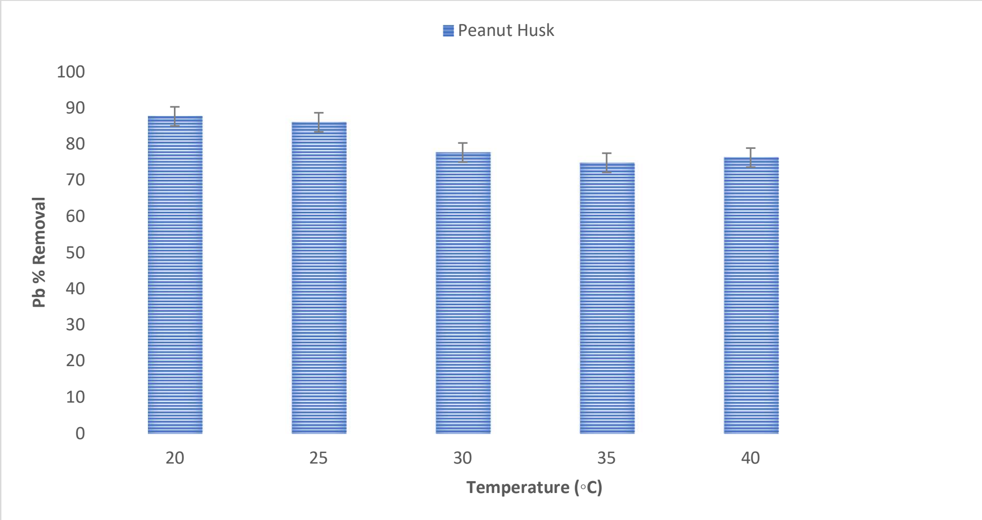


Fig. 3: Effect of temperature on lead adsorption efficiency.

in temperature, there was a decrease in lead adsorption efficiency (Tanyildizi et al. 2011, Zhao et al. 2021), as depicted in Fig. 3 below. Also, under specific conditions, At a pH range of 4-6, Temperature 20°C, metal concentration of 50-100ppm, 100% metal removal was observed. Furthermore, the Kruskal Wallis test statistically shows significant removal of Pb across all the variables. The inverse variance weighting approach reveals that Temperature also exerts influence amongst all the adsorption parameters with % weights ranging from 2.27 – 18.25%.

Effect of Particle Size

To investigate the effect of particle size on metal sorption, particle sizes ranging from 100 to 300 mm were tested. It was observed that particle size did not exhibit a major trend or significant difference in lead uptake. Previous studies have shown that smaller particle sizes result in higher surface areas available for sorption, leading to increased removal efficiency (Amuda et al. 2007). Smaller particles possess a greater surface area compared to larger particles, providing more adsorption sites and resulting in a higher adsorption capacity (Wang & Shadman 2013, Manyangadze et al. 2020). In this study, the highest average adsorption efficiency was recorded at a particle size of 100 mm, achieving 89.18% lead removal, as seen in Fig. 4 below. The active sites on the biomass interact with metal ions. Smaller particles expose more of these sites, leading to better metal uptake (Baker 2020). Also, out of the 25 experiments conducted

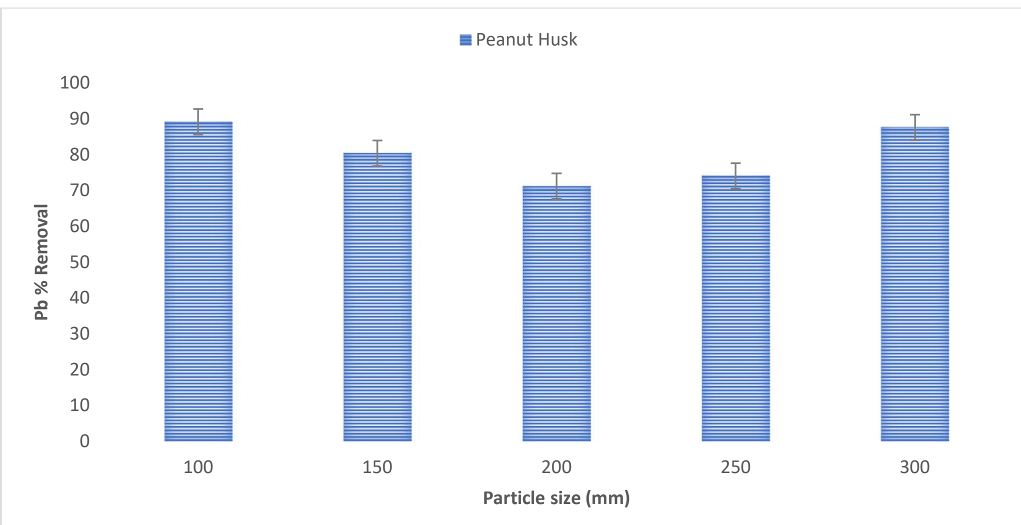


Fig. 4: Effect of particle size on lead adsorption efficiency.

in triplicates under varying variables, the best result with 100% lead removal was observed at an initial concentration of 50 ppm, pH 4, temperature of 20°C, particle size of 100 mm, biomass dose of 1 $g.L^{-1}$, and contact time of 30 min. Furthermore, the Kruskal Wallis test statistically shows significant removal of Pb across all the variables. The inverse variance weighting approach reveals that particle size has less influence amongst all the adsorption parameters with % weights ranging from 0.0001-0.0002%

Effect of Biomass Dose

The biomass dose, or the amount of biosorbent used, is a crucial factor in determining the efficiency of biosorption studies. In the present study, varying doses, ranging from 1 $g.L^{-1}$ to 5 $g.L^{-1}$, were investigated for the removal of lead from water with different metal concentrations (50, 100, 150, 200, and 250 ppm) and varying parameters. The maximum average adsorption efficiency, i.e., 84.7%, was observed at an adsorbent dose of 5$g.L^{-1}$, as seen in Fig. 5 below. As the adsorbent dose increases, the surface area available for adsorption also expands, enhancing the interaction between lead (Pb) and the adsorbent. Consequently, the removal efficiency improves with the increased adsorbent dosage (Elkhaleefa et al. 2021, Ahmad et al. 2022). This results in more adsorption sites and a stronger binding capacity, leading to more effective removal of lead from the solution (Shah et al. 2022). However, there is a great impact of other variables, which sometimes leads to the fluctuating behavior of this parameter on the adsorption efficiency. The result of the study clearly states a dose-response relationship where the lead uptake increases with an increase in biosorbent dosage (5g) until a maximum uptake is reached. Also, under specific conditions, at an initial metal concentration of 100 ppm, pH 6, Temperature of 20°C, particle size of 200 mm, biomass dose of 5 $g.L^{-1}$, and Contact time of 180 min, 100% metal removal was observed. Furthermore, the Kruskal Wallis test statistically shows significant removal of Pb across all the variables. The inverse variance weighting approach reveals that Biomass is also one of the most important factors, with % weights ranging from 31.34-50.1%.

Effect of Contact Time

Contact time is also a crucial variable as it determines the duration needed for metal sorption onto the peanut hull biosorbent. It reflects the time period of the sorption process, influencing the efficiency and effectiveness of metal removal from the solution. The average maximum adsorption efficiency, i.e., 91.3%, was observed at 180 min. Initially, the biosorption was near to constant within a time range of 30-120 min, it gradually started increasing after 120 min, and the maximum biosorption of lead on peanut hull was observed at 180 min, and after that, it started decreasing. As contact time increases, the availability of adsorption sites also increases, leading to a higher adsorption rate (Li et al. 2022). However, after a certain point, these sites become saturated, causing the adsorption process to slow down (Abbas et al. 2020).

Also, under specific conditions, at an initial metal concentration of 150 ppm, pH 5, Temperature 40°C, Particle

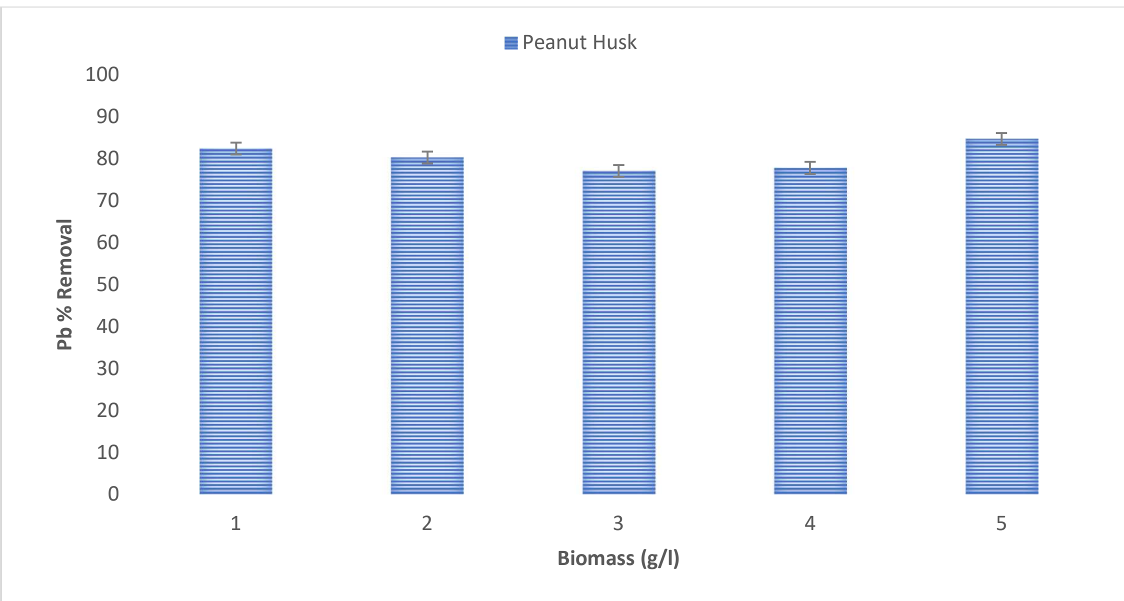


Fig. 5: Effect of biomass dose on Lead adsorption efficiency.

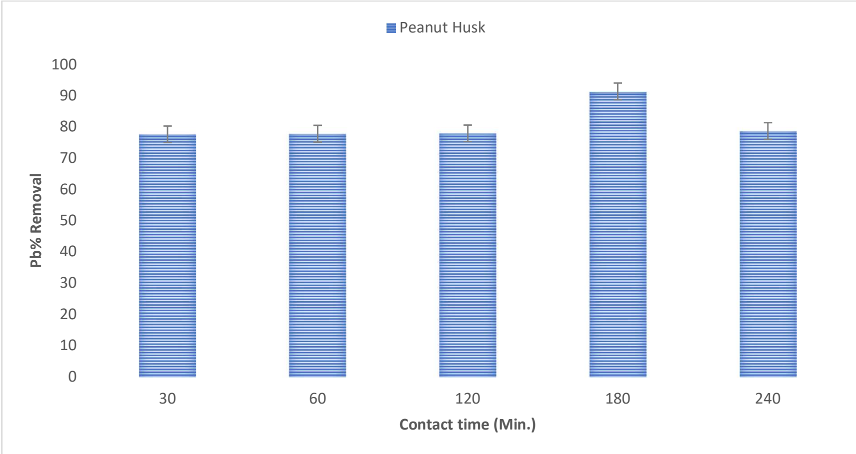
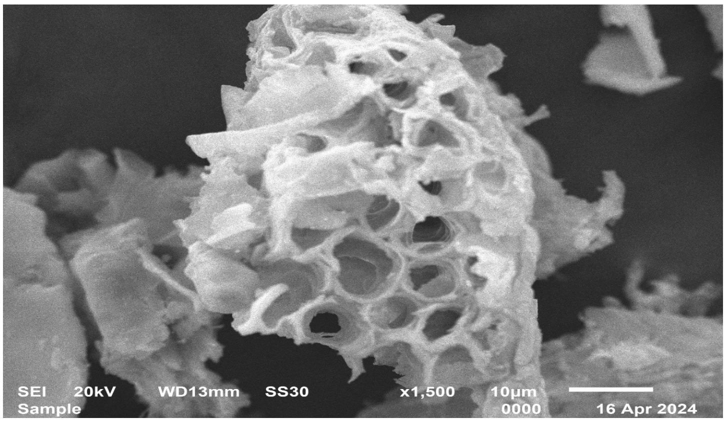
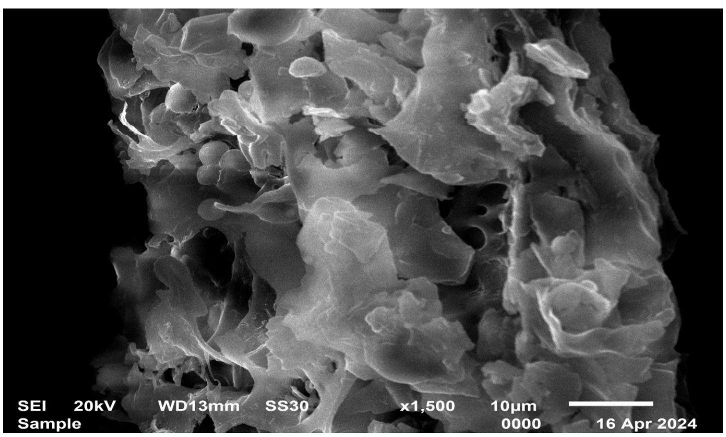


Fig. 6: Effect of Contact time on Lead adsorption efficiency.

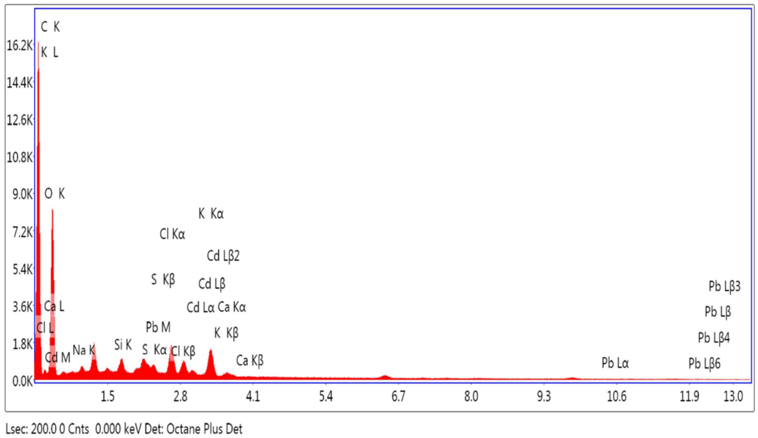


a) SEM Scans of Peanut hull before Biosorption of Lead metal

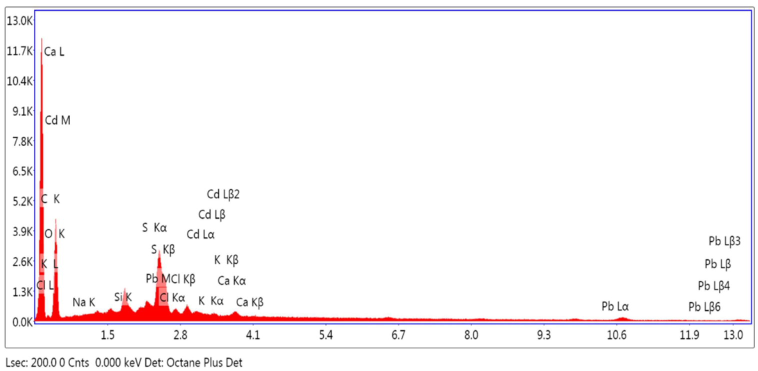


b) SEM Scans of Peanut hull after Biosorption of Lead metal

Fig. 7: a) Scanning electron micrographs before biosorption, b) After biosorption.



a) Elemental map for visualization of lead before biosorption



b) Elemental map for visualization of lead after biosorption

Fig. 8: a) Energy Dispersive X-Ray Spectroscopy graphs before biosorption b) after biosorption.

size 100 mm, Biomass 2 $g.L^{-1}$, and contact time of 180 min, 100% lead removal was observed (Fig. 6). Moreover, the Kruskal Wallis test statistically shows significant removal of Pb across all the variables. The inverse variance weighting approach reveals that contact time has less influence amongst all the adsorption parameters, with % weights ranging from 0.00001-0.0001%.

Characterization

The scanning electron micrograph of the peanut hull biomass at bar lengths of 10 µm and a voltage of 20 kV with 1500 magnification was recorded. Fig. 7a shows the porous texture of the peanut hull, which provides ample surface area and adsorption sites for biosorption. Fig. 7b reveals the changes in the surface morphology of the biomaterial after biosorption. The altered surface structure enhances the adsorption efficiency which facilitates the smooth sorption of lead on the surface of peanut hull. This type of porous surface is suitable for the retention of metals. The adsorption of Pb on the surface of the biomaterial was further confirmed by Energy Dispersion X-ray Spectroscopy (EDS) analysis, as depicted in Fig 8a and 8b, and their elemental composition is shown in Table 1.

The characterization results indicate that the selected biomaterial effectively removes Lead (Pb) from water and demonstrates efficient performance. Further, the chemical properties of the biosorbent play an important role in its efficiency to remove a particular metal therefore, the elemental composition of the peanut hull before and after

Table 1: Elemental composition of peanut hull biosorbent before and after biosorption.

Element	Weight %		Atomic %	
	Before	After	Before	After
Carbon	55.54	44.53	63.46	56.74
Oxygen	41.24	42.97	35.38	41.11
Sodium	0.09	0.01	0.06	0.01
Lead	0.19	8.25	0.01	0.61

the process of biosorption of lead is shown in Table 1. It was generated during the SEM-EDS integrated analysis. The weight percentage of Lead increased from 0.19% to 8.25% after the biosorption process, which proves this material is a good biosorbent.

LIMITATIONS

Our study was conducted in controlled laboratory conditions, which may not reflect real-life water treatment processes. Several additional factors could arise, thereby posing challenges during the scaling up of the process for large-scale water treatment. These include the availability and uniformity of peanut hulls for maintaining uniform biosorption efficiency, the renewal and reusability of peanut hulls after lead adsorption, and the presence of other heavy metals or contaminants in the water that could potentially interfere with lead biosorption.

These limitations highlight the need for further research and consideration in treatment applications, while they do not undermine the potential of peanut hulls as a good biosorbent, especially because peanut hulls are presently discarded as waste material.

CONCLUSIONS

This study shows the impressive biosorption potential of peanut hulls, revealing a high adsorption efficiency for the targeted lead metal. There was significant removal of lead across all the variables with pH and biomass dose being the most influential factors. The weighted contributions on the adsorption efficiency ranged from 47.52% to 50.40% for pH 31.34% to 50.1% for Biomass dose. The Variables are aligned by their maximum weighted contributions as follows: pH > biomass dose > temperature. Thus, pH and biomass do have the highest impact,x followed by temperature and other variables for peanut hull biosorbent. The findings of the studies accentuate the importance of pH and biomass dose to maximize the adsorption of peanut hulls. Hence, Peanut hulls, an agricultural by-product, can be an economically and eco-friendly solution for lead contamination in water. The use of such biosorbents could reduce reliance on expensive and chemically intensive methods of water purification. Future research should explore the reusability and regeneration of peanut hull biosorbents as well as their effectiveness in removing other heavy metals and contaminants from water. Additionally, investigations are required to refine the biosorption process, comprehend the mechanisms involved, and examine the feasibility of scaling up for industrial use. Large-scale peanut shell use needs to be studied for its long-term stability and environmental effects, as well as its potential for promoting a circular economy by minimizing waste discard and recycling. Multidisciplinary research might also investigate the synergistic effects of integrating peanut hull biosorbents with currently used water treatment technologies. Overall, Peanut hull proves to be a potential, sustainable, and effective material for the removal of lead contamination, thereby contributing to cleaner water resources, enhanced public health, and reduced environmental footprints.

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