Comparative Evaluation of Unmodified Eggshell, Cow Bone, and Wood Shavings Biomass for the Remediation of Chromium-Contaminated Soils

Ananaba J. C. [a], Ideriah T. J. K. [b], Nitonye V. I. P. [a], and Akinfolarin M. O. [a]
Judith.ananaba@rsu.edu.ng
[a] Department of Chemistry, Rivers State University, Port Harcourt, Nigeria
[b] Institute of Pollution Studies, Rivers State University, Port Harcourt, Nigeria.
Authors' contributions
This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.
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Abstract
Heavy metal contamination of soils poses significant environmental and public health concerns, particularly in areas affected by industrial and urban activities. This study evaluated the remediation potential of eggshell (ES), cow bone (CB), and wood shavings (WS) for chromium (Cr)-contaminated soils collected from Lagos bus stop, Community Secondary School, Nkpolu, and Eagle Island in Rivers State, Nigeria. Soil samples were artificially contaminated with Cr and amended individually with ES, CB, and WS at application rates of 10, 20, and 40 g per 500 g of soil, as well as with combined biomass treatments. The amended soils were monitored for four weeks, with measurements taken at Weeks 1, 2, and 4. All biomass treatments produced progressive reductions in Cr concentrations over the experimental period, although their effectiveness varied with biomass type, application rate ,and soil locationl. The highest reduction was 99.9% with 20 g cow bone in Lagos bus stop soil, followed by 99.5% with 40 g cow bone in Eagle Island soil and 99.4% with 20 g eggshell in Nkpolu. Cow bone generally showed strong performance, particularly in Lagos bus stop and Eagle Island soils; however, eggshell and wood shavings also produced substantial reductions under specific treatment conditions. The combined biomass treatment was effective in several cases but did not consistently outperform the individual biomass materials. Overall, the findings demonstrate that eggshell, cow bone, and wood shavings have potential as low-cost biomass amendments for remediating Cr contaminated soils. Their effectiveness is associated with complementary mechanisms involving adsorption, ion exchange, complexation, and mineral precipitation. The study highlights the potential for converting locally available agricultural and animal wastes into useful materials for sustainable heavy metal remediation.

Keywords: *Biomass, Cow bone, Eggshell, Wood shavings, Chromium, Remediation.*

1. INTRODUCTION

Heavy metal contamination of soils has become one of the most persistent environmental challenges associated with industrialization, urban expansion, mining, petroleum exploration, transportation, and indiscriminate waste disposal (Swain, 2024; Selvam et al., 2024; Hanif et al., 2025). Unlike many organic pollutants, heavy metals are non-biodegradable and persist in soils

for extended periods, posing serious ecological and public health risks through bioaccumulation and biomagnification (Xu & McKay, 2024; Chowdhury & Rahman, 2024). Among these contaminants, chromium (Cr) is particularly important because of its toxicity, persistence, and widespread occurrence in contaminated environments (Mishra et al., 2019; Ali et al., 2019).

Chromium is a metal whose behavior in soil is particularly influenced by its oxidation state and the physicochemical properties of the soil. Trivalent chromium [Cr(III)] and hexavalent chromium [Cr(VI)] are the two forms of chromium usually encountered in environmental systems. They differ substantially in bioavailability, toxicity and mobility. Cr(III) commonly has a lower mobility because it can adsorb to soil constituents or form sparse soluble precipitates, whereas Cr (VI) is more mobile, toxic and occurs as soluble oxyanions (Zulifqar et al., 2023). Several remediation techniques have been developed for contaminated soils, including excavation, soil washing, vitrification, stabilization, electrokinetic remediation, phytoremediation, and chemical immobilization (Derakhshan Nejad et al., 2018). However, many conventional remediation technologies remain economically prohibitive, technically demanding, and environmentally disruptive, particularly in developing countries (Akansha et al., 2024). Consequently, adsorption using low-cost biomass materials has emerged as one of the most promising green remediation technologies because of its simplicity, affordability, and environmental compatibility (Zhang et al., 2022). Recent reviews emphasize that agricultural residues and animal-derived wastes contain abundant functional groups capable of binding heavy metals through adsorption, ion exchange, complexation, and precipitation mechanisms (Krishnani et al., 2023; Wang et al., 2022; Solomon et al., 2026; Jeyakumar & Vashishth, 2026).

Agricultural and animal wastes such as eggshells, cow bones, and wood residues are generated in large quantities worldwide and are frequently disposed of without beneficial utilization. Eggshells consist primarily of calcium carbonate, cow bones are rich in hydroxyapatite containing phosphate groups, while wood shavings contain cellulose, hemicellulose, lignin, hydroxyl, and carbonyl functional groups (Lizundia et al., 2022). These materials possess chemical characteristics that make them effective biosorbents for immobilizing toxic metals in contaminated soils. Their utilization simultaneously addresses waste management challenges while providing environmentally sustainable remediation technologies consistent with circular economy principles (de Siqueira et al., 2026).

In Nigeria, especially within the Niger Delta region, numerous studies have documented elevated heavy metal concentrations in soils arising from petroleum exploration, industrial emissions, traffic activities, waste disposal, and urbanization (Abayomi et al., 2021; Onyena et al., 2024; Numbere et al., 2023; Ossai et al., 2025). However, comparative information on the remediation performance of locally available biomass materials under identical experimental conditions remains limited (Simić et al., 2026). Furthermore, few studies have simultaneously evaluated animal-derived and plant-derived biomass materials using identical contamination levels and remediation periods.

This study therefore investigated the comparative remediation efficiencies of unmodified eggshell, cow bone, and wood shavings for reducing chromium concentrations in contaminated soils collected from selected locations representing commercial, residential, and educational environments in Rivers State, Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study was conducted using soils collected from selected locations in Rivers State, Nigeria, representing different land-use types. Rivers State lies within the Niger Delta region of southern Nigeria and is characterized by a humid tropical climate with annual rainfall ranging from 2,000 to 3,000 mm, mean annual temperatures of 26–32 °C, and high relative humidity throughout the year (WMO 1996). Rapid urbanization, industrial activities, heavy vehicular traffic, agricultural practices, and improper waste disposal have contributed to environmental contamination in many parts of the state.

Three representative sampling stations were selected based on their dominant land-use characteristics**.** Station 1 is Community Secondary School, Nkpolu, a school environment (4°48′31.15044″ N, 6°59′15.20268″ E). Station 2 is Lagos bus stop, a commercial/industrial area (4°45′41.661″ N, 7°01′4.48176″ E). Station 3 is Eagle Island, a residential area (4°46′52.49208″ N, 6°58′36.52428″ E). The selection of these locations enabled the comparison of biomass remediation performance across soils exposed to varying anthropogenic activities.

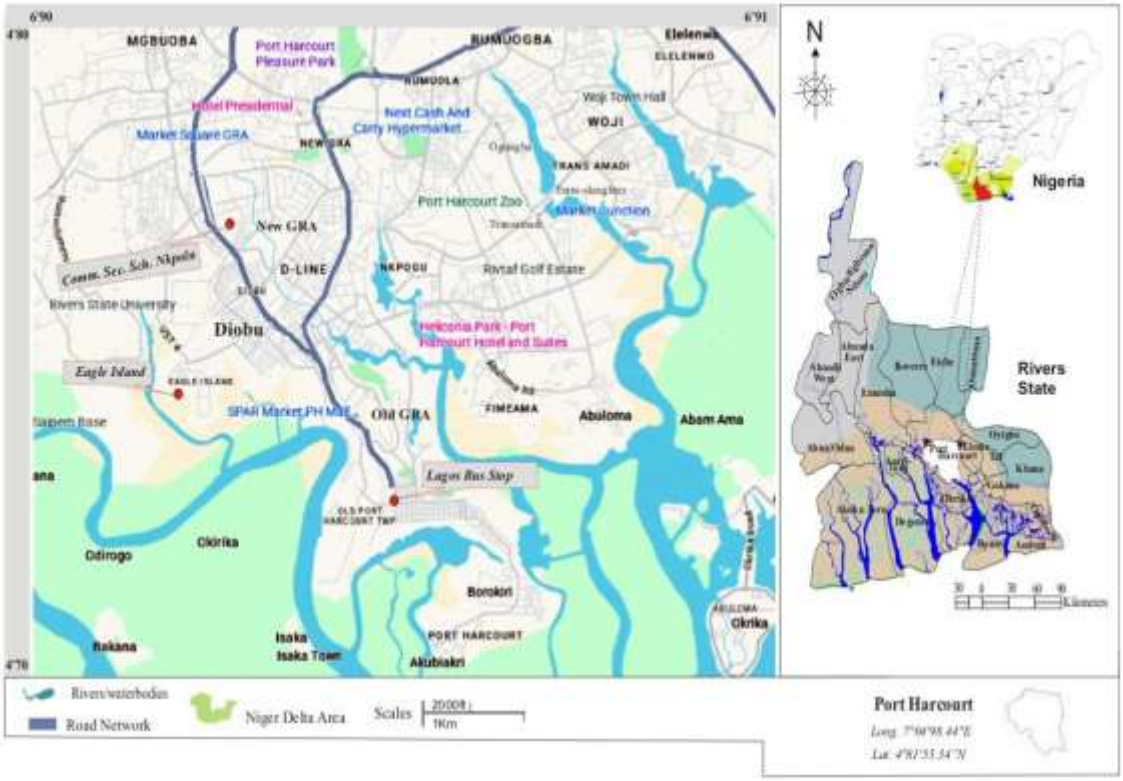


Fig. 1. Map of Study Area Showing Sampling Locations

2.2 Sample Collection and Preparation

A handheld Global Positioning System (GPS) receiver was used to record the geographical coordinates of each sampling location before sample collection. Soil samples were collected using a stainless-steel soil auger from two depths (0–15 cm and 15–30 cm), representing the surface and subsurface soil horizons commonly affected by anthropogenic contamination. The collected samples were transferred into clean polyethylene zip-lock bags, properly labelled, transported to

the Environmental Chemistry Laboratory, homogenized and air-dried at room temperature. Stones, roots, and other debris were removed manually before the samples were gently crushed using a porcelain mortar and pestle and passed through a 2-mm sieve to obtain homogeneous samples. 500 g of each homogenized soil sample was weighed into plastic experimental containers for the remediation experiment.

2.3 Preparation of Biomass Amendments

Three locally available waste biomass materials were selected because of their abundance, low-cost, and reported heavy metal adsorption potential.

Eggshell: Discarded chicken eggshells were collected from local food vendors. The shells were washed repeatedly with distilled water to remove adhering albumen and impurities, air-dried, oven-dried to constant weight, crushed using a laboratory grinder, and sieved to obtain fine particles suitable for soil amendment.

Cow Bone: Waste cow bones were obtained from an abattoir. The bones were thoroughly washed to remove attached tissues, oven-dried, ground into fine powder using a mechanical grinder, and sieved to achieve uniform particle size before use.

Wood Shavings: Wood shavings were collected from local furniture workshops. The samples were washed with distilled water to remove dust and contaminants, oven-dried, pulverized, and sieved before application.

The prepared biomass materials were stored in airtight polyethylene containers until required for the remediation experiment. Similar preparation procedures have been widely adopted for biomass amendments used in heavy metal remediation studies.

2.4 Preparation of Standard Heavy Metal Solutions

Analytical-grade chromium (III) nitrate [$Cr(NO_3)_3$] was used to prepare the contaminating solution.

Chromium Stock Solution: A 1000 ppm Cr(III) stock solution was prepared by accurately weighing 0.77 g of chromium(III)nitrate [$Cr(NO_3)_3.9H_2O$] and dissolving it in a small volume of distilled water. The solution was quantitatively transferred into a 100 ml volumetric flask and made up to the mark with distilled water, then thoroughly mixed.

A 10 mg/L intermediate solution was prepared by pipetting 1.00 ml of the 1000 mg/l stock solution into a 100 ml volumetric flask and made up to the mark with distilled water. Subsequently, 50 ml of the 10 mg/l intermediate solution was diluted to 150 ml and used to spike the individual soil samples giving a nominal chromium concentration of 1.0 ppm in the soil.

Fresh solutions were prepared immediately before the contamination experiment.

2.5 Soil Contamination and Experimental Design

Artificial contamination was employed to ensure uniform distribution of heavy metals within the soil samples. A volume of 150 ml of the chromium nitrate solution was added separately to each container holding 500 g of soil. The contaminated soils were allowed to equilibrate for 24 hours before treatment. During the equilibration period, the containers were left undisturbed to avoid soil compaction and to allow adequate interaction between the soil matrix and the heavy metals. The remediation experiment consisted of individual biomass treatments and combined biomass treatments. Eggshells treatment consisted of 10 g, 20 g and 40 g. Cow bones are 10 g, 20 g and 40 g. Wood shavings are 10 g, 20 g and 40 g.

Combined biomass treatments consisted of equal proportions of eggshell, cow bone, and wood shavings: 10 g treatment**,** 3.33 g of each biomass, 20 g treatment: 6.66 g of each biomass and 40 g treatment: 13.33 g of each biomass. The biomass materials were thoroughly mixed with the contaminated soils to ensure uniform distribution throughout the soil matrix.
Soil samples that were not artificially contaminated with was used as the control.

2.6 Incubation and Sampling

Following biomass amendment, the treated soils were incubated for 28 days under laboratory conditions. Subsamples were collected from each treatment on day 7, 14 and 28 (Week 1, Week 2 and Week 4) to monitor changes in chromium concentrations over time. The soils were not stirred during incubation to minimize disturbance of the soil structure and prevent compaction.

2.7 Determination of Chromium Concentrations

Following acid digestion, the concentrations of chromium (Cr) in the soil samples were determined using Atomic Absorption Spectrophotometer whilst adhering to standard instrumental analytical procedures. Metal concentrations were expressed in mg kg^{-1} (dry weight)**.** Quality assurance measures included reagent blanks, duplicate analyses, and calibration with certified standard solutions to ensure analytical accuracy and precision. The removal efficiency of each biomass treatment was calculated using the following equation:

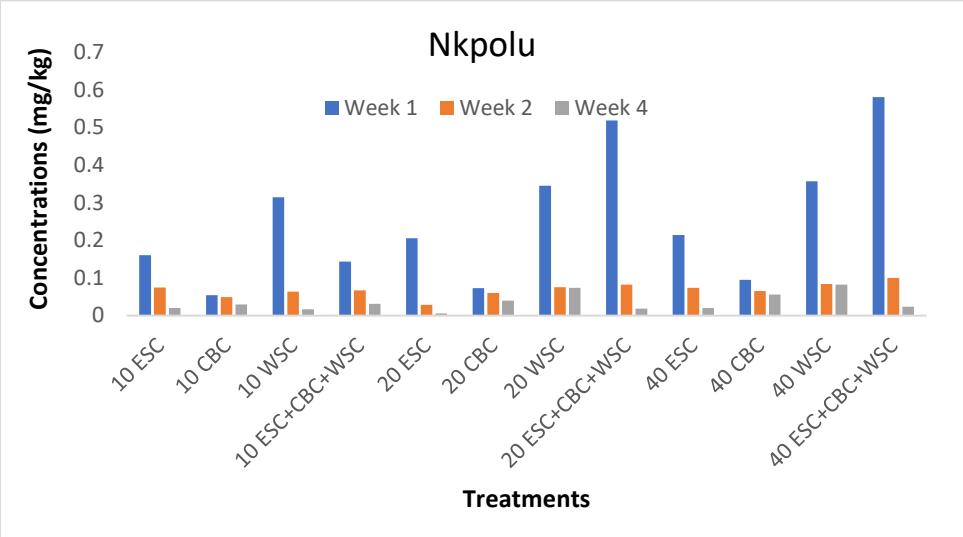
$$\text{Removal Efficiency (\%)} = \frac{C_i - C_f}{C_i} \times 100$$

Where:

- C_i= Initial concentration of the heavy metal (mg/kg)
- C_f= Final concentration of the heavy metal after treatment (mg/kg)

3. RESULTS AND DISCUSSION

The concentrations of chromium (Cr) remaining in contaminated soils after treatment with eggshell (ES), cow bone (CB), wood shavings (WS), and their combined amendments (ES + CB + WS) at application rates of 10 g, 20 g and 40 g over four weeks are presented in Figures 2 to 4. Measurements were carried out using soils collected from Nkpolu, Lagos bus stop and Eagle Island.



Fig, 2: Chromium Remediation of Nkpolu by biomass

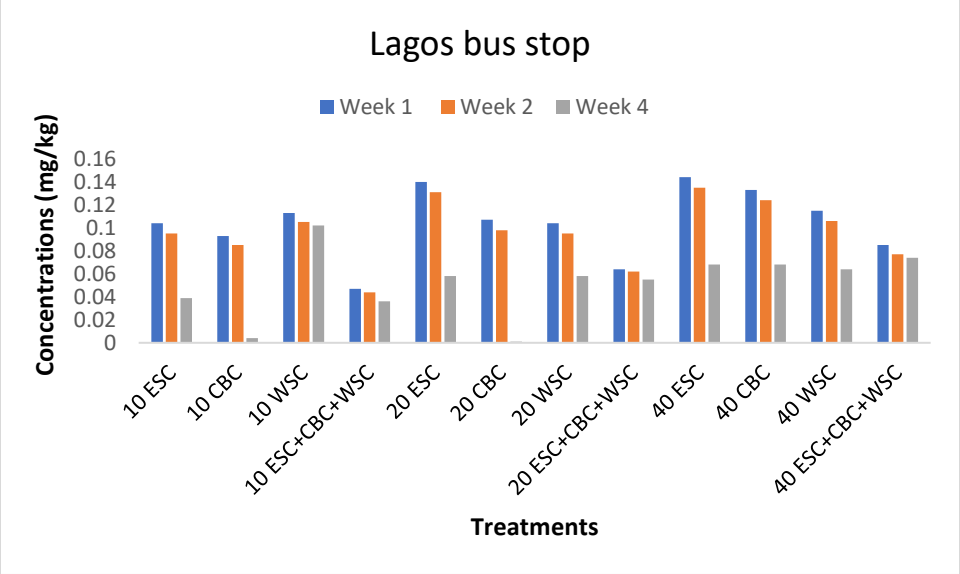


Fig. 3: Chromium Remediation of Lagos bus stop by biomass

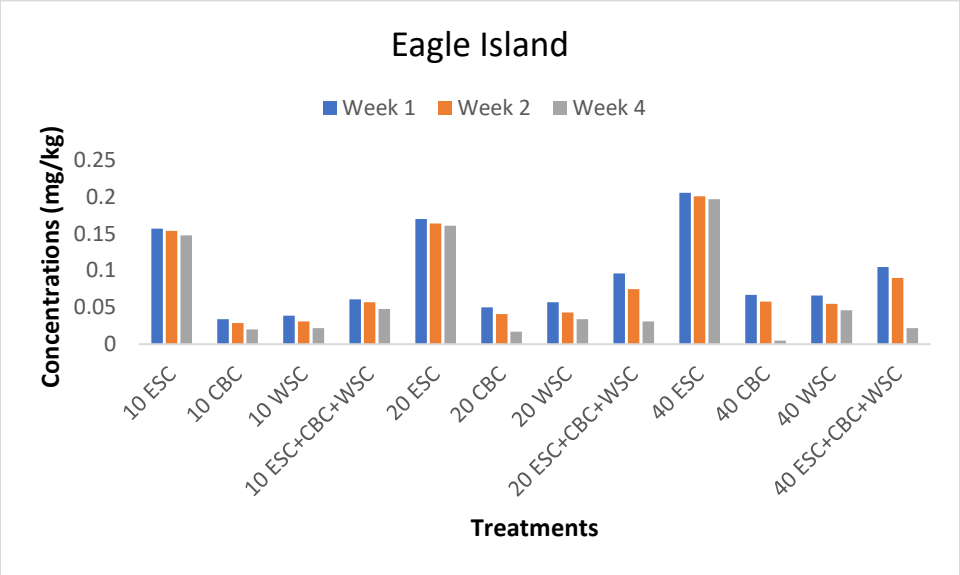


Fig. 4: Chromium Remediation of Eagle Island by biomass

3.1 Effect of Eggshell, Cow Bone and Wood Shavings Biomass on Chromium (Cr) Concentration in Contaminated Soils

Chromium concentrations consistently decreased from Week 1 to Week 4 for all treatments across Nkpolu, Lagos bus stop and Eagle Island. This progressive decline indicates that remediation efficiency increased with contact time. Cow bone exhibited the highest chromium removal efficiency in most treatments. In Lagos bus stop, chromium concentration decreased to 0.001 mg/kg after four weeks using 20 g cow bone, while Eagle Island recorded a minimum concentration of 0.005 mg/kg with the 40 g treatment. The measured concentration for the control showed concentration below detectable limits throughout the incubation duration as concentration before amendment cross all sampling locations were <0.001 mg/kg. These results suggest that hydroxyapatite present in cow bone effectively immobilized chromium through precipitation and ion exchange. This finding agrees with Fanidi et al., 2017, who reported that hydroxyapatite has potential for chromium immobilization because its mineral surface can interact with chromium ions. Experimental studies have demonstrated the adsorption of Cr(III) by hydroxyapatite, although adsorption efficiency depends on chromium oxidation state, pH, and adsorbent properties.

Eggshell also reduced chromium concentrations considerably, although its performance varied with soil location and application rate. The calcium carbonate-rich composition of eggshell may contribute to metal retention; however, the specific mechanisms responsible for chromium reduction in the present soil experiment require further investigation. Katha et al. (2021) reported chromium removal from wastewater using calcined and non-calcined eggshell, demonstrating the potential of eggshell waste as a low-cost adsorbent. Their findings provide supporting evidence for the use of eggshell-based materials in chromium remediation, although their aqueous system differs from the contaminated soils investigated in the present study.

Wood shavings also reduced chromium concentrations under the experimental conditions. This finding suggests that wood-derived biomass may contribute to chromium retention in contaminated soil. Irdhawati et al. (2020) investigated the adsorption of chromium(III) using

EDTA-activated teak sawdust and reported an optimum adsorption capacity of 39.7 mg/g. Their findings demonstrate the potential of sawdust-based materials for Cr(III) adsorption.
Based on the nominal initial Chromium concentration of 1.00 mg/kg the highest Week 4 reductions were 99.4% at Nkpolu, 99.9% in Lagos bus stop and 99.5% at Eagle Island.

Table 1: Concentrations of Chromium after Biomass Remediation

	NKPOLU			LAGOS			EAGLE ISLAND		
SAMPLE LABEL	Week 1	Week 2	Week 4	Week 1	Week 2	Week 4	Week 1	Week 2	Week 4
10 g ESC	0.161	0.075	0.02	0.104	0.095	0.039	0.157	0.154	0.148
20 g ESC	0.206	0.029	0.006	0.14	0.131	0.058	0.17	0.164	0.161
40 g ESC	0.214	0.074	0.02	0.144	0.135	0.068	0.206	0.201	0.197
10 g CBC	0.054	0.049	0.03	0.093	0.085	0.004	0.034	0.029	0.02
20 g CBC	0.073	0.06	0.04	0.107	0.098	0.001	0.05	0.041	0.017
40 g CBC	0.095	0.065	0.056	0.133	0.124	0.068	0.067	0.058	0.005
10 g WSC	0.315	0.064	0.017	0.113	0.105	0.102	0.039	0.031	0.022
20 g WSC	0.345	0.076	0.074	0.104	0.095	0.058	0.057	0.043	0.034
40 g WSC	0.357	0.084	0.082	0.115	0.106	0.064	0.066	0.055	0.046
10 g ESC + CBC+WSC	0.144	0.067	0.031	0.047	0.044	0.036	0.061	0.057	0.048
20 g ESC + CBC + WSC	0.519	0.082	0.019	0.064	0.062	0.055	0.096	0.075	0.031
40 g ESC + CBC + WSC	0.581	0.1	0.024	0.085	0.077	0.074	0.105	0.09	0.022
CONTROL	<0.001			<0.001			<0.001		

3.2 Comparative Performance of the Biomass Materials

The remediation performance of cow bone, eggshell and wood shavings varied with soil location, and application rate. Overall, cow bone showed strong performance across several treatments, particularly in Lagos Bus Stop and Eagle Island. However, eggshell also performed well in Nkpolu, while wood shavings produced reductions in metal concentrations but showed comparatively variable performance.
The observed differences may be related to the composition of the biomass materials. Cow bone contains phosphate-rich mineral components that may contribute to metal immobilization, while the calcium carbonate content of eggshell may influence metal retention. Wood shavings contain cellulose and lignin, whose functional groups may contribute to metal binding. However, the specific mechanisms responsible for the observed reductions were not independently confirmed in this study.
The combined biomass treatment also reduced metal concentrations in several treatments, although it did not consistently outperform the most effective individual biomass. Therefore, the results suggest that combining the materials may be useful under certain treatment conditions, but further investigation is required to establish whether the combination offers an advantage over individual amendments. These findings are consistent with numerous previous studies, including Ahmad et al. (2012), Xu & McKay. (2017), and Spark et al. (2022), all of whom concluded that biomass

materials rich in phosphate and carbonate generally outperform purely lignocellulosic materials in heavy metal remediation.

The results of this study demonstrate that eggshell, cow bone, and wood shavings are effective low-cost biomass amendments for the remediation of chromium-contaminated soils. These findings support the use of agricultural and animal waste-derived biomasses as sustainable, environmentally friendly, and cost-effective alternatives for the remediation of heavy metal-contaminated soils.

CONCLUSION

This study evaluated the potential of eggshell, cow bone and wood shavings for reducing chromium (Cr) concentrations in contaminated soils collected from Nkpolu, Lagos Bus Stop and Eagle Island over a four-week remediation period.

The results showed reductions in measured chromium concentrations across the treatment period. Cow bone demonstrated strong performance in several treatments, while eggshell and wood shavings also showed remediation potential. However, performance varied according to soil location, and application rate; consequently, no single ranking should be assumed to apply to every treatment. The combined biomass treatment also produced appreciable reductions in selected treatments, but its performance was not consistently superior to that of the best individual amendment.

These findings indicate that eggshell, cow bone and wood shavings warrant further investigation as potential biomass-based amendments for contaminated soils. Further studies should evaluate optimal application rates, changes in soil properties, metal mobility, long-term retention and the economic feasibility of treatment before firm conclusions are drawn about permanent immobilization, improved soil quality or cost-effectiveness.

Overall, the findings confirm that eggshell, cow bone, and wood shavings are effective, environmentally friendly, and potentially low-cost biomass amendments for the remediation of chromium-contaminated soils. Their utilization also provides an environmentally sustainable approach for converting agricultural and animal wastes into valuable materials for environmental pollution control.

This study further recommends that cow bone biomass should be considered the preferred biomass amendment for the remediation of chromium-contaminated soils due to its superior removal efficiency. Eggshell and wood shavings should be promoted as low-cost alternative amendments, particularly in communities where these agricultural wastes are readily available. Combined application of eggshell, cow bone, and wood shavings should be further investigated to optimize application ratios that maximize heavy metal removal while improving soil fertility.

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