

RESEARCH PAPER

*Influence of Soil Properties and Metal Interactions on the Phytoremediation of Impacted Soils by *Jatropha gossypifolia**

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Citation

Agi Michael Ejeh, Godwin Asukwo Ebong and Eno Anietie Moses (2025), Influence of Soil Properties and Metal Interactions on the Phytoremediation of Impacted Soils by *Jatropha gossypifolia*. *Green Energy and Environmental Technology* 4(1), 1–20.

DOI

<https://doi.org/10.5772/geet.20250005>

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Received: 26 January 2025

Accepted: 20 May 2025

Published: 26 June 2025

Abstract

Phytoremediation is a popular technique used for the reduction of toxic substances from impacted soils; however, the influence of soil properties on the process has not been given sufficient attention. This study examined the influence of soil properties and metal interactions on phytoremediation of impacted soils by *Jatropha gossypifolia*. Seeds of *J. gossypifolia* were cultivated on soils impacted by wastes from dumpsite, paint industry, automobile and electronic shops in polythene pots. These soils were amended with mixed citric and ethylenediaminetetraacetic acids chelants after six weeks; soils without amendment with chelants were used as the control. After twelve weeks, the cultivated *J. gossypifolia* were harvested from both amended soil and control, treated, and analysed for Cd, Cu, Pb, and Zn contents. The mean concentrations (mg kg^{-1}) of Cd, Cu, Pb, and Zn in plants from the control soils were 3.00 ± 0.82 , 23.85 ± 3.31 , 36.10 ± 2.27 , and 21.13 ± 2.31 , respectively. In the plants from the amended soils, the mean concentrations (mg kg^{-1}) of Cd, Cu, Pb, and Zn were 0.73 ± 0.18 , 1.33 ± 0.27 , 1.29 ± 0.16 , and 1.28 ± 0.55 , respectively. Dumpsite soil had higher concentrations of the metals and most of the soil properties which resulted in a more efficient phytoextraction of metals from the soil. Correlation analysis revealed that soil properties and metal interactions can influence the phytoremediation process.



Keywords: *Jatropha gossypifolia*, Nigeria, phytoextraction, phytoremediation, soil pollution, trace metals

1. Introduction

The accumulation of toxic metals in the soil environment is a serious problem for humans. While, few metals are essential for human life, they become toxic when their concentrations exceed the quantity required by biological cells [1–3]. Edible plants extract these metals from impacted soils and transport them via the food chain to human [4–6]. Metals without any biological significance to human life include mercury, arsenic, lead, and cadmium and are toxic even at the very low concentrations [7, 8]. Studies have indicated that, most of the high concentrations of metals in soil environment are a result of human activities [9, 10]. Thus, in the quest to control the accumulation of metals in the environment and their implications; the use of plants was introduced in the 20th century [11]. This pollution control technique became very popular due to its simplicity and environmental-friendly nature [12]. The process is significantly enhanced by the application of chelating agents [13, 14]. The common chelants used for phytoremediation of impacted soils are ethylenediamine-N,N'-disuccinic acid (EDDS), nitrilotriacetic acid (NTA), ethylenediaminetetraacetic acid (EDTA), L-glutamic acid N,N-diacetic acid (GLDA), and citric acid (CA). EDTA is the most widely used single chelant because of its high solubility. It is unaffected by pH and has a great number of binding sites [14, 15]. Studies have shown that the use of mixed chelants for phytoremediation is more effective than single chelants and the combination of EDTA and CA has been highly recommended [15–17]. Hence, a mixture of EDTA and CA was used in this study for effective phytoextraction process and achievement of optimal results.

Phytoremediation is a plant-based technique and several plants have been employed for the extraction of metals from impacted soils [18]. This study utilized the phytoextraction potential of *J. gossypifolia* for the remediation of impacted soils. *Jatropha gossypifolia* commonly called bellyache bush is mostly used in Africa and America for its medicinal potency to treat various ailments [19]. This plant grows well in clay soils with proper drainage and can reach a height of 7 meters in a fairly fertile soil [20]. *Jatropha gossypifolia* was chosen as an agent for phytoremediation in this study because the plant is common in the study area and has exceptional potential for phytoextraction of metals from impacted soils [21, 22]. *Jatropha gossypifolia* also has the capacity to accumulate more Cd, Cr, Mn, Cu, Fe, Ni, Pb and Zn from impacted soil environments [21, 23].

Several studies have established the application of plants for extraction of toxic metals from impacted soils globally. Shehata *et al.* [24] studied the potential of kenaf



(*Hibiscus cannabinus* L) and flax (*Linum usitatissimum*) on the extraction of Cr, Co, Cd and Mn from impacted soils of Sahl El Husseinia, Egypt. Results showed that the extraction of metals by kenaf was in a descending order of Cr > Co > Mn > Cd with removal percentages of 50.7, 38.3, 34.0, and 14.4, respectively. Flax phytoremediation efficiency was in a descending order of Mn > Cr > Co > Cd, with removal percentages of 54.36, 36.95, 28.72, and 11.37, respectively. The phytoremediation capacity of *Alhagi camelorum* for extraction of total petroleum hydrocarbons (TPH), Pb, Cr, Cd, and Ni from oil-contaminated soil in Iran was carried out by Nemati *et al.* [25]. Results obtained after six weeks showed that 53.6%, 50.0%, 47.6%, 45.4%, and 48.1% of TPH, Pb, Cr, Cd, and Ni, respectively were extracted. Osman *et al.* [26] investigated the ability of *Brassica juncea* and *Brassica napus* in extracting metals from a contaminated Mahd AD'Dahab mine in Saudi Arabia. The results showed that the percentages of Zn, Pb, Ni, Mn, Fe, Cu, and Cd extracted by *Brassica juncea* were 18%, 27%, 29%, 24%, 23%, 24%, and 28%, respectively. *Brassica napus* extracted 17%, 27%, 31%, 24%, 21%, 23%, and 26% of Zn, Pb, Ni, Mn, Fe, Cu, and Cd, respectively.

A study on the phytoextraction efficiency of Cd and Pb from artificially contaminated soil using *Ageratum conyzoides*, *Syndrella nodiflora* and *Cleome rutidosperma* plants was carried out in Port Harcourt, Nigeria by Tanee and Abbey-Kalio [27]. These plants were harvested after 13 weeks and the proportions of Cd extracted by *Ageratum conyzoides*, *Cleome rutidosperma*, and *Syndrella nodiflora*, were 35.8%, 55.3%, and 45.1%, respectively. The amounts of Pb extracted by *Ageratum conyzoides*, *Cleome rutidosperma*, and *Syndrella nodiflora* were 68.7%, 24.8% and 27.3%, respectively. The phytoextraction ability of *Spinacia oleracea*, *Tithonia diversifolia*, *Helianthus annuus*, and *Eucalyptus camaldulensis* for the extraction of Cr, Mn, Fe, Cu, Zn, and Ni from abandoned Tin mine in Barkin Ladi, Plateau State, Nigeria was assessed by Nenman *et al.* [28]. The concentrations (mg kg⁻¹) of Cr, Mn, Fe, Cu, Zn, and Ni in soil before phytoextraction process were 670.5, 2415.0, 128,956.0, 678.93, 304.94, and 267.47, respectively. The concentrations (mg kg⁻¹) of Cr, Mn, Fe, Cu, Zn, and Ni phytoextracted by the plants ranged as follows: 608.95–1,984.21, 2,633.8–100,704.0, 14,700.0–222,442.0, 1,996.87–9,295.78, 481.48–3,611.11, and 385.47–1,966.67 mg kg⁻¹. These results indicate that the potential of plants to extract metals and other toxic substances from contaminated soils vary with plant species (Eben *et al.* [29]).

The effects of soil properties on the phytoextraction of metals from the impacted soils by *J. gossypifolia* was considered in this study since the properties of soil have significant impact on the phytoremediation process as reported by Kafle *et al.* [12] and Cui *et al.* [30]. Studies have shown that the accumulation and availability of metals in soil are influenced by the soil's characteristics [31–34]. Literature has also shown that soil properties such as pH, organic matter, cation exchange capacity



(CEC) of soil, clay and others have significant influence on the extraction of metals from impacted soils by plants [30, 35–38]. However, studies done within the study area on phytoremediation of impacted soils never considered soil properties as major factors that can influence the outcome of the process [39–41]. Metal interactions affect the extraction of metals by plants from impacted soils effectively [42, 43]. Studies on phytoremediation of contaminated soils by plants done within the study region have not elucidated the influence of metal's interactions in contaminated soils on the outcome of the process. Consequently, this study was carried out to investigate the influence of soil properties and interaction among metals on the phytoextraction of metals from impacted soils by *J. gossypifolia*. The results highlight the necessity of considering the soil properties and interaction among metals during studies on phytoremediation of impacted soils within the study area.

2. Materials and methods

The procedures of this study were adopted from the methods of Njoku and Nwani [39], and Azorji *et al.* [44]. Polythene pots with a capacity of 4.5 L were filled separately with 1.50 kg of soil from waste dumpsite soil (WDS), automobile waste-impacted soil (AIS), electronic waste-impacted soil (EWS), and paint waste-impacted soil (PIS) obtained from Akwa Ibom State, Nigeria. Seeds of *Jatropha gossypifolia* were cultivated on the soils within the pots and these soils were amended with 20 mL day⁻¹ of mixed citric acid (CA) (99.5% pure, Sigma-Aldrich, EMPLURA® brand, USA) and ethylenediaminetetraacetic acid (EDTA) (99.0% pure, Sigma-Aldrich, BioUltra, USA). These pots were placed in an open space and 500 mL of distilled water was used to irrigate the plants daily. Plants cultivated in the amended and control soils were harvested after twelve weeks, prepared properly and preserved for further treatment [45, 46].

Soil pH was determined by mixing 10 g of soil with 10 mL of distilled water and stirred until a soil-water suspension was achieved. The glass electrode of pH meter (Hanna instrument model 211, Italy) was then inserted in the suspension and rotated slightly. The pH reading was recorded after 50 s to the nearest 0.1 unit [47]. Total organic matter (TOM) of the soils was assessed by the use of Walkey-Black procedure of weighing 1.0 g of the sieved soil into a 500 mL Erlenmeyer flask (Thermo Scientific Nalgene, USA) 10 mL of 0.167 M potassium dichromate solution (99.5% pure, Spectrum Chemical, USA) added and the mixture in the flask was swirled gently until uniformity was achieved. Then 20 mL of conc. sulfuric acid (95% pure, Sigma-Aldrich, USA) was added rapidly with care and the flask was swirled again vigorously for 1 min to obtain a proper mixture of the soil and the reagents. The flask was allowed to stand for 30 min before 200 mL of distilled water was added. The mixture was allowed to cool and 10 drops of diphenylamine indicator (99% pure, Thermo Fisher Scientific, USA) added. The solution was then



titrated with a standardized ferrous ammonium sulphate (98% pure, Vishnu Priya Chemicals, India) until the colour changed from dull green to bright green. The blank was also prepared using the same procedures but without the soil sample. The organic matter was determined by calculating the difference in the quantity of dichromate consumed in the blank and the soil sample titration [48, 49]. CEC of the studied soils was determined by adding 50 mL of 1M ammonium acetate solution (99% pure, Vinipul Chemicals, India) to 2.5 g of the dried soil sample in a 50 mL centrifuge tube (BKMAM, China) and shaken in a mechanical shaker (Sigma-Aldrich, Laboratory Shaker) for two hours. The supernatant was decanted into a 100 mL volumetric flask using centrifuge (benchtop, Thermo Fisher Scientific, USA) (2,000 rpm) for ten minutes. Another 30 mL of ammonium acetate was added to the residue and shaken for thirty minutes, centrifuged and the leachate transferred to the same volumetric flask. The last procedure was repeated and leachate also transferred to the same volumetric flask. The leachate in flask was then made up to mark with NH_4OAc solution and kept for the spectroscopic analysis of calcium, magnesium, potassium and sodium. The values of the cations were added up to obtain the CEC of each soil sample as reported by Mustapha *et al.* [49] and Nel *et al.* [50]. The clay content of the studied soils was determined by hydrometer method as described by Mozaffari *et al.* [51]. A cup containing 50 g of the dried soil was half filled with distilled water and 50 mL of sodium hexametaphosphate reagent (68% pure, Welychem Co. Ltd, China) was added. The cup was placed on a mechanical stirrer (H4000-HS–Benchmark Scientific, Inc., USA) and stirred for ten minutes. The mixture was then transferred to a Bouyoucos cylinder (Analytica, Germany) and filled to the lower mark with distilled water with a hydrometer (ASTM 151H, Gilson Company, USA) in suspension. The hydrometer was removed and the suspension shaken vigorously in a back and front manner. The cylinder was then placed on a table and time was recorded. After 20 s, the hydrometer was carefully inserted and at the expiration of 40 s the reading was taken. Temperature of the suspension was taken and to every degree above 20 °C, 0.36 was added to the hydrometer reading and for every degree below 20 °C, 0.36 was subtracted from the hydrometer reading to compensate for the added dispersing agent. The sand settled to the bottom of the cylinder within 40 s, thus, the 40 s hydrometer reading actually gave the quantity of silt and clay in suspension. The percentage clay was determined by shaking the suspension again and placed on a table for two hours and the corrected hydrometer reading was recorded. At the end of two hours, silt contents in addition to sand had settled. The hydrometer reading taken after 2 hrs represented the grams of clay in the sample. The percentage clay was calculated by dividing this mass by the weight of sample and multiplying by 100.

The harvested plants (*J. gossypifolia*) were washed thoroughly with distilled water and dried in the air for three weeks. The plants biomass was then ground and sieved



following the procedures of Ejeh *et al.* [46] and Ebong *et al.* [52]. The soil samples (both before and after remediation process) were dried under the sun for three days, ground, and sieved using 2 mm diameter mesh as reported by Ebong *et al.* [52]. Then 1 g of the sieved plant and soil samples were digested by adding 10 mL 1:1 (w/v) mixture of HNO_3 : H_2O in a beaker and heated on a hot plate (IKA C-MAG HS IKAMAG, Sigma-Aldrich, USA). The mixture was homogenized, the beaker covered with a watch glass and heated to 95 °C, and then refluxed for 15 min. The mixture was allowed to cooled, and 5 mL conc. HNO_3 (65% pure, Merck, Germany) was added and refluxed again for 30 min. The beaker was covered with a ribbed beaker and allowed to evaporate to 5 mL. After this was completed, the mixture was cooled and 2 mL of distilled water and 3 mL 30% H_2O_2 (30% pure, Merck, Germany) were added. The mixture was heated until effervescence from the peroxide reaction stopped. The mixture was cooled again and 1 mL H_2O_2 introduced until effervescence was at minimum. The mixture was cooled; then 2 mL conc. HNO_3 and 10 mL of distilled water were applied subsequently, the mixture was refluxed for 15 min once again. The mixture was later centrifuged at 4000 rpm for 30 min to separate the filtrate from the residue [53, 54]. The concentrations of Cd, Cr, Ni, and Pb in the samples were analysed with Inductively Coupled Plasma Optical Emission spectroscopy (ICP-OES, Model 4300 DV, Perkin Elmer, USA) using the methods of Njoku and Nwani [39]. The analyses of all the parameters were carried out in triplicate and the mean values obtained were used for interpretations.

3. Results and discussion

The results of soil properties of the impacted soils assessed are shown in Table 1. Soil pH varied between 6.56 and 7.21; the highest pH level was recorded for PIS, while the lowest was obtained in WDS. The pH of the studied soils varied between weakly acidic and weakly alkaline as reported by Xia *et al.* [55]. Soil pH is one of the most important properties of the soil that can influence the availability of both the essential and toxic metals for plant uptake [56, 57]. The reported range of soil pH supports metal availability and optimal plants growth [58]. The low pH reported for WDS could be attributed to the high organic matter contents of the soil [59, 60]. The results also revealed that paint-related waste may have increased the soil pH as opined by Orjiakor *et al.* [61] and Chukwuma *et al.* [62]. Consequently, the low soil pH in WDS may have resulted in the concentrations of metals obtained [63].

The cation exchange capacity (CEC) of the studied impacted soils ranged from 6.53 to 13.17 cmol kg^{-1} . The highest CEC value was reported for the WDS, while the lowest was obtained in EWS. The reported high CEC in WDS could be attributed to the high organic matter and clay contents of the soil [64, 65]. Similarly, the low CEC obtained in EWS could be attributed to the low organic matter content in the underlying soil as reported by Ocheoibo and Atuanya [66]. The CEC of soil is



Table 1. Physiochemical properties of the studied impacted soils.

	pH	CEC (cmol kg ⁻¹)	TOM (%)	Clay (%)
WDS	6.58	13.17	29.50	64.20
AIS	7.11	8.02	11.20	53.28
EWS	7.06	6.53	8.90	34.11
PIS	7.21	9.26	10.40	30.60
MIN	6.58	6.53	8.90	30.60
MAX	7.21	13.17	29.50	64.20

*WDS = Waste dumpsite soil, AIS = Automobile waste-impacted soil, EWS = Electronic waste-impacted soil, PIS = Paint Waste-impacted soil, MIN = Minimum, MAX = Maximum.

controlled by the accumulation and availability of metals in soil [67–69]. Hence, the high CEC in WDS may have led to the relatively high concentrations of trace metals reported [70, 71].

Table 1 shows that the TOM contents of the impacted soils ranged from 8.9 to 29.5%. The highest TOM value was recorded for WDS, while the lowest was obtained in EWS. The reported high TOM in WDS was in agreement with the results published by Azuka & Ezeme [72] and Orimisan *et al.* [73]. Whereas the low TOM obtained in EWS was in agreement with the finding by Adesokan *et al.* [74]. The reported low TOM in EWS could encourage leaching of metals into the sub soil making them unavailable for plants uptake. The high level of TOM recorded for WDS could be attributed to the high level of organic wastes at the dumpsite [59]. TOM is an important soil property that plays a crucial role in the availability of trace metals for plants uptake [75, 76]. Thus, the high TOM in WDS may have resulted in the high concentrations of metals recorded [77].

The clay contents of the studied soils varied from 34.11 to 64.20% between EWS and WDS. Clay content in soil has the potential of influencing the level of metal availability [57, 69]. Hence, high clay content in soil may result in the availability of metals for plants uptake [78, 79]. Studies have indicated that clay in soil has a direct relationship with the organic matter content [80, 81]. Thus, soils with high TOM may accumulate elevated levels of clay as observed in WDS.

The mean concentrations of trace metals in the studied impacted soils amended with mixed chelants before and after phytoremediation by *J. gossypifolia* are shown in Figure 1. The mean concentrations of Cd, Cu, Pb, and Zn obtained before phytoextraction (BFP) were 3.00 ± 0.82 mg kg⁻¹, 23.85 ± 3.31 mg kg⁻¹, 36.10 ± 2.27 mg kg⁻¹, and 21.13 ± 2.31 mg kg⁻¹, respectively. These values, seen in the impacted soils before phytoextraction, are lower than values reported in literature



[28, 39, 82]. However, after phytoremediation (AFP), the mean concentrations of Cd, Cu, Pb, and Zn were reduced to $0.69 \pm 0.16 \text{ mg kg}^{-1}$, $1.26 \pm 0.24 \text{ mg kg}^{-1}$, $1.24 \pm 0.13 \text{ mg kg}^{-1}$, and $1.22 \pm 0.51 \text{ mg kg}^{-1}$, respectively. The concentrations of Cd, Cu, Pb, and Zn in soils after phytoextraction were lower than $7.63 \pm 1.08 \text{ mg kg}^{-1}$, $187.78 \pm 4.23 \text{ mg kg}^{-1}$, $169.45 \pm 4.97 \text{ mg kg}^{-1}$, and $288.14 \pm 36.68 \text{ mg kg}^{-1}$ which were obtained by Njoku and Nwani [39] in soils after extraction by *Vigna unguiculata* leaf. Thus, *J. gossypifolia* has a higher potential to extract metals from contaminated soils than *Vigna unguiculata* leaf. Consequently, *J. gossypifolia* could be very effective for the remediation of impacted soils, provided optimal conditions for the process are provided. The mean concentrations of Cd and Cu that were higher than their recommended limits for soils (0.8 and 10.10 mg kg^{-1}), set by FAO/WHO [83], before phytoextraction were significantly reduced to safe limits after the process. Hence, the environmental and human health risks associated with these metals in impacted soils could be eradicated or reduced by the use of *J. gossypifolia* as an agent for phytoremediation. The results of Pearson correlation analysis of parameters

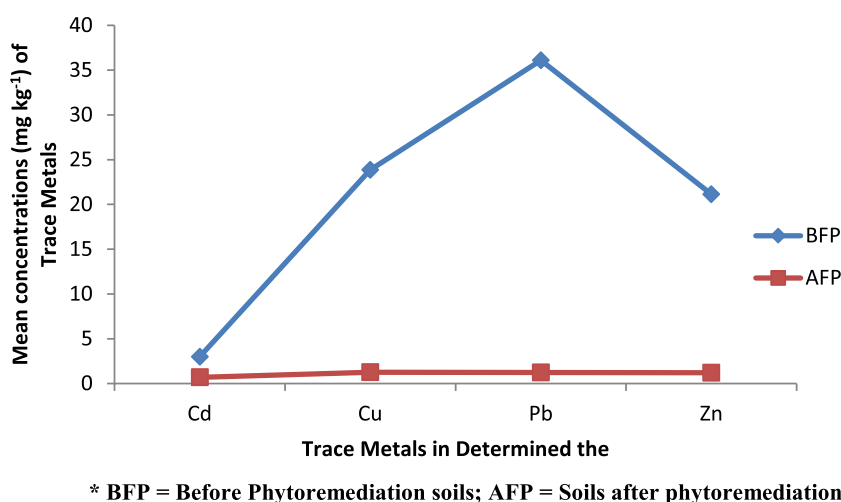


Figure 1. Mean concentrations of trace metals in the studied impacted soils before and after phytoremediation process.

determined in the studied impacted soils are shown in Table 2. The interactions among trace metals and physicochemical properties of the soils resulted in the following observed relationships: Cd correlated positively and significantly with Cu at $p < 0.01$ but; with Pb at $p < 0.10$ (r values, as shown in Table 2). The relationship between soil pH and Cd was a moderate negative one with r value of -0.489 . Accordingly, the high concentrations of Cd obtained in WDS and EWS may have resulted in a corresponding increase in the concentrations of Cu and Pb extracted by *J. gossypifolia*. The low pH level at WDS may have resulted in the reported high concentration of Cd extracted from the soil. The results also revealed the high pH



levels at AIS and PIS may have contributed to the low concentrations of Cd extracted by *J. gossypifolia* from these soils (Table 2). Cd correlated negatively with Zn hence; they can antagonize themselves in the studied soils as reported in literature [84, 85].

Table 2. Correlation analysis of the parameters in the studied soils.

	Cd	Cu	Pb	Zn	pH	CEC	TOM	Clay
Cd	1.000							
Cu	0.720 ^b	1.000						
Pb	0.568 ^d	0.871 ^a	1.000					
Zn	-0.027	0.672 ^c	0.688 ^c	1.000				
pH	-0.489	-0.849 ^a	-0.995 ^a	-0.741 ^b	1.000			
CEC	-0.080	0.417	0.760 ^b	0.743 ^b	-0.812 ^a	1.000		
TOM	0.229	0.695 ^c	0.930 ^a	0.804 ^a	-0.960 ^a	0.942 ^a	1.000	
Clay	0.158	0.799 ^a	0.769 ^a	0.982 ^a	-0.806 ^a	0.695 ^c	0.817 ^a	1.000

*^a ($p < 0.01$); ^b ($p < 0.02$); ^c ($p < 0.05$); ^d ($p < 0.10$).

Cu showed significant positive relationships with Pb and clay at $p < 0.01$. However, with Zn and TOM at $p < 0.05$ (r values in Table 2), Cu exhibited a positive but moderate association with CEC at r value of 0.417 and correlated negatively and strongly with soil pH at $p < 0.01$ ($r = -0.849$). Thus, the high concentration of Cu in WDS may have resulted in the elevated levels of Pb and Zn extracted by *J. gossypifolia* from the soil (Table 2). The high clay content in WDS, AIS, and EWS may be attributed to the high concentrations of Cu extracted by *J. gossypifolia* from these impacted soils (Table 2). Nevertheless, the high pH level in PIS may have led to the low concentration of Cu extracted from the soil.

Pb correlated positively and significantly with TOM and clay at $p < 0.01$, however, with CEC at $p < 0.02$ (r values are in Table 2) Pb also correlated positively and significantly with Zn at $p < 0.05$ but; with pH at $p < 0.01$ (r values in Table 2). Thus, the high concentrations of Zn, CEC, TOM, and clay, and the low level of pH obtained in WDS may have resulted in the high concentration of Pb extracted. Similarly, the high pH recorded for AIS and PIS may have resulted in the low concentrations of Pb phytoextracted from these soils.

Zn correlated positively and significantly with TOM and clay at $p < 0.01$, however, with CEC at $p < 0.02$ (r values in Table 2), Zn correlated negatively and strongly with the pH at $p < 0.02$ ($r = -0.741$). Accordingly, the levels of clay, TOM, and CEC content may have contributed positively to the high concentrations of Zn phytoextracted from WDS and AIS. Table 2 also indicates that the low TOM and clay content as well as the high soil pH obtained in EWS and PIS may have caused the low levels of Zn extracted by *J. gossypifolia* from these soils.



Soil pH exhibited strong negative correlations with CEC, TOM, and clay contents at $p < 0.01$ (r values as shown in Table 2). This was similar to the results obtained in other studies [86–88]. Thus, an increase in the pH of the impacted soils could impact negatively on the levels of CEC, TOM, and clay of the impacted soils and vice versa. The pH of the impacted soils also correlated negatively with all the trace metals in the studied soils. Hence, a low pH level could favour the concentrations of trace metals in the impacted soils examined as reported by Aigberua [89] and Wen *et al.* [90]. Obviously, the low pH recorded for WDS may have caused the high concentrations of most of the metals extracted by *J. gossypifolia*. CEC showed significantly positive correlations with TOM and clay contents of the studied soils at $p < 0.01$ and $p < 0.05$, respectively (r values in Table 2). This is consistent with the reports published by Kong *et al.* [91] and Mishra *et al.* [92]. The key determinants of CEC in soil are organic matter and clay, as both properties have strong negative charges to attract the positively charged metals [93]. TOM of the studied soils exhibited a strong positive association with the clay contents of the soils at $p < 0.01$ ($r = 0.817$). This is in agreement with the findings reported by Xue *et al.* [94] and Zhao *et al.* [95]. Correlation analysis has confirmed that soil properties can influence the outcome of phytoremediation of impacted soils as reported by Kafle *et al.* [12].

The concentrations of trace metals extracted from the impacted soils by the entire biomass of *J. gossypifolia* are shown in Figure 2. The concentrations of Cd extracted varied between 1.55 and 3.05 mg kg⁻¹. The range of Cd extracted was lower than 0.02 to 65.70 mg kg⁻¹ reported by Alaboudi *et al.* [82] from the remediation study using *Helianthus annuus* plant. The highest Cd concentration was extracted from EWS, while the lowest was extracted from PIS. The high concentration of Cd extracted by *J. gossypifolia* from EWS corroborates the findings by Han *et al.* [96] and Ma *et al.* [97]. The low level of Cd extracted from PIS is a confirmation of low concentration of Cd in the soils contaminated with paint-related wastes as previously reported [98, 99]. The trend of Cd extracted by *J. gossypifolia* followed the sequence, EWS > WDS > AIS > PIS. The concentrations of Cu extracted from the studied impacted soils ranged from 18.13 to 26.02 mg kg⁻¹. The obtained range of Cu phytoextracted from the impacted soils was lower than 8.45–35.34 mg kg⁻¹ Cu extracted from a contaminated soils by Sivakumar *et al.* [100] using *Portulaca oleracea* L plant. The highest concentration of Cu phytoextracted from the impacted soils was obtained in WDS, while the lowest was recorded in PIS (Figure 2). The reported high concentration of Cu extracted by *J. gossypifolia* WDS was similar to the results obtained by Orimisan *et al.* [73] and Onwukeme and Eze [101]. The quantities of Cu extracted by the studied plant from the impacted soils followed a decreasing order of WDS > EWS > AIS > PIS.

The concentrations of Pb extracted from the impacted soils by *J. gossypifolia* ranged between 32.81 and 38.20 mg kg⁻¹ (Figure 2). The values of Pb extracted from



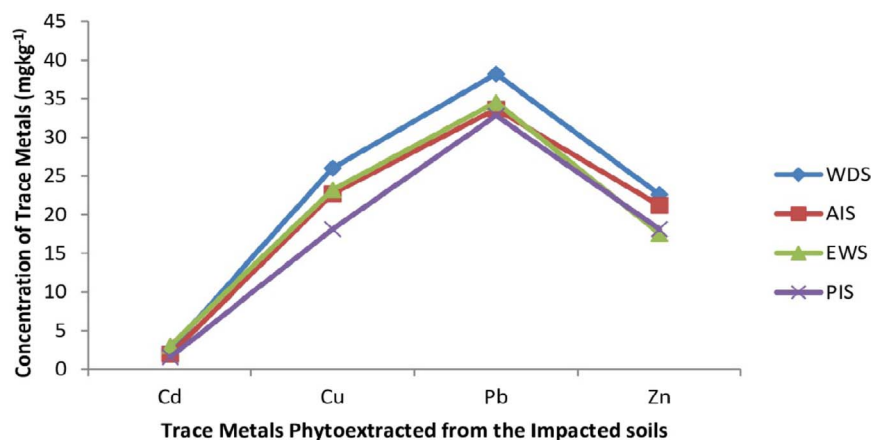


Figure 2. Total concentrations of trace metals extracted by *J. gossypifolia* from the impacted soils.

impacted soils by *J. gossypifolia* were higher than the 23.5 mg kg^{-1} extracted by *Vigna unguiculata* from contaminated soils as reported by Yao *et al.* [102]. The highest level of Pb extracted was from WDS, while the lowest was from PIS. Consequently, the concentration of Pb in the soil of WDS was high as published in literature [103, 104]. The trend for the concentrations of Pb extracted by *J. gossypifolia* from the impacted soils was in the order $\text{WDS} > \text{EWS} > \text{AIS} > \text{PIS}$.

Figure 2 indicates that the concentrations of Zn extracted from the impacted soils varied from 17.54 to 22.59 mg kg^{-1} . The levels of Zn extracted from the contaminated soils were consistent with the values reported by Njoku and Nwani [39]; but, higher than 5.212 mg kg^{-1} obtained by Rolli *et al.* [105] from related studies. The highest concentration of Zn extracted from the studied soils was in WDS, while lowest was reported in EWS. Hence, WDS accumulated high concentrations of Zn as documented by Afolagboye *et al.* [103] and Kolawole *et al.* [106]. The concentrations of Zn extracted from the different impacted soils by *J. gossypifolia* followed a decreasing order of $\text{WDS} > \text{AIS} > \text{PIS} > \text{EWS}$. The concentrations of metals extracted by plants during remediation studies depend significantly on the levels of each metal in the contaminated soils. Hence, this may have resulted in the observed values of the results of this study by other authors.

Generally, the highest concentrations of most of the metals were extracted from WDS and EWS. Consequently, waste at municipal dumpsites and electronic shops can pollute the adjoining soil environment as documented by Agbeshie *et al.* [59] and Houessionon *et al.* [107].

The proportions of trace metals extracted by *J. gossypifolia* from the different impacted soils examined are shown in Figure 3. The results obtained revealed that 75%, 73%, 79%, and 77% of Cd were extracted from WDS, AIS, EWS, and PIS,



respectively. The percentages of Cu extracted by *J. gossypifolia* from WDS, AIS, EWS, and PIS were 96, 95, 93, and 94, respectively. The quantities of Pb phytoextracted from the studied WDS, AIS, EWS, and PIS were 97%, 96%, 97%, and 96%, respectively. The amounts of Zn extracted by *J. gossypifolia* from WDS, AIS, EWS, and PIS were 96%, 94%, 95%, and 90%, respectively. The study revealed that the proportions of the trace metals extracted by *J. gossypifolia* were also influenced by their total concentrations in the different soils as opined by Laghlimi *et al.* [108] and Tan *et al.* [109]. The proportions of all the metals extracted relative to their concentrations in the impacted are higher than those reported in literature for these metals in similar studies [25–27]. This also confirms the efficiency of *J. gossypifolia* for remediation of contaminated soils. As indicated in Figure 3, the concentrations of Pb were the highest in all the impacted soils while Cd had the lowest values in all locations. This is similar to the results of the phytoremediation study undertaken by Nemati *et al.* [25] and Osman *et al.* [26], respectively. The study has revealed that *J. gossypifolia* can extract more metals from impacted soils amended with mixed citric and EDTA chelants.

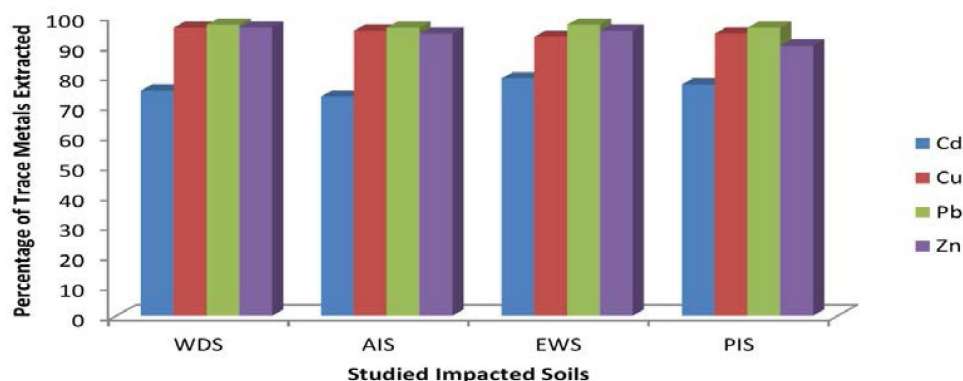


Figure 3. Total percentage of Trace Metals extracted by *J. gossypifolia*.

4. Conclusion

The research indicated that soil pH, TOM, CEC, and clay of the impacted soils can have significant effect on the phytoremediation process of impacted soils. Consequently, soil properties should be considered when performing remediation study in contaminated soils. This study has also revealed that the initial concentrations of metals and their interactions in the impacted soils may also determine the proportion of these metals extracted by plants from contaminated soils. The results of the study have revealed that the interactions by metals in impacted soils can affect the phytoremediation process. Based on the concentrations



of metals extracted from the impacted soils, it can be concluded that the mixed CA and EDTA chelants may be utilized as effective soil amendment materials during remediation process. The concentrations of the metals left in soil after phytoextraction enhanced by the mixed chelants revealed that the technique could be an efficient tool for ameliorating the environmental and health problems related to soils impacted with metals. The outcome of the study also revealed that *J. gossypifolia* has the capacity to extract very high proportions of metals from impacted soils; hence, the plant could be effectively used for the remediation of impacted soils. It could be inferred that wastes at municipal dumpsites and electronic shops have the capacity to affect the soil quality significantly. Hence, the cultivation of crops on these impacted soils should be avoided to forestall adverse hazards along the food chain. Nevertheless, the study had few limitations including the disposal of plant materials after the phytoextraction process to avoid additional harm to the environment. The other limitation was the eradication of the chelants introduced into the impacted soils before disposal since chelants may affect the environment negatively if they are not managed properly. Hence, an improved technique that can overcome these limitations should be introduced for a safer environment in future.

Author's contribution

Ejeh, Agi Michael: Conceptualization, Data curation, Formal analysis, Writing – review & editing; **Ebong, Godwin Asukwo:** Writing – review & editing, Supervision; **Moses, Eno Anietie:** Writing – review & editing, Supervision.

Funding

This research did not receive external funding from any agencies.

Ethical statement

Not applicable.

Data availability

Source data is not available for this article.

Conflict of interest

The authors declare no conflict of interest.



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