

Phytoremediation of Contaminated Soils from Challawa Industrial Estate, Kano-Nigeria

U. Abdullahi^{1,*}, A. A. Audu¹, Kalimullah², L. Shuaibu³

¹Department of Pure and Industrial Chemistry, Faculty of Natural and Applied Sciences, Umaru Musa Yar'Adua University, Katsina-Nigeria

²Department of Biological Sciences, Faculty of Natural and Applied Sciences, Umaru Musa Yar'Adua University, Katsina-Nigeria

³Department of Pure and Industrial Chemistry, Faculty of Science, Federal University Birnin Kebbi, Kebbi-Nigeria

Email address:

ussydaddy@gmail.com (U. Abdullahi)

*Corresponding author

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Abstract: Field studies to examine the phytoremediation potential of some plants for metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in metals contaminated soils of Challawa industrial estate, Kano has been carried out. A total of one hundred and eighty (180) samples comprising of 80 (soils), 20 (effluents), and 80 (plant parts) of *Jatropha* (*Jatropha curcas*), *Neem* (*Azadirachta indica*) and *Baobab* (*Adansonia digitata*) were analyzed. 0.50g of the plant tissue and 1.0g of soil sample and 50mL of the effluent sample were digested using triacid digestion method and the levels of the metals were determined by the use of atomic absorption spectrophotometry. The mean levels of the metals in plants and soils from contaminated and control sites were found to be in the sequence of Fe (406.27±45.93)> Zn (137.20±8.00)> Cu (118.60±0.00)> Cd (62.57±6.86)> Mn (21.53±1.79)> Ni (14.36±2.22)> Cr (13.73±1.79)> Pb (12.80±0.00) and Fe (130.23±18.01)> Zn (65.36±4.90)> Cu (26.22±5.50)> Cd (23.08±2.43)> Ni (5.70±0.00)> Mn (4.86±2.21)> Cr (4.80±2.10)> Pb (3.03±1.50) respectively. The contamination factor (CF) of all the metals in the plants were found to be in the sequence of Cd (8.45±1.42)> Cu (2.52±1.00)> Cr (2.28±0.00)> Zn (1.80±1.19)> Fe (1.56±0.00)> Pb (1.49±0.11)> Mn (1.09±0.18)> Ni (1.00±0.06). The results showed that these plants can be used for the phytoextraction of the metals from contaminated soils. The values of bioaccumulation and translocation factors were also found to be more than one in almost all cases. From these results it could be recommended that the three plants investigated would be ideal for phytoremediation in multi-metal contaminated soils.

Keywords: Phytoremediation, Contamination Factor, Bioaccumulation Factor, Translocation Factor, Heavy Metals, Contaminated Soils

1. Introduction

Plant based bioremediation technologies have been collectively termed as phytoremediation, referring to the use of green plants and associated micro biota for the in-situ treatment of contaminated soil and ground water [1]. The idea of using metal accumulating plants to remove heavy metals and other compounds was firstly introduced more than 310 years ago [2]. Phytoremediation is an environmentally friendly, safe and cheap technique to remove the pollutants from the environment. Phytoremediation as a technology uses plants to clean up contaminated environment. It is a low cost, long term, environmentally and aesthetically friendly method

of immobilizing/stabilizing, degrading, transferring, removing, or detoxifying contaminants, including metals, pesticides, hydrocarbons and chlorinated solvents [3, 4, 5].

Over the past three decades, it has become a highly accepted means of detoxifying contaminated water and soils [6]. The development of phytoremediation is being driven primarily by the high cost of many other soil remediation methods as well as a desire to use a "green", sustainable process. Metals contaminated soils are remediated by conventional or unconventional techniques but the in-situ (unconventional) techniques are favored over the ex-situ (conventional) techniques due to their low cost and reduced impact on the ecosystem. Conventionally, the ex-situ

technique is to excavate soils contaminated with heavy metals and their burial in landfill sites [7, 8]. The offsite burial is not an appropriate option as it merely shifts the contamination problem elsewhere [8] and also because of the hazard associated with the transportation of contaminated soils [9]. Most of the conventional remediation technologies are costly to implement and cause further disturbances to the already damaged environment [10, 11]. Basically, phytoremediation of contaminants is categorized under five major sub-groups: phytoextraction, phytostabilisation, phytofiltration, phytovolatilization and phytodegradation [12, 13]. The effluents from the industries in the estate were connected by a canal and channeled directly into the river. The increasing discharge of industrial wastes into this river is posing serious danger to the soils, water resources and the health of people in the area [14]. The major problem facing the city is the management of the wastewater discharged from the Challawa industrial estate and other industries located within the state. Effluents from Challawa industrial estate have been assessed and found that the level of Cr, Zn, SO₄²⁻, NO₃⁻ and DO were above the FEPA and WHO maximum limits [15, 16]. Also the physico-chemical pollutant indicators from textiles and tanneries in Challawa industrial area were assessed and it was noted that higher levels of pH, temperature, conductivity, turbidity and color, TSS, oil and grease exist above WHO standard limit [17]. Mu'azu *et al.* [18] had reported that the concentrations of Cu, Zn, Mn, Pb, Cr and Ni were significantly higher than the levels recommended by Food and Agriculture Organization (FAO), Federal Environmental Protection Agency (FEPA) and the WHO/EU joint limits. This study was aimed at examining the phytoremediation potentials of *Jatropha* (*Jatropha curcas*), *Neem* (*Azadirachta indica*) and *Baobab* (*Adansonia digitata*) on contaminated soils, by assessing the ability of the plants to clean up environment. The Contamination factor (C_f) is used to determine the contamination status of soil and is expressed in terms of contamination factor (C_f) calculated using the relation described [19]. Four contamination categories are recognized on the basis of the contamination factor (C_f) and its interpretation is as follows: C_f < 1 means low contamination; 1 < C_f < 3 means moderate contamination; 3 < C_f < 6 means considerable contamination; C_f > 6 means very high contamination [20]. The bioaccumulation factor (BAF) represents the contaminant concentration in plants comparing with the environment concentration in soil [21-22]. Bioaccumulation Coefficient (BAC) was determined to quantify the heavy metal accumulation efficiency in plants by comparing the concentration in the plant parts (roots, stems and leaves) and on external medium such as the soil or water [23]. This gives the metal level per plant organ which is a better estimate of heavy metal extraction efficiency in a given plant species [24].

The Translocation factors (TF) is defined as the ratio of metal concentration in the shoots to those in the roots. TF=[Ts]/ [Tr], where Ts and Tr are the concentration (mg/kg) accumulated in the shoots and roots respectively. TF>1 indicates that the plants translocate metals effectively from the

roots to the shoots [21].

The bioaccumulation factor (BAF) is defined as the ratio of metal concentration in the roots to those in the soil or water, and is determined using $BAF = [C_{plants}] / [C_{environment}]$. Where C_{plants} and C_{environment} are concentration (mg/kg) in the plant and in the environment (soil or water) while BAF>1 indicates that the plant is a metal accumulator [21].

2. Material and Methods

2.1. Study Area

Challawa industrial estate is located in Kumbotso Local Government Area of Kano State. It is located in the northern Nigeria covering an area extending between latitude 12° 40' and 10° 30' and longitude 7° 40' and 9° 40' (Figure 1). The industries in the Challawa industrial estate range from tanneries and textiles to food and packaging / processing.

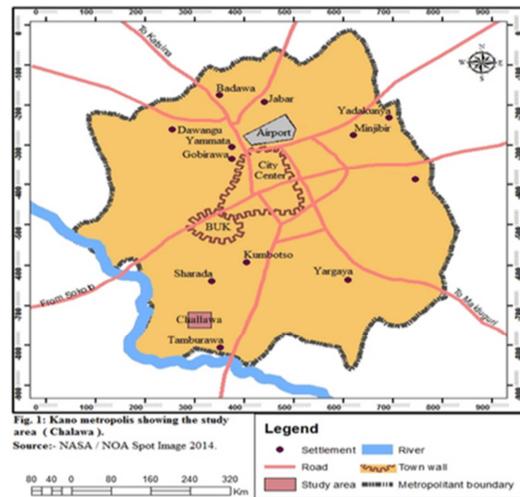


Figure 1. Map of Kano Metropolis Showing the Study Area (Challawa).

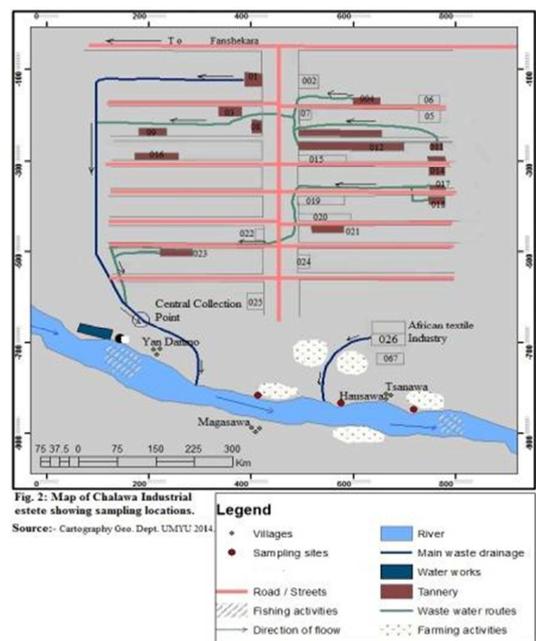


Figure 2. Map of Challawa industrial estate showing the sampling sites.

2.2. Cleaning of Glass Wares

Glass wares, plastic containers, crucibles, pestle and mortar were washed with liquid detergent, rinsed with distilled deionized water and then soaked in 10% HNO₃ solution for 24 hours [25]. They were then washed with distilled water and dried in an oven at 80°C for 3 hours. Other chemicals and reagents used in this study were of analytical grade obtained from BDH and Sigma-Aldrich. Distilled water was also used for dissolution of metals salts used in the analysis. Procedural and reagent blanks were used and a clean laboratory environment was ensured during the analysis and preparation of solutions. The Atomic Absorption Spectrophotometer (Buck Scientific AAS Model 210VGP) was calibrated with multi-element standard solution (MESS) and the calibration standards were analyzed after 10 sample runs to ensure that the instrument remained calibrated [26].

2.3. Samples Collection

A total of one hundred and eighty (180) samples comprising of eighty (80) soils, twenty (20) of effluents and eighty (80) of leaves, stems and roots of *Jatropha (Jatropha curcas)*, *Neem (Azadirachta indica)* and *Baobab (Adansonia digitata)* were collected from the sites and transported to the laboratory. The control samples were collected at Barhin village which is 50km off Mani - Katsina Road. The samples were air-dried separately at room temperature in the laboratory.

2.4. Samples Preparation

The plant samples were separated into portions of roots, stems and leaves and then cut into small pieces and washed with tap water and then rinsed with distilled deionized water. These were placed on card board papers and dried in an open-air in the laboratory for three weeks. The dried samples were ground into fine powder using ceramic pestle and mortar and stored in labeled stoppered plastic bottles. Soil samples were air-dried, ground to fine powder, sieved using a 10 mesh nylon sieve and stored in labeled polythene bags.

2.5. Soil pH Determination

The pH of the soil samples were measured using a calibrated SB20 pH meter. The calibration of the pH meter was carried out using two buffer solutions of pH 4 and 10. 20 mL distilled deionized water was added to 15 g of the soil sample and allowed to stand for 5 minutes. The mixture was stirred vigorously and allowed to stand for another 3 minutes, with occasional stirring. The electrode of the pH meter was inserted into the swirled slurry and three replicate readings taken for each sample [27].

2.6. Sample Digestion

The water samples were digested according to procedure described by APHA [28]; in which 50 mL was first treated with 20 mL concentrated HNO₃ and the mixture was heated on a hot plate until it is boiled. The heating was continued until white fumes from the solution appeared. It was allowed to cool, filtered using Whatman No. 42 filter paper into 100 mL standard volumetric flask and made up to the mark with distilled water.

The plant samples were digested according to procedure adopted by Awofolu [29]; whereby 0.5g of the powdered sample was weighed into a 100 mL beaker and 5 mL of concentrated HNO₃ and 2 mL HClO₄ were added. The mixture was then heated on hot plate at 95°C until the solution became clear. It was then filtered into a 100 mL volumetric flask and made up to the mark with distilled water.

The soil samples were digested using USEPA method 3050 [30]; whereby 1g portion of soil sample was placed into a 100 mL beaker, followed by addition of 10 mL of 1:1 HNO₃: H₂O. The mixture was then heated on hot plate at 105°C for 1 hour and allowed to cool to room temperature. This was followed by sequential addition of 5 mL of concentrated HNO₃, 1 mL of H₂O₂ and 5 mL of HCl. The resulting solution was filtered and diluted with distilled deionized water to a final volume of 100 mL in volumetric flask.

2.7. Atomic Absorption Spectrophotometer Analysis

The concentration of heavy metals in the samples were determined using Atomic Absorption Spectrophotometer (Buck 210 VGP Model) equipped with a digital read-out system. Working standards were used, after serial dilution of 1000ppm metal stock solution in each case. Calibration curves were generated by plotting absorbance values versus concentrations. By interpolation, the concentrations of the metals in sample digests were determined as described by Audu and Lawal [31].

2.8. Statistical Analysis of Data

Analysis of variance for the heavy metals concentrations (in soil and plants parts) were computed by the Duncan's multiple range test DMRT method [32]. The statistical variations were considered significant at $p < 0.05$. Comparison using t-test was also done to detect any significant differences in metal concentrations between plants from polluted and unpolluted site (Control).

3. Results and Discussion

The mean levels of heavy metals (mg/kg) in contaminated soils were significantly ($p < 0.05$) higher compared with those from the uncontaminated site (Control) as shown in Table 1.

Table 1. Table showing the mean levels of heavy metals (mg/kg) in the Soils samples analyses in comparison to the maximum allowed Concentrations.

Metals	Contaminated soils (Mean±SD)	Uncontaminated soils(Control) (Mean±SD)	MAC Values in soils
Cd	23.08±9.83	2.73±0.08	0.03-0.30 ^a
Cr	4.80±1.17	2.11±1.85	5.00 ^a
Cu	26.22±4.17	10.40±2.70	5.00-20.00 ^a
Fe	130.23±31.25	87.67±32.77	3000-5000 ^b

Metals	Contaminated soils (Mean±SD)	Uncontaminated soils(Control) (Mean±SD)	MAC Values in soils
Mn	4.86±1.68	4.45±2.04	40.00-900 ^c
Ni	5.70±0.70	5.60±2.15	2.00-7.50 ^a
Pb	3.03±0.44	2.02±0.62	2.00-20.00 ^a
Zn	65.36±10.68	36.23±4.63	1.00-900 ^a
pH range	5.37 – 5.56	7.12 – 8.04	6.79-7.13 ^a

Key: MAC=Maximum Allowable Concentration; Source: a=Bowen (1979) [33], b=Awokunmi *et al.* (2010) [34], c=ATSDR (2000) [35].

The results in Table 1 showed that the soils in Challawa industrial estate are contaminated with metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) and their pH was slightly acidic. Lower pH values in soil lead to higher heavy metal solubility [36].

The figures (3 - 10) comparing the contents of each metal distribution in the tissues of the plants species in the polluted and unpolluted sites, showed that the plant species accumulated high concentrations of Cd, Cr, Cu, Fe, Pb and Zn in their tissues in polluted sites while high concentrations of Mn and Ni were accumulated by the plants species in unpolluted site. High metal accumulation in plant parts above normal limit indicates their tolerance to the heavy metal pollution in soil.

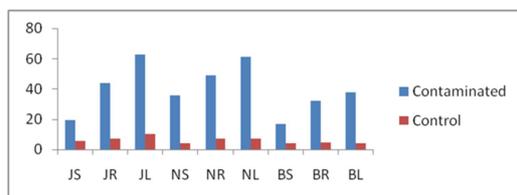


Figure 3. Showing the distribution of Cd metal in plants tissues in polluted and Non-polluted sites.

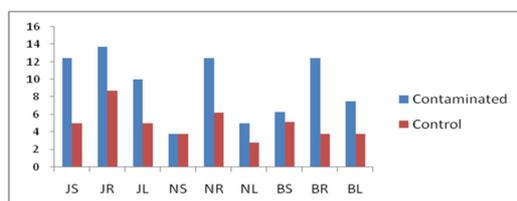


Figure 4. Showing the distribution of Cr metal in plants tissues in polluted and Non-polluted sites.

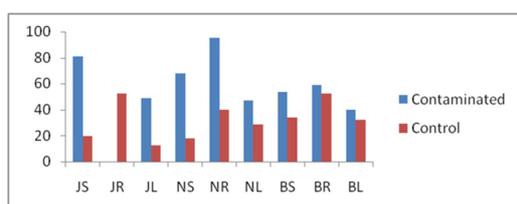


Figure 5. Showing the distribution of Cu metal in plants tissues in polluted and Non-polluted sites.

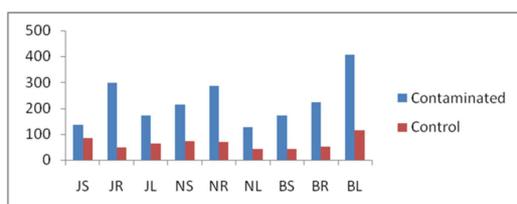


Figure 6. Showing the distribution of Fe metal in plants tissues in polluted and Non-polluted sites.

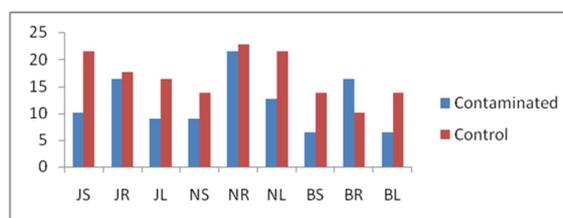


Figure 7. Showing the distribution of Mn metal in plants tissues in polluted and Non-polluted sites.

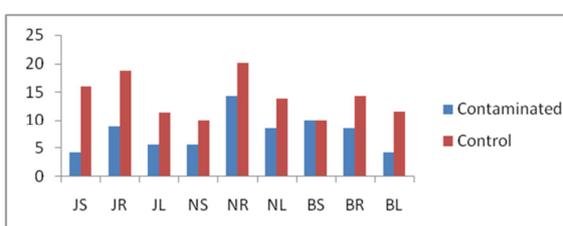


Figure 8. Showing the distribution of Ni metal in plants tissues in polluted and Non-polluted sites.

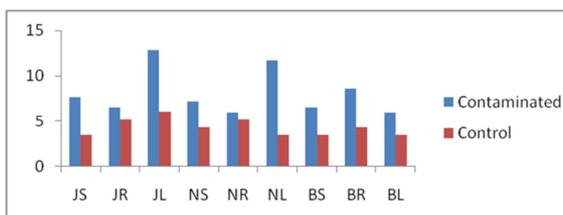


Figure 9. Showing the distribution of Pb metal in plants tissues in polluted and Non-polluted sites.

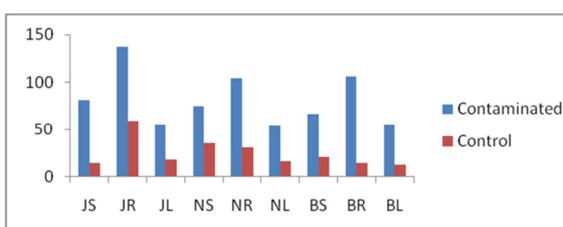


Figure 10. Showing the distribution of Zn metal in plants tissues in polluted and Non-polluted sites.

Key: JS=Jatropha Stems, JR= Jatropha Roots, JL= Jatropha Leaves, NS=Neem Stems, NR= Neem Roots, NL= Neem leaves, BS= Baobab Stems, BR= Baobab Roots and BL= Baobab Leaves.

The roots of *Jatropha curcas* accumulated high levels of the metals (Cr, Cu, Fe, Mn and Zn) while the leaves accumulated high levels of Cd, Ni and Pb (Figure 11). This is in agreement with the findings of Qihang *et al.* [37] and Islam *et al.* [38] for the same plant. Thus, *Jatropha curcas* can be an ideal option for phytoremediation in multi-metal contaminated sites. The uptake of metals in the plant tissues indicates that the soluble

metals can enter into the root cytoplasm by crossing the plasma membrane of the root of the endodermal cells [38]. The roots of Neem (*Azadirachta indica*) accumulated high levels of all the heavy metals: Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn (Figure 12), indicating that it has great potentials for phytoextraction of these metals from contaminated soil. Similarly, Baobab (*Adansonia digitata*) roots accumulated metals: Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn (Figure 13) which is consistent with observations of Barman et al. [39] and Malik et al. [36]. The highest concentration of Cd was accumulated by the leaves of all the three plant species and is similar to the report of Sun et al. [40]. Cadmium is one of the more mobile heavy metals in the soil-plant system, easily taken up by plants and with no essential function known to date [41]. As for the accumulation strategy, plants accumulate high amounts of Cd in their tissues, with only a small amount of Cd is stored in the roots and the rest translocated to the shoot.

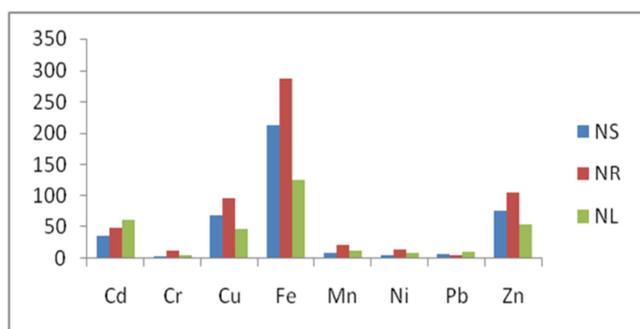


Figure 11. Showing the distribution of metals (mg/kg) in the stems, roots and leaves of Jatropha (*Jatropha curcas*) in the polluted area.

The contamination factor (C_f) values revealed that the soils are highly contaminated with Cd (8.45 ± 1.42) and Cu, Cr, Zn and Fe are said to have considerably contaminated the soils. Pb, Mn and Ni are considered to have only moderately contaminated the soils (Table 2).

Table 2. Variation of Contamination Factor Values (CF) (mg/kg) with Soil Samples.

Soil samples	Contamination factor (mg/kg)							
	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Contaminated Soil	8.45 ± 1.42	2.28 ± 0.00	2.52 ± 1.00	1.56 ± 0.00	1.09 ± 0.18	1.00 ± 0.06	1.49 ± 0.11	1.80 ± 1.19

The results revealed that the translocation factors of all the metals in the plants tissues were greater than one except for Cr and Ni in Neem (*Azadirachta indica*) and Mn in Baobab (*Adansonia digitata*) (Table 3).

Table 3. Translocation of Metals (mg/kg) from Roots to Shoots of Plant Samples in Polluted Area.

Plant Sample	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Jatropha	1.86	1.64	1.09	1.04	1.15	1.15	3.03	1.00
Neem	1.98	0.71	1.21	1.18	1.00	0.99	1.19	1.24
Baobab	1.30	1.11	1.58	2.58	0.77	1.82	1.47	1.15

These values indicated higher availability and distribution of metals in soils contaminated with heavy metals in the three plant species which can be labeled as translocators of Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn based on $TF > 1$. Heavy metal tolerance with high TF value have been suggested for phytoaccumulator of contaminated soils [42, 43] and therefore these plant species can be used as phytoremediators for multi-metal contaminated soils.

Also the results revealed high bioaccumulation factors (BAF)

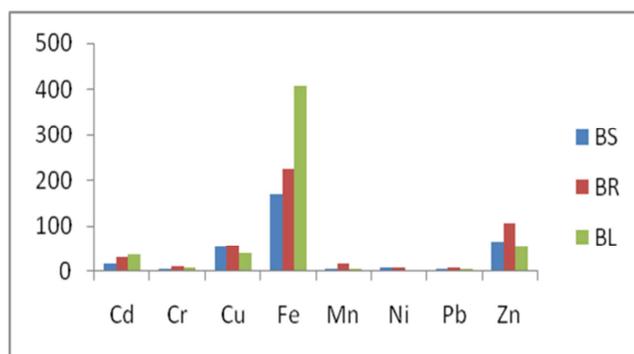


Figure 12. Showing the distribution of metals (mg/kg) in the stems, roots and leaves of Neem (*Azadirachta indica*) in the polluted area.

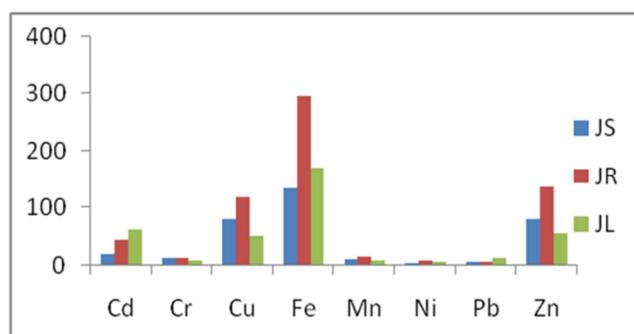


Figure 13. Showing the distribution of metals (mg/kg) in the stems, roots and leaves of Baobab (*Adansonia digitata*) in the polluted area.

Key: JS=Jatropha Stems, JR= Jatropha Roots, JL= Jatropha Leaves, NS=Neem Stems, NR= Neem Roots, NL= Neem leaves, BS= Baobab Stems, BR= Baobab Roots and BL= Baobab Leaves.

of all the metals examined in the tissues. All the BAF values were greater than one, except for Zn (0.96), Cd (0.76) and Ni (0.84) in Jatropha (*Jatropha curcas*) leaves and stems respectively; Cr (0.90), Fe (0.96) and Zn (0.70) in leaves and Cr (0.63), Ni (0.89) and Zn (0.97) in stems of Neem (*Azadirachta indica*); Ni (0.99) and Zn (0.92) in the leaves of Baobab (*Adansonia digitata*) (Table 4). The bioaccumulation of the metals indicates a great performance of these plant species for metals phytoextraction and could be labeled as accumulator plants [44].

Table 4. Bioaccumulation Coefficient (BAC) Values for Heavy Metals in the Tissues of Plants.

Plant	Plant Parts	Bioaccumulation Coefficient (BAC)							
		Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Jatropha	Leaves	2.43	2.00	1.42	1.74	1.75	1.13	4.22	0.96
	Stems	0.76	2.49	2.37	1.37	2.00	0.84	2.38	1.41
	Roots	1.71	2.75	3.45	3.00	3.25	1.72	2.18	2.37
Neem	Leaves	3.09	0.90	2.10	0.96	3.33	1.34	2.77	0.70
	Stems	1.79	0.63	3.04	1.64	2.33	0.89	2.31	0.97
	Roots	2.45	2.23	4.27	2.20	5.67	2.24	4.26	1.35
Baobab	Leaves	2.09	1.97	1.29	2.52	1.11	0.99	1.73	0.92
	Stems	1.09	1.65	1.75	1.06	1.11	1.75	1.90	1.11
	Roots	2.47	3.28	1.93	1.39	2.89	1.51	2.48	1.76

4. Conclusion and Recommendations

The results obtained showed that *Jatropha* (*Jatropha curcas*), *Neem* (*Azadirachta indica*) and *Baobab* (*Adansonia digitata*) can accumulate heavy metals from contaminated soils. The bioaccumulation and translocation factors were found to be greater than one except in few cases; indicating that all the three plant species are potentially useful for remediating heavy metals contaminated soils for these metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn). It is recommended that these plants: *Jatropha* (*Jatropha curcas*), *Neem* (*Azadirachta indica*) and *Baobab* (*Adansonia digitata*) can be ideal option for the phytoremediation in multi-heavy metal contaminated soils. These plants if massively planted in and around the industrial estate would reduce these metals in the soil and would also in the long run help to prevent the ground water contamination by heavy metals in the industrial effluents.

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