Phytoremediation Potentials of *Cynodon dactylon* on Heavy Metal Contaminated Soils from Challawa Industrial Estate, Kano-Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author LS designed the study and wrote the first draft of the manuscript. Authors UA, AIY and JIB managed the statistical analysis of the study and the literature searches. All authors read and approved the final manuscript.

Article Information

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ABSTRACT

This study investigated the phytoremediation potentials of *Cynodon dactylon* in heavy metal contaminated soils of Challawa Industrial Estate, Kano, Kano State, Nigeria. A total of 100 samples comprising of 50 soils and 50 plant parts of *C. dactylon* were evaluated for the presence of heavy metals by the use of atomic absorption spectrophotometry (AAS) method. Extent of heavy metal soil contamination and phytoremediation potentials of the study plant were assessed by the use of metal contamination factor (C_f) for soil; Bioaccumulation and translocation factors for the plant sample respectively. From the results, levels (mg/kg) of the metals in the *C. dactylon* from contaminated and control sites were found to be in the sequence of Fe (442.60) > Cu (138.35) > Zn (133.53) > Cd (61.50) > Pb (42.47) > Mn (28.40) > Ni (18.40) > Cr (17.73) and Fe (88.60) > Zn (38.18) > Cu (33.60) > Ni (13.70) > Mn (12.67) > Pb (6.07) > Cd (5.60) > Cr (5.03) respectively.

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The contamination factor values C_f, (mg/kg) of all the metals in the soils were found to be in the sequence of Cd (10.73) > Cu (5.64) > Cr (3.07) > Pb (2.98) > Ni (2.17) > Zn (2.09) > Mn (2.00) > Fe (1.72). The results showed that the soils are highly contaminated with Cd, considerably contaminated with Cu and Cr, and moderately contaminated with Fe, Mn, Zn, Ni and Pb. The bioaccumulation and translocation factor values (BAF>1 and TF<1) for Cd, Cr, Cu, Mn, Ni, Pb and Zn suggest accumulation in roots and qualify the plant as good candidate for phytostabilization. Moreover, the bioaccumulation and translocation factor values (BAF and TF>1) for the plant species were greater than 1 for Fe suggesting efficient accumulation in the shoot. However, *C. dactylon* could be recommended as good candidate for phytoextraction of Fe and phytostabilization of the study investigated metals (Cd, Cr, Cu, Mn, Ni, Pb and Zn) in multi-metal contaminated soils.

1. INTRODUCTION

Phytoremediation is an emerging technology that exploits the use of green plants for the decontamination of polluted environment. It employs the ability of plants to act as solar-driven pumps leading to the extraction and concentration of certain environmental metal pollutants [1]. Phytoremediation has the advantages being a low cost, with a longer term effect, coupled with it being environmentally and aesthetically friendly way of immobilizing and stabilizing, degrading, transferring, removing, or detoxifying contaminants including metals, pesticides, hydrocarbons and chlorinated solvents [2-4]. Over the past three decades, it has become the method of choice for detoxification of contaminated water and soils [5]. The escalating cost and the desire to use environmentally friendly methods of soil phytoremediation is the prime mover of the development of phytoremediation as a sustainable process of environmental decontamination. There are two methods usually employed in remediating metal contaminated soils. Which are the conventional (ex-situ) or the unconventional (in-situ) techniques, but the latter techniques are favored over the former techniques because of their lower cost and reduced detrimental effect on the ecosystem. Ideally, the ex-situ technique employs the excavation of heavy metals polluted soils and their subsequent transfer and burial in landfill sites [6,7]. Thereby shifting the contamination problem elsewhere [7] in addition to the risk of exposure that may probably be associated with the transportation of the contaminated soils [8]. Majority of the conventional remediation technologies are not cost effective and may further lead to disturbances to the already damaged environment [9,10].

Effective management of the wastewater discharged from the Challawa Industrial Estate and other industries located within Kano state is a major problem overwhelming the overstretched resources of the state. Discharges emanating from Challawa Industrial Estate have been evaluated for contaminants and it was discovered that the level of Cr, Zn, SO_4^{2-}, NO_3^- and dissolved oxygen (DO) were beyond the Federal Environmental Protection Agency (FEPA) and World Health Organization (WHO) permissible limits [11,12]. A study [13] was also conducted to assess the physico-chemical pollutant indicators from textiles and tanneries in Challawa Industrial Area, with the results of the study revealing higher levels of pH, temperature, conductivity, turbidity and color, total soluble solids (TSS), oil and grease existing above WHO standard limit. The study of Mu'azu *et al.* [14] had reported concentrations of Cu, Zn, Mn, Pb, Cr and Ni from the same industrial area to be significantly higher than the levels recommended by Food and Agriculture Organization (FAO), FEPA and the WHO/ European Union (EU) joint limits.

The plant *C. dactylon* is of the family *poaceae* and order *poales*. It is often called Bermuda/crab grass and sometime goes by the name *digitaria sanguinalis,* possessing short, rough edged gray-green colored blades that are usually 2-15 cm long [15]. The erect stem can grow up to 1-30 cm tall. They possess an often tingled purple colored stem that is slightly flattened, with the seed heads produced in a cluster of two to six spikes each 2.5 cm long located at the top of the stem. It has a deep root system that can grow to over 2 meters deep in drought situations; though most of the root mass is less than 60 centimetres under the soil surface. The grass forms a dense mat as it creeps along the ground

due to the ability of the roots to form nodes wherever they touch the ground [15].

This study was aimed at investigating the ability and extent of *C. dactylon* to phytoremediate heavy metals from polluted soils, by assessing the ability of the plant to clean up the environment through the removal of Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn from industrially contaminated soils of the Challawa Industrial Estate located in Kano, Kano state, Nigeria, with the use of the plant bioaccumulation factor (BAF) [15] and translocation factor (TF) [16].

2. METHODOLOGY

2.1 Study area

Located in Kumbotso Local Government Area of Kano State Northern Nigeria, Challawa Industrial Estate covers an area extending between latitude 12^0 40' and 10^0 30' and longitude 7^0 40' and 90^0 40' (Fig. 1). The Challawa Industrial Estate comprises mostly tanneries, textiles and, and food packaging / processing industries (Fig. 2).

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% HNO_3 solution for 24 hours [17]. Additional washing of the materials were done with distilled water and dried in an oven at 80^0C for 3 hours. All the used chemicals and reagents in the present study were of analytical grade and were 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.

2.3 Samples Collection

A total of 100 samples comprising of 50 soils and 50 each of shoots and roots of *C. dactylon* were collected from the sites and transported to the laboratory. The control samples were collected at Barhin village which is 50 m off Mani - Katsina Road. The samples were air-dried separately at room temperature in the laboratory.
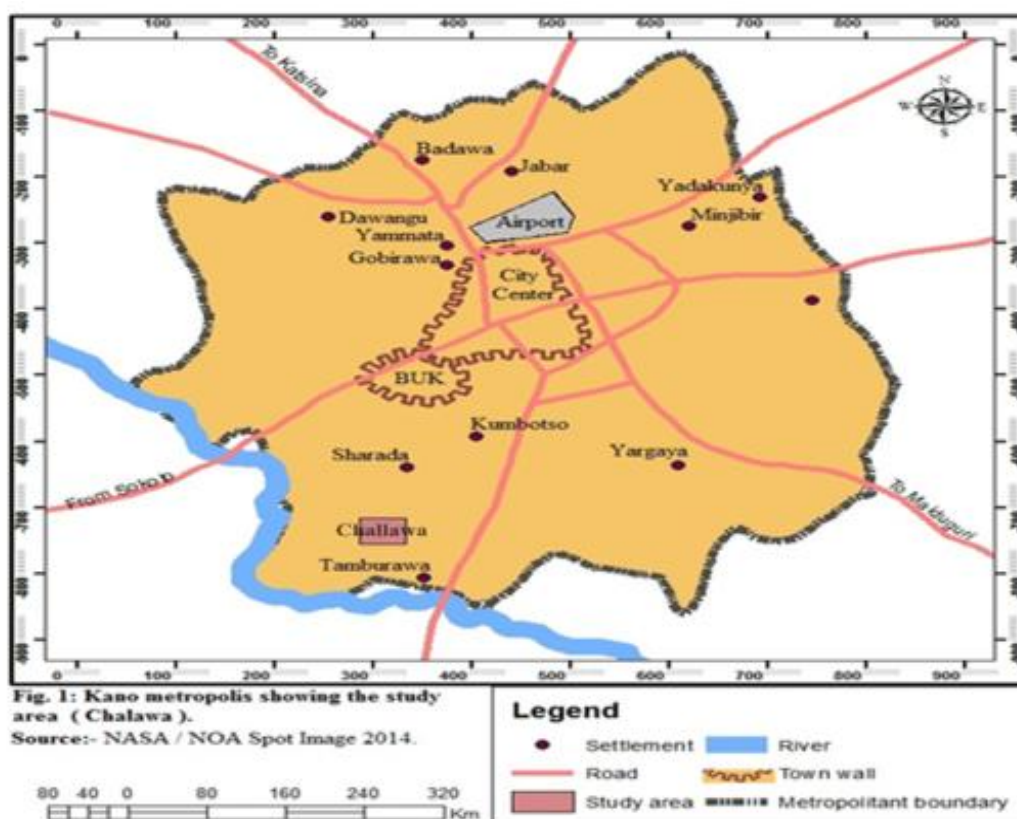

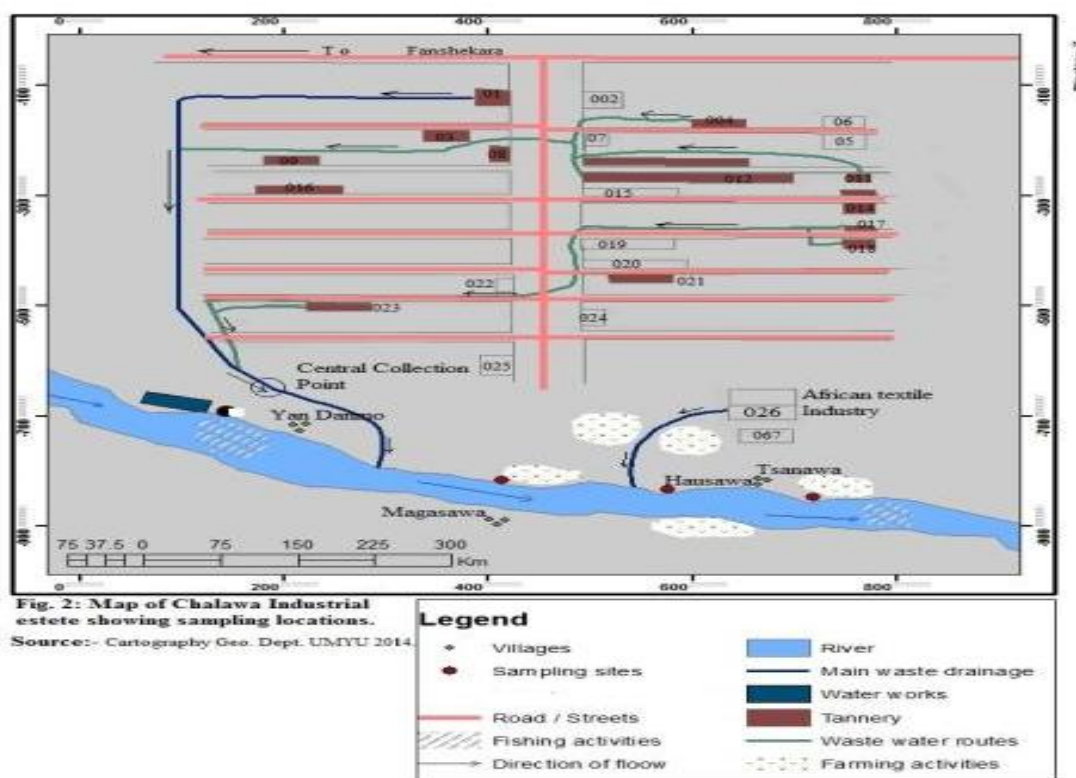Fig. 1: Kano metropolis showing the study area (Challawa).
Source:- NASA / NOA Spot Image 2014.

Fig. 1. Map of Kano metropolis showing the study area (Challawa)

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

2.4 Samples Preparation

The plant sample separated into portions of roots and shoots were cut into small pieces, washed with tap water and then rinsed with distilled deionized water. These were placed on card board papers and dried in open-air in the laboratory for three weeks. The dried samples were then grinded into fine powder using a 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 soil samples pH were measured using a calibrated SB20 pH meter. The pH meter was calibrated using two buffer solutions of pH 4 and 10. 20 mL distilled deionized water was added to 15 g of the soil sample and the mixture was allowed to stand for 5 minutes, followed by vigorous stirring, allowed to further stand for another 3 minutes, with occasional stirring. After which the electrode of the pH meter was inserted into the swirled slurry and three replicate readings taken for each sample [18].

2.6 Samples Digestion

The plant samples were digested according to procedure adopted by Awofolu [19]; whereby 0.5 g of the powdered sample was weighed into a 100 mL beaker and 5 mL of concentrated HNO_3 and 2 mL $HClO_4$ were added. The mixture was then heated on hot plate at 95^0C 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 [20]; whereby 1 g portion of soil sample was placed into a 100 mL beaker, followed by the addition of 10 mL 1:1 HNO_3: H_2O. The mixture was then heated on hot plate at 105^0C for 1 hour and allowed to cool at room temperature. This was followed by sequential addition of 5 mL concentrated HNO_3, 1 mL H_2O_2 and 5 mL HCl. The resulting solution was filtered and diluted with distilled deionized water to a final volume of 100 mL in a volumetric flask.

2.7 Evaluation of Heavy Metals in Samples

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 1000 ppm 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 [21].

2.8 Calculation of the Contamination, Bioaccumulation and Translocation factor

The contamination status of the soils was calculated using contamination factor (C_f) as described by Guptal *et al.* [22].

$$C_f = [Metal]_{soil} / [Metal]_{background\,soil} \qquad .eqn. (1)$$

Four contamination categories are recognized on the basis of the contamination factor and its interpretation is as follows [23].

$C_f < 1$ means low contamination; $1 < C_f < 3$ means moderate contamination; $3 < C_f < 6$ means considerable contamination; $C_f > 6$ means very high contamination.

The accumulation of metals in the plant shoot and roots were determined by bioaccumulation factor (BAF) according to the formulas [24].

$$BAF_{roots} = [Metal]_{roots} / [Metal]_{soil} \qquad \dots eqn. (2)$$

$$BAF_{shoots} = [Metal]_{shoots} / [Metal]_{soil} \qquad .eqn. (3)$$

The transfer of metals from the roots to the shoots were determined based on the translocation factor (TF) expressed by the formula [24].

$$TF = [Metal]_{shoots} / [Metal]_{roots} \qquad .eqn. (4)$$

2.9 Statistical Analysis of Data

Concentrations of heavy metals were presented as mean ± standard deviation. Students't-independent test was used to determine differences between the mean levels of metals analyzed in plant and soil samples from polluted and unpolluted site (Control). Statistical variations were considered significant at $p < 0.05$.

3. RESULTS AND DISCUSSION

The results of the mean heavy metals concentrations analyzed in the soil samples are presented in Table 1. From the results, the mean concentration of the heavy metals Cd, Cr, Cu and Ni from the contaminated soil samples and Cd in control sites were above the maximum allowable concentrations of heavy metals in soil [25]. 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. The result for the mean heavy metal concentration was higher than the results reported in a study that evaluated heavy metal concentrations of soil samples in Katsina state Nigeria [26].

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	32.95 ± 1.43	3.07 ± 0.46	0.03-0.30[a]
Cr	11.00 ± 1.04	3.58 ± 0.71	5.00[a]
Cu	55.80 ± 3.12	9.90 ± 0.51	5.00-20.00[a]
Fe	163.23 ± 1.50	94.93 ± 7.04	3000-5000[b]
Mn	8.87 ± 1.10	4.43 ± 1.10	40.00-900[c]
Ni	14.38 ± 2.58	6.64 ± 0.42	2.00-7.50[a]
Pb	9.83 ± 1.48	3.03 ± 0.75	2.00-20.00[a]
Zn	71.89 ± 9.89	34.43 ± 0.78	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 [25], b= Awokunmi et al. [27], c=ATSDR [28]

The results in Table 1 showed that the soils in Challawa Industrial Estate are contaminated with heavy 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 [29].

The Figs (3 - 10) comparing the contents of metal distribution in the tissues of the plant in the polluted and unpolluted sites, showed that the plant accumulated high concentrations of the heavy metals Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn in its tissues from the polluted site. High metal accumulation in plant parts above normal limit indicates their tolerance to the heavy metal pollution in soil [29].

The results have revealed that high levels of the metals (Cd, Cr, Cu, Mn, Ni, Pb and Zn) were accumulated by the roots of *C. dactylon*, while the shoots accumulated high levels of the heavy metal Fe (Fig. 11). This result is in agreement

with the findings of the study conducted by Archer and Caldwell [30] using a similar plant as that used in the present study. As such, *C. dactylon* can be an ideal option for phytostabilization in a multi-metal polluted environment. 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 [31]. Moreover, the highest concentration of Cd was accumulated by the roots of the plant, a finding that is in agreement with the report of Sekabira *et al.* [32]. Cadmium ranks among the more mobile heavy metals in the soil-plant system that is easily assimilated by plants and with no known essential function [33]. With the exception of Fe; the plant accumulated high amounts of all the metals (Cd, Cr, Cu, Mn, Ni, Pb and Zn) in its roots and only small amounts of the metals are translocated to the shoots. However, the plant accumulated high amount of Fe in the shoots.
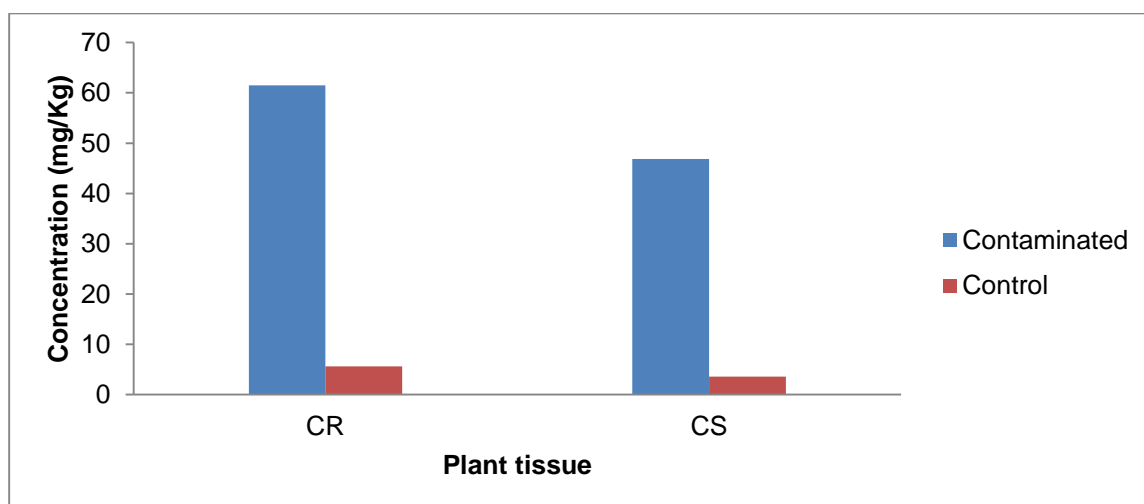

Fig. 3. Showing the distribution of Cd metal in plant tissues in polluted and Non-polluted sites
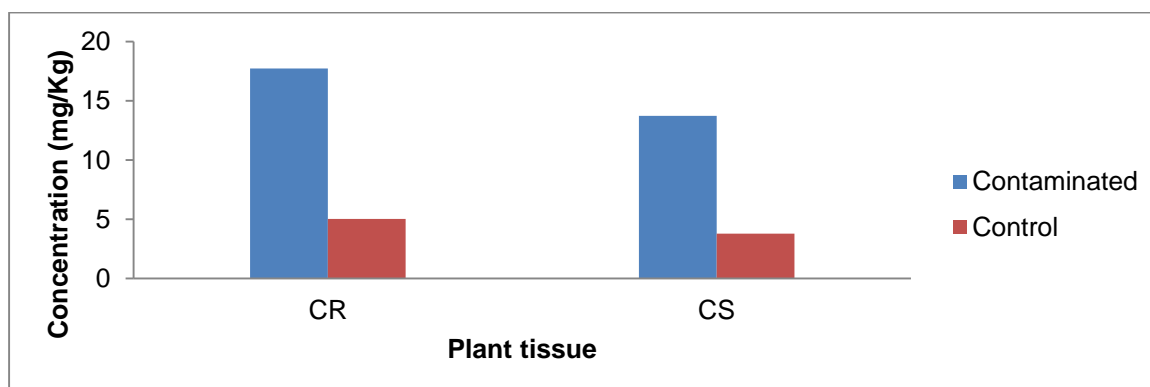

Fig. 4. Showing the distribution of Cr metal in plant tissues in polluted and Non-polluted sites
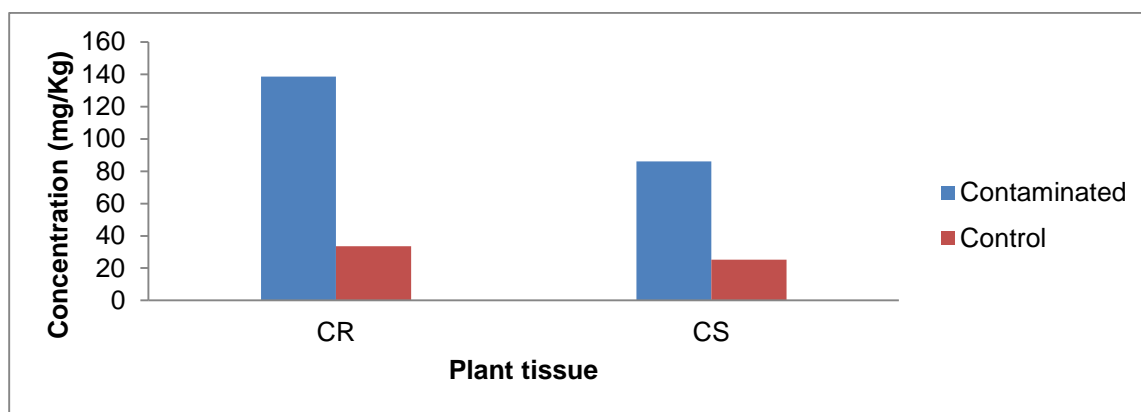
Fig. 5. Showing the distribution of Cu metal in plant tissues in polluted and Non-polluted sites
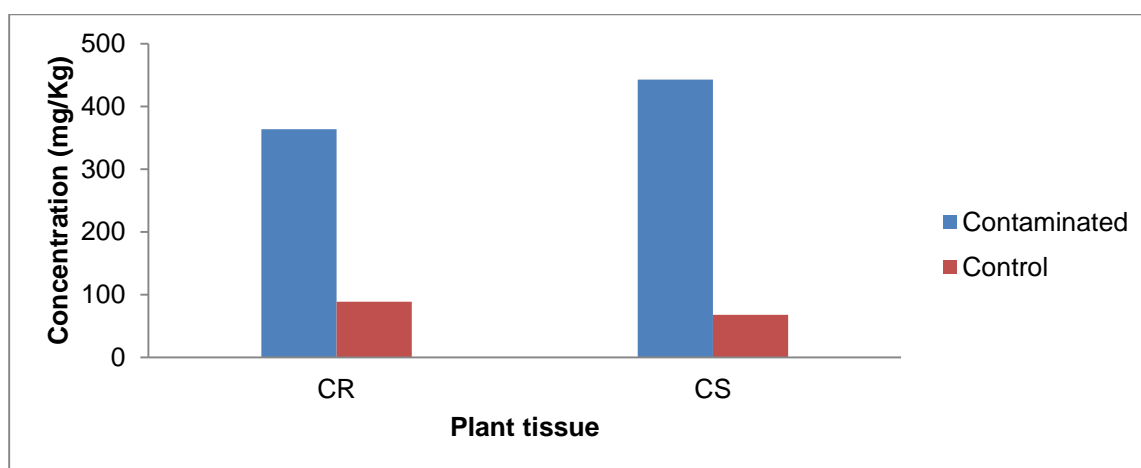

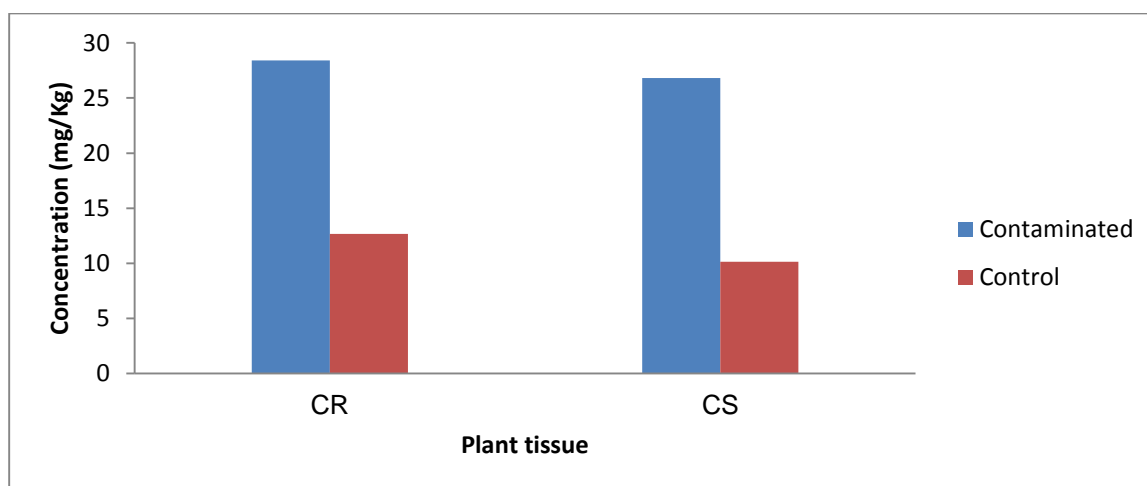**Fig. 6. Showing the distribution of Fe metal in plant tissues in polluted and Non-polluted sites**

Fig. 7. Showing the distribution of Mn metal in plant tissues in polluted and Non-polluted sites

The contamination factor (C_f) values revealed that the soils are highly contaminated with Cd (10.73); Cu and Cr are said to have considerably contaminated the soils while Fe, Mn, Ni, Pb and Zn are considered to have moderately contaminated the soils as shown in Table 2. The results are similar to the report of Sanusi *et al.* [34] for the heavy metal Cu in an abandoned Pb-

Zn mine in Yelu, Alkaleri local Government Area of Bauchi state, Nigeria and the report of Olagunju *et al.* [35] for heavy metals C_f in soil of residential Areas around awotan land fill, Ibadan, Southwestern Nigeria and the report of Yaradua *et al.* [26] for agricultural soils from Katsina state, Nigeria.
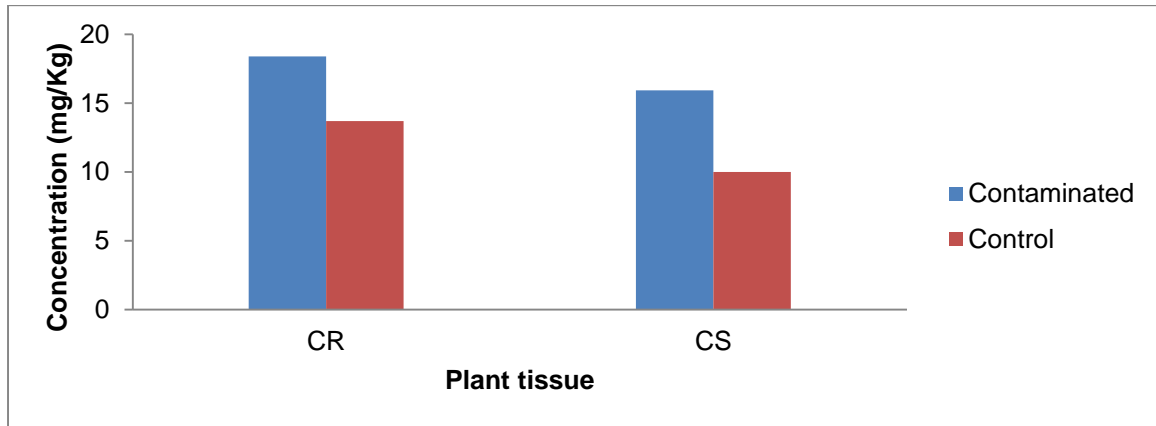

Fig. 8. Showing the distribution of Ni metal in plant tissues in polluted and Non-polluted sites
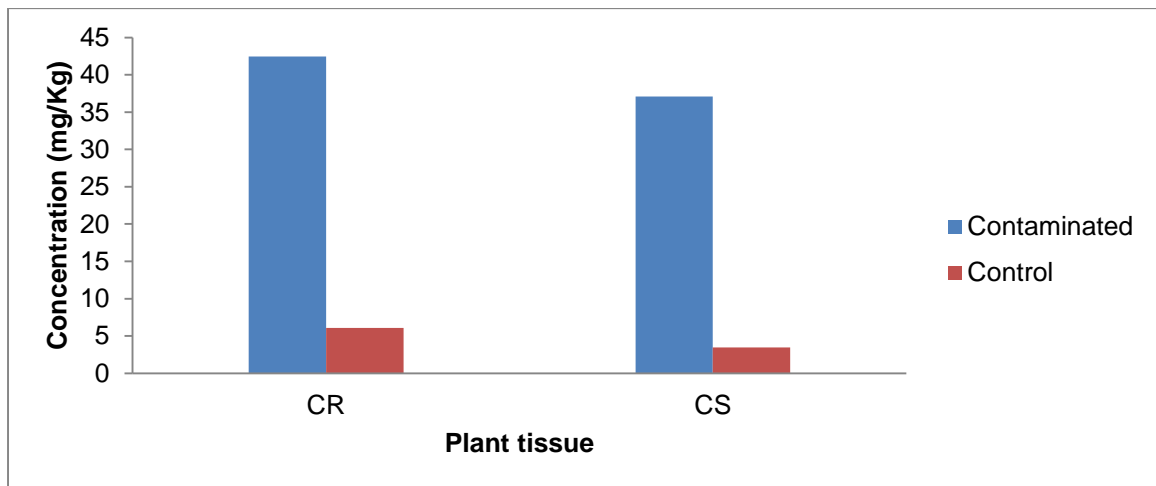

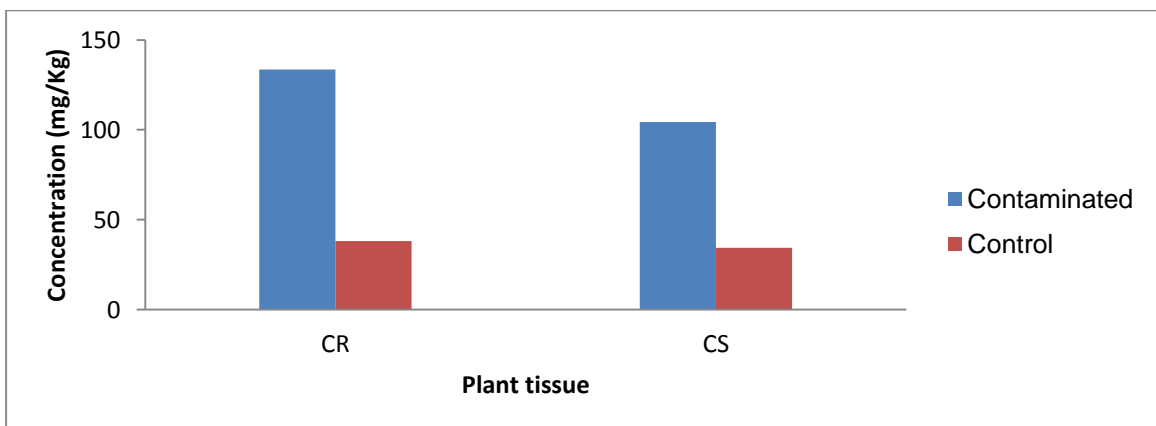**Fig. 9. Showing the distribution of Pb metal in plant tissues in polluted and Non-polluted sites**

Fig. 10 Showing the distribution of Zn metal in plant tissues in polluted and Non-polluted sites
Key: CR= Cynodon dactylon Roots, CS= Cynodon dactylon Shoots

The results revealed that the translocation factors of all the metals in the plant tissues were less than 1 except for the heavy metal Fe (Table 3).

These values indicated higher availability and distribution of metals in the roots of the plant based on the TF<1. Moreover, the plant can be labeled as translocator of Fe based on TF>1. High accumulation of heavy metals in roots and low translocation in shoots may indicate appropriateness of a plant for phytostabilization [30, 31].

The results have also revealed high bioaccumulation factors (BAF) of all the metals examined in the tissues. From the results, all the BAF values were greater than 1 (Table 4). The bioaccumulation of the metals indicates a greater ability of the plant for metals phytoremediation and could be labeled as a heavy metal accumulator plant [36].

Analysis of the results indicates that there are significant differences (p<0.05) between the metal contents of the soils from Challawa Industrial Estate and those from Barhin village (control site). This observation confirms the heavy metals' soil pollution at Challawa Industrial area.

However, the plant showed metal concentrations of less than 1000 mg/kg and thus it could not be categorized as a hyper-accumulator [37]. The plant can form a dense mat on the soil surface and is cosmopolitan. It shows very fast vegetative growth and seedlings [33].
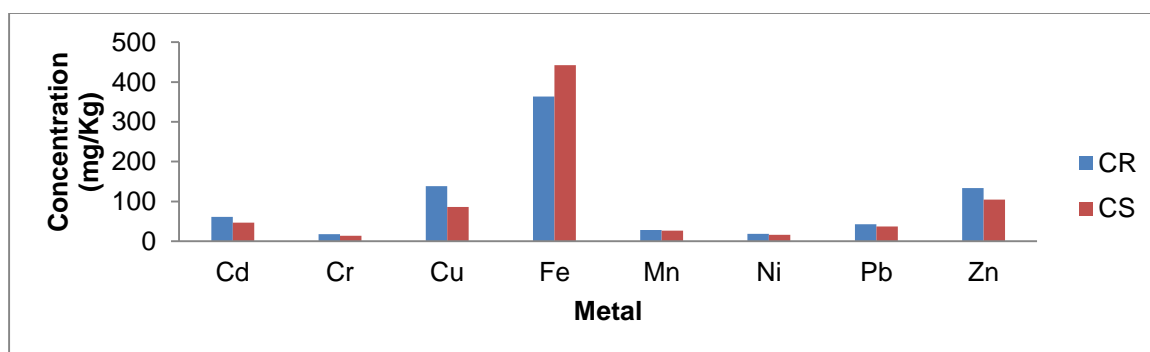

Fig. 11. Showing the distribution of metals (mg/kg) in the roots and shoots of Cynodon dactylon in the polluted area
Key: CR= Cynodon dactylon Roots, CS= Cynodon dactylon Shoots

Table 2. Variation of contamination factor values (C$_f$) (mg/kg) with Soil samples

Metal	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
C$_f$ value	10.73±3.11	3.07±1.46	5.64±1.12	1.72±0.10	2.00±0.42	2.17±0.75	2.98±0.11	2.09±0.78

Table 3. Translocation of metals (mg/kg) from roots to shoots of *C. dactylon* in Polluted Area

Metal	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
T$_f$ Value	0.76	0.77	0.62	1.22	0.94	0.87	0.87	0.78

Table 4. Bioaccumulation Coefficient (BAC) values for heavy metals in the tissues of *C. dactylon*

Plant Part	Bioaccumulation Factor (BAF)							
	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Shoots	1.42	1.25	1.54	2.71	3.02	1.11	3.78	1.45
Roots	1.87	1.61	2.50	2.23	3.20	1.28	4.32	1.86

4. CONCLUSION

The results have revealed that the plant *C. dactylon* can accumulate heavy metals from metal polluted soils. The bioaccumulation and translocation factor values (BAF>1 and TF<1) for Cd, Cr, Cu, Mn, Ni, Pb and Zn is a pointer to the accumulation of these heavy metals in roots. An indication that the plant can potentially be useful for phytostabilization, moreover, the bioaccumulation and translocation factor values (BAF and TF>1) of the plant were greater than 1 for the heavy metal Fe suggesting efficient accumulation in shoots. It is recommended that *C. dactylon* can be ideal for phytoextraction of Fe and phytostabilization of the other investigated metals (Cd, Cr, Cu, Mn, Ni, Pb and Zn) in multi-metal contaminated soils.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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