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RESEARCH ARTICLE

ASSESSING THE PERFORMANCE OF *RACINUS COMMUNIS* (L.) IN DECONTAMINATING HEAVY METALS POLLUTED SOIL USING PHYTOEXTRACTION STRATEGY

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ABSTRACT

Globally, our environments (soil, water and air) are increasingly exposed to heavy metals (HMs) contaminations through natural and anthropogenic activities. Thus, it is a matter of great significance to remediate these metals from the ecosystem in order to maintain a safe and healthy environment. The research was carried out to evaluate the phytoextraction capacity of *Racinus communis* (L) grown on contaminated soils with HMs obtained from three sites in urban Kano. The physicochemical parameters of the soil samples were analysed using Near-Infrared spectrometer (NIRS D-2500) and other standard procedures. The HMs concentrations were analyzed using Micro Plasma Atomic Emission Spectrometer (MPA-ES, Model 4210). The degree of HMs contaminants were evaluated using Mueller's Geoaccumulation Index (I_{geo}). Data were statistically analysed using one way Analysis of Variance at P<0.05. The physicochemical results revealed that all the soil samples were sandy-loam in texture and slightly acidic with pH values ranging between (6.11±0.02-5.02±0.06). Other concentration of soil physicochemical parameters varies across the soil samples. The results of the HMs analyses across the soils revealed highest concentrations of Fe (311.02 ±0.04 mg/kg), Cu (208.62±0.01 mg/kg) and Zn (112.04±0.04 mg/kg) in soil sample A, Pb (34.03±0.16 mg/kg) and Cr (4.63±0.03mg/kg) were observed to be higher in soil sample C, while the highest concentration of Cd (1.20±0.00 mg/kg) was recorded in soil sample B. Relatively all the concentrations of HMs in the contaminated soil samples after the experiment were defined uncontaminated to moderately contaminated based on Igeo values. The findings provide scientific evidence that *R. communis* can be used as a veritable tool for the control of HMs pollution in the soil.

KEYWORDS

Contaminated Soils, Geoaccumulation Index, Heavy Metals, Phytoextraction, *Racinus communis*.

1. INTRODUCTION

Phytoextraction is the plants based technology, used to remediate polluted soil with heavy metals and concentrate them in the harvestable biomass, and thus, scientist reported that when such metals recover from the plants biomass can also be used for other industrial applications. Globally, environments (soil, water and air) are increasingly exposed to various contaminations through natural and anthropogenic activities such as weathering, erosion, mining, industrial processing and agricultural activities. In Kano state, like any other city in the world, these activities are also pronounced. Presence of heavy metals in soil environment is a major concern due to their non-biodegradable nature, they accumulate in the environment and ultimately get biomagnified via the food chain (Hazrat et al., 2013). This contamination poses a health risk to plants which are the major depository alongside animals including human beings. Heavy metals affect soil fertility, depreciate valuable land, damage soil microbial structural diversity and affect the ecological balance of the soil (Ambika et al., 2016). Heavy metals also affect the economic and tourism development of the areas concerned (Bao et al., 2008). Thus, it is a matter of great significance to remediate heavy metals from the ecosystem in order to maintain a safe food chain and healthy environment using plants based technology.

Different physical, chemical and microbiological methods used for the cleanup heavy metal contaminants from the soil environment such us solidification, stabilization, soil flushing, chemical reduction, soil washing, low temperature thermal desorption, incineration, vitrification and soil excavation are all limited by high cost, intensive labor, alteration of soil properties and disturbance of soil autochthonous microflora (Mahar et al., 2016).

Phytoextraction is the most recognized and applied phytoremediation technique of heavy metals and metalloids with permanent reclamation solution, which is non-intrusive, aesthetic and eco-friendly (Pajevic et al., 2016; Bañuelos *et al.*, 2017; Prieto et al., 2018; Jacob et al., 2018). Selection of plant species for phytoextraction is based on high tolerance and accumulation rate for several metals, adaptation to local climates, high biomass, depth root structure, growth rate, ease of planting and maintenance, and ability to take up large quantities of water through the roots (Zhao et al., 2001; Ali et al., 2013).

Ricinus communis L. (Castor oil plant) is a fast-growing (annual or perennial) species of flowering plant which belongs to the family Euphorbiaceae. Mostly native to the tropics and sub-tropical countries (Patel et al., 2016; Abu-kamal et al., 2021). The plant grows on different types of disturbed or undisturbed soils, easy to establish on the field and

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resistant to drought. The plant is also an important oilseed crop with great utilitarian value in pharmaceutical industries and agricultural sectors, it is commonly known as Zurman or Zurmami by the native populace of urban Kano. Locally, all the parts of the plant are used to treat various ailments such as fever, stomach constipation, cough, and rheumatism. The medicinal use of castor plant is extensive. Castor oil is most commonly used as a laxative, the leaves and seeds have been used to augment labour, promote lactation and to treat syphilis and leprosy. It's used as contraceptic among the Rukuba women of Plateau State in Nigeria (McNeil et al., 2021). Globally, the plant have been widely used in traditional medicine such as skin diseases, abdominal disorders, arthritis, bilharziasis, weakened immune system, chronic headache, backache, muscle aches constipation, expulsion of placenta, gallbladder pain, intestinal worms, menstrual cramps, rheumatism, sleeplessness, tumour, and insomnia (Samantha, 2010; Ross, 2003; Sarfaraz et al., 2017). Thus, due to paucity of research concerning phytoextraction of HMs in urban Kano Nigeria, this research aimed at employing an endemic plant (*R. communis*) for HMs decontamination (Phyto-decontamination) of soil using phytoextraction techniques, and evaluation of HMs accumulated in the research plant various organs.

2. Materials and Methods

2.1 *Study Area*

The research was conducted between January, 2019 and December, 2021 at Kano metropolis, the capital city of Kano State, Nigeria. Located between latitude 11°59'59.57''N to 12°02'39.57''N and longitude 8°31'19.69''E to 8°33'19.69''E, with a total urban land area of 137Km² and 499Km². Kano metropolis is about 481 meters above sea level. It is the most developing and urbanizing city and commercial centre of the Northern Nigeria which encompassed many industries including tannery, textile, chemicals, food, and plastic. The three (3) specified sites were selected based on diverse human activities, which involve disposal of industrial waste that may lead to an increase the amount of toxic metals entering into the environment, and the control site was selected based on neither human no industrial activities in the area.

Table 1: Sampling Sites and Co'ordinates of the Study Area

	Sampling Sites	Coordinates: Latitude/ Longitude
1	Metals Scraps dumpsite Sharada [A]	11⁰ 57'49''N 8⁰30'29'' E
2	Stone Crusher (Quarry) site Sauna [B]	12⁰1'32''N 8⁰35'50'' E
3	Industrial waste dumpsite Sharada [C]	11⁰57'44''N 8⁰30'44''E
4	Ecological Study Area BUK Control site [D]	11⁰58'39''N 8⁰28'43''E

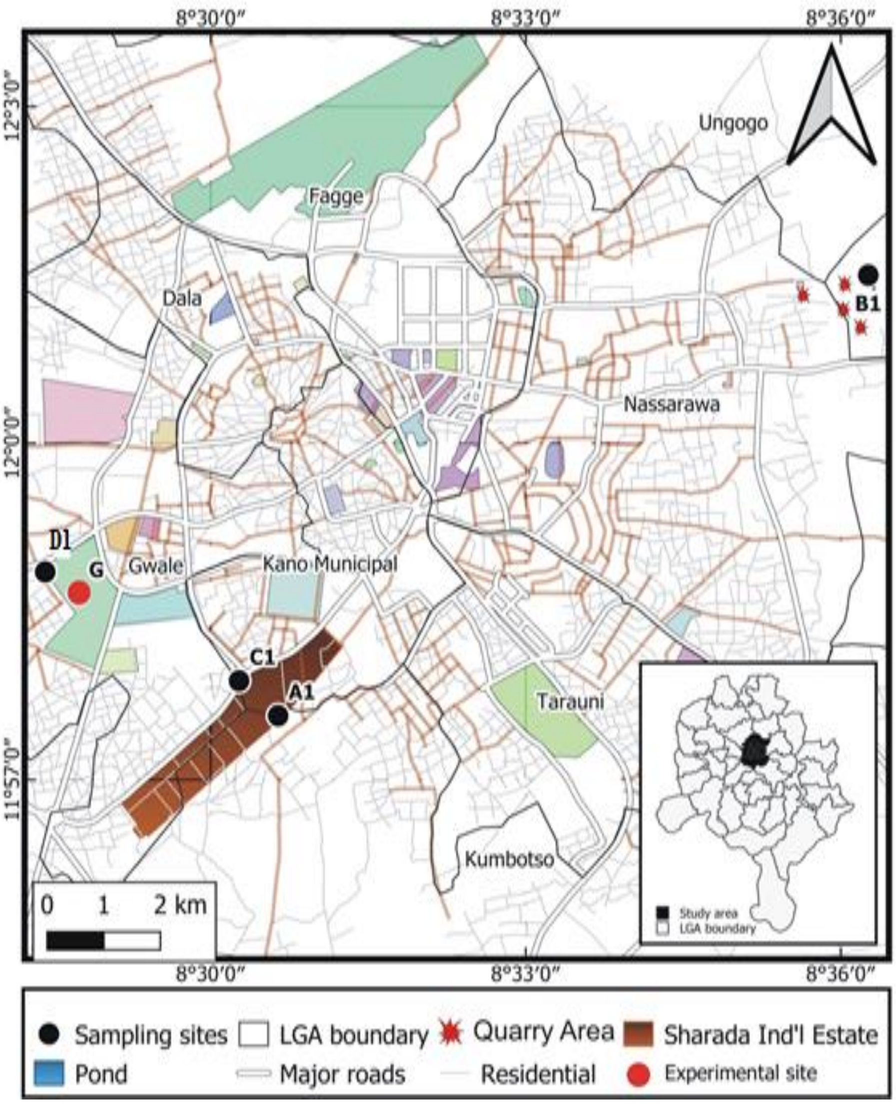


Figure 1: Map of the study area (Kano, Urban) indicating sampling sites. Source: - GIS Lab. Geography Department (BUK, 2022).

2.2 *Collection of Soil Sample and Processing*

Using method six points were established, in each sample site 2 m interval each and top soil (0-15 cm) depth were collected at 3points (1, 3, and 5) and combined as one samples into polyethene bags and transferred to Bayero university botanical garden for further studies (Qihang et al., 2014; Mumtahina and Sirajul, 2021). Using a top loading balance (Model 680, A & D Weighing, US), 45 kg of each contaminated soil sample was measured, 15 kg of the soil sample was also collected from ecological garden Bayero University Kano which served as a control of the experiment. The soil samples were mixed thoroughly after passing through stainless steel sieve (4 mm) to remove non-soil particles such as broken bottles, plastics and stones.

2.3 Analyses of Experimental Soil Samples

Using various equipment/apparatus the studied soil physicochemical parameters and concentrations of HMs were analysed.

2.4 Near-Infrared Spectrometry (NIRS)

Using Near-Infrared Spectrometer (NIRS D-2500, Metrohm, Switzerland) analyzer, some physicochemical parameters of the soil samples was analyzed. The machine setting was according to manufacturers' instruction and calibration was according to Centre for Dry Land Agriculture (CDA) standard operation procedure. All the parameters were equated with the spectra obtained from the machine library. Other parameters such as pH, available nitrogen and available sulphur are determined using procedure described by (Motsara and Roy, 2008; ASTM, 2017).

2.5 Heavy Metals Analyses

The quantitative HMs analyses were carried out using Micro Plasma Atomic Emission Spectrometer (MP-AES: 4210model Agilent, UK). Sample preparation (Using Advanced Microwave Digestion System, Model: EHOS EASY). Nine (9) heavy metals were analysed namely, Arsenic (As), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Nickel (Ni), Iron (Fe), Lead (Pb), and Zinc (Zn). The analysis was done at Bayero University Kano Centre for Dry land Agriculture (CDA) laboratory.

2.6 Experimental Design

The experiment was laid out in a Completely Randomize Design (CRD). The greenhouse plastic pots with the depth of 19 cm and width of 26.5 cm containing 5 kg of the soil samples were randomly arranged in triplicate, each pot contained four small holes beneath to avoid eutrophication which may leads to unnecessary dying of the research plants.

2.7 Screen House Condition and Seedling Rising

The temperature and the relative humidity of the screen house were measured using a temperature/humidity meter (CTH 288; Beetech, India). The screen house experiment was commenced in July, 2019 with maximum temperature range 33-40.3^{0}C and relative humidity of 55-37%. Fifteen (15) seeds were planted in each pot and after emergence; seedlings were thinned to 8 plantlets per pots. The plantlets were cultivated for 16 weeks (112days). During the experiment, the seedlings were irrigated with tap water to maintain soil moisture at a day interval.

2.8 Measurement of Growth Parameters

Using different measuring devices, selected growth parameters were observed and measured, such as; Chlorophyll content (chlorophyll meter (CCM 200plus), Plant height (tape cm) and dry weight biomass ((XY300C, Wincom, China) of the experimental.

2.9 Experimental Plants Harvest

At sixteen weeks (112days), the plants were carefully uprooted from the experimental soils, the soil particles were removed by shaking and washed with tap water. The roots stem and leaves were separated and were temporarily dried in the screen house before taking to the laboratory hot air oven (DHG 9023, Everich, China) at 60^{0}C for 72hrs, 96hrs and 120hrs for leaves, roots and stem respectively.

2.10 Bioaccumulation Factor (BAF)

The value of BAF of metals was used to determine the quantity of HMs absorbed by the plants from the soil. This is an index of the ability of the plant to accumulate a particular metal with respect to its concentration in the soil and is calculated using the formula below: - (Kachenga et al., 2020).

$$BAF = \frac{Heavy\ metals\ concentration\ in\ plants\ (\frac{mg}{kg})}{Heavy\ metals\ concentration\ in\ the\ soil\ (\frac{mg}{kg})}$$

2.11 Translocation Factor (TF)

This is an indication of the ability of plants to translocate HMs from the roots to the aerial parts. To evaluate the potential of plants for phytoextraction, the translocation factor was calculated using the formula below (Naz et al., 2022)

$$TF = \frac{Heavy\ metals\ concentration\ in\ stem+leaves\ (\frac{mg}{kg})}{Heavy\ metals\ concentration\ in\ the\ root\ (\frac{mg}{kg})}$$

2.12 Statistical Analyses

The data obtained were subjected to both descriptive and inferential statistics. One-way analysis of variance (ANOVA) was used to compare means and significantly different means were pairs using Turkey's multiple comparisons to define which specific mean pairs were significantly different. With the help of Graphad prism software version 6.The programmed software R. version 4.2.0.was used for the Principal Component Analysis (PCA). All the data presented in figures and tables were expressed as mean ± standard deviation (STD) of three replicates (n=3).

3. Results and Discussion

3.1 Physicochemical parameters of the soil samples

Table 1 below revealed the physicochemical condition of the experimental soil samples, such as particle size distributions (sand, silt and clay), pH, OM, EC, CEC, Available Phosphorous (Avail. P), and Available Nitrogen (Avail. N). The results of particle size distributions (PSD) of the experimental soil samples defined the textural classes of the soils which is sandy-loam deduced from soil triangle, International Soil Science Society (ISSS) (version Hirotatsu and Toshiyuki, 2015).

Table 2: The Physicochemical parameters of the experimental soil samples prior to the experiment.

Soil Parameters		Soil Samples			
		A	B	C	D (Ctr)
*PSD	Sand (%)	62.12±0.02^b	58.22±0.01^a	64.18±0.02^b	61.21±0.02^b
	Silt (%)	16.04±0.01^b	24.01±0.01^c	11.01±0.01^a	18.01±0.01^b
	Clay (%)	21.67±0.01^b	17.17±0.01^a	24.67±0.01^b	20.67±0.01^b
Soil texture		Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH		5.02±0.06^a	5.94±0.03^a	5.91±0.08^a	6.11±0.02^a
Electrical Conductivity (S/m)		12.26±0.41^c	4.96±0.23^b	12.14±0.16^c	2.94±0.12^a
Organic Matters (%)		1.05±0.04^a	2.70±0.22^b	3.87±0.14^c	2.96±0.11^b
Avail. N (%)		2.11±0.04^a	2.31±0.00^a	4.21±0.02^b	2.10±0.03^a
Avail. P(mg/kg)		11.48±0.02^b	27.51±0.02^c	11.48±0.02^b	8.27±0.01^a
CEC (cmol/kg)		56.7±0.34^c	40.94±0.61^b	86.04±0.28^d	38.24±0.42^a

Values along row with different superscript are significantly different from each other and are mean of three replicates ± standard deviation, using one way analysis of variance (ANOVA) and Turkey's multiple comparisons (P<0.05). PSD= Particle Size Distribution; CEC= Cation Exchange Capacity.

Table 3: Post analyses of physicochemical parameters of experimental soil samples.

Soil Parameters		Soil Samples			
		A	B	C	D (Ctr)
*PSD	Sand (%)	71.11±0.02[b]	68.11±0.00[a]	74.11±0.01[b]	68.41±0.00[a]
	Silt (%)	18.02±0.02[a]	21.64±0.01[b]	12.24±0.01[a]	16.24±0.01[a]
	Clay (%)	10.67±0.01[a]	09.67±0.01[a]	12.67±0.00[a]	14.67±0.01[b]
Soil texture		Sandy loam	Sandy loam	Sandy loam	Sandy loam
pH		6.62±0.04[a]	7.06±0.12[b]	7.01±0.04[b]	6.86±0.06[a]
Electrical Conductivity (S/m)		6.12±0.12[c]	1.91±0.76[b]	3.11±0.19[c]	0.62±0.13[a]
Organic Matter (%)		0.04±0.41[a]	0.68±0.05[b]	0.03±0.00[a]	0.69±0.01[b]
Nitrogen (%)		2.12±0.03[a]	4.91±0.81[b]	6.11±0.19[c]	2.62±0.17[a]
Phosphorus (mg /kg)		6.13±0.31[b]	10.31±0.00[c]	6.06±0.29[b]	6.11±0.00[a]
CEC (cmol/kg)		20.72±0.67[b]	16.15±1.01[b]	59.1±1.25[d]	14.31±0.68[a]

Values along row with different superscript are significantly different from each other and are mean of three replicates ± standard deviation, using one way analysis of variance (ANOVA) and Turkey's multiple comparisons ($P < 0.05$). PSD = Particles Size Distribution; CEC = Cation Exchange Capacity.

The PSD of the experimental soil recorded highest proportions of sand in soil sample C (64.18±0.02%) and the least was recorded (58.22±0.01%) for soil collected from side B. The highest proportion of silt was recorded (24.01± 0.01%) for soil sample B while the least was revealed (11.01±0.01%) for soil sample C. Highest proportion of Clay was also reveal in soil sample C (24.67±0.01%) and least was recorded in soil sample B (17.17±0.01). This type of soil (sandy-loam) is regarded as the most suitable for raising plants particularly crop plants in Kano. The soil sample is suitable for the growth of both wild and domesticated plant species. The work of has reported the sandy- loam nature of the study area (Dawaki et al., 2013; Chukwulobe and Saeed, 2014; Olayinka et al., 2017). Table 2 present the post analysis results, which relativity showed the reduction of all the physicochemical parameters, a clear indication of plants uptake for metabolism and other physiological activities.

The experimental soil pH ranged between 5.02± 0.06 to 6.11± 0.02 which clearly indicates that all the experimental soil samples were slightly acidic as showed in Table 1. The pH ranges obtained in this study were similar to those reported by (Berefo and Chaney et al., 2014; Audu et al., 2016 and Abdulhamid et al., 2017). This study to reported the similar pH results in 10 different metal scrap sites (Chukwu et al., 2019). pH in the soil plays an important role in the sorption of HMs; it controls the hydrolysis of metal hydroxides and also influences ion-pair formation and solubility of organic matter (Tokalioˇglu, et al., 2006). Soil pH is, therefore, described as the "master soil variable" that influences varieties of soil biological, chemical, and physical properties and affects plant growth and biomass yield. (Dora, 2019). The availability of plant nutrients, which might have an impact on how the soil and plants interact with regard to the accumulation of HMs, is also strongly influenced by soil pH. (Husson, 2013).

The electric conductivity (EC) of the study soils which is a major indicator of salinity was found to be low, in soil sample collected from site B 4.96±0.23 S/m and D 2.94±0.12 S/m), while higher EC was recorded 12.26±0.41 S/m in soil sample collected from site A. These finding is in line with (Sandip et al., 2015). Generally, EC is used to estimate the soluble salt concentrations in soil and is commonly used as a measure of salinity. Soil with EC below 0.4 S/m are considered marginally or non-saline while soils above 0.8 S/m are considered severely saline (Wagh et al., 2013). In post study soils analyses the values of EC were decreased. The decreased of EC is due to the absorption of some ions including HMs by experimental plants species during metabolisms and other activity for the growth.

The highest percentage of organic matter (OM) was revealed (3.87±0.14%) in experimental soil collected from sample site C and lowest in soil sample site A (1.05±0.04%). Generally, the results of the OM is low compared with organic matter recorded both the authors characterized the physicochemical property of soil samples obtained from selected anthropogenic areas in Abeokuta and Markurdi, Nigeria (Olayinka et al.,2017; Ogbodo et al., 2019). The low level of organic matter from both contaminated soils attributed to sandy texture of soils. The physical, chemical, and biological properties of soil are significantly influenced by soil organic matter. Specifically for sandy soils that can control heat absorption and release, soil organic matter can improve soil permeability, raise soil resistance to erosion, increase water holding capacity, and play a role in delivering moisture (Wibowo and Kasno 2021). Biologically, soil organic matter contributes to the active character of soil colloids and their physiological functions as a growth hormone (Wibowo and Kasno, 2021). While chemically, soil organic matter provides a source of nutrients for plants.

The result of the available nitrogen across studied soil samples was also low ranging between 2.11±0.04 - 4.21±0.02 mg/kg with the highest showed in experimental soil sample collected from site C and the least in soil sample collected from site A. The values of Nitrogen reported in this study is high while compared with low Nitrogen content reported on industrially contaminated dump site soil and also reported similar results of low nitrogen in Kano Urban Agricultural Lands by (Abdulhamid et al., 2017; Dawaki et al., 2013).

Phosphorus content of the experimental soil samples were recorded higher in soil sample collected from site B (27.51±0.02 mg/kg) due to the facts that phosphorus is one of the major components of rocks (Porder et al., 2013). And soil sample site D was showed the least content of phosphorus (8.27±0.01 mg/kg). The study reported similar soil phosphorus content in some selected solid waste dumpsite (Wunzani et al., 2020). After nitrogen, phosphorus ranks as the second-most crucial nutrient for crops. In all metabolic processes, including photosynthesis, respiration, energy storage, transfer, cell division, cell enlargement, and nitrogen fixation, it is a crucial macronutrient (Esther, 2019).

Cation Exchange Capacity (CEC) Soil sample collected from site C revealed the highest value of CEC (86.04±0.28 cmol/kg), while the least CEC was recorded in experimental soil collected from site D (38.24±0.42 cmol/kg). In soil post experiment reduction of CEC was recorded in all the soil samples which indicate the uptakes of ion by the experimental plants species. Soils that have higher CEC are considered to be more fertile than soils with low CEC, since is an important measure of the soil's ability to retain and to supply nutrients (Wodaje and Alemayehu, 2014).

The post analyses result of soil samples physicochemical parameters presented in Table 3, revealed the textural characteristics of the soil remained sandy loam with little reduction of some values. The pH values of soil samples collected from site A and D remained slightly acidic ranged between 6.62±0.04 and 6.86±0.06 whereas the pH of soil sample collected from site B and C changed from acidic to neutral 7.06±0.12, 7.01±0.04 respectively. There was reduction of some values in other parameters such as OM, EC, Avail. N and Avail. P in post analyses across sites as presented in Table 2, which proved evidence of biological activity of the experimental plant species.

3.2 Heavy Metals Concentrations In Soil Samples

The mean concentration of each HMs in soil samples before and after the experiments was presented in Table 4. The means concentrations result varies across experimental soils and virtually all the concentration of HMs across the experimental soils are above WHO/FAO set standard HMs in soil.

Table 4: Mean Values of Heavy Metals Concentrations (mg/kg) of Study Soil Samples Before and After the Experiment.

	Heavy Metals								
	Zn	Cd	Cu	Ni	As	Co	Pb	Fe	Cr
Sample Sites									
Before Experiments									
CSA	112.04±0.04^{d}	0.06±0.04^{a}	208.62±0.01^{d}	0.09±0.05^{a}	0.32±0.21^{b}	0.05±0.00^{a}	4.18±0.01^{b}	311.02±0.04^{d}	0.53±0.11^{b}
CSB	6.34±0.61^{b}	0.01±0.00^{a}	20.02±0.10^{c}	0.01±0.08^{a}	0.34±0.11^{b}	0.04±0.00^{a}	0.07±0.03^{a}	28.14±0.61^{c}	0.56±0.12^{b}
CSC	50.14±0.16^{c}	1.20±0.00^{b}	20.14±0.06^{c}	0.01±0.05^{a}	0.24±0.02^{b}	0.03±0.00^{a}	43.77±0.01^{c}	34.03±0.16^{c}	4.63±0.02^{c}
SSD	6.10±0.13^{b}	0.01±0.00^{a}	3.28±0.03^{b}	0.04±0.00^{a}	0.35±0.03^{b}	0.03±0.00^{a}	0.01±0.00^{a}	16.06±0.13^{b}	0.13±0.04^{b}
After Experiments									
CSA	33.01±0.06^{d}	0.01±0.00^{a}	12.21±0.01^{c}	0.03±0.01^{a}	0.17±0.01^{b}	0.05±0.00^{a}	0.06±0.01^{a}	42.21±0.01^{c}	0.13±0.00^{b}
CSB	0.04±0.21^{a}	0.01±0.00^{a}	4.02±0.10^{b}	0.01±0.13^{a}	0.06±0.01^{a}	0.04±0.00^{a}	ND	10.02±0.10^{b}	0.11±0.10^{b}
CSC	11.0±0.01^{c}	0.01±0.00^{a}	0.02±0.01^{a}	0.01±0.05^{a}	0.08±0.02^{a}	0.03±0.00^{a}	8.03±0.00^{b}	6.12±0.01^{a}	0.21±0.01^{b}
SSD	0.16±0.02^{b}	ND	0.12±0.03^{a}	0.01±0.00^{a}	0.06±0.03^{a}	0.01±0.00^{a}	ND	2.09±0.03^{a}	ND
WHO (2016)	3.00	0.003	1.00	0.05	1.00	1.3	0.1	0.02	0.1

Values are means of three replicates ± standard deviation, all values along a particular column with different superscripts are statistically not significant from each other. Using one way analysis of variance (ANOVA) and pairs using Turkey's multiple comparisons ($P < 0.05$).

CSA= Contaminated Soil [A] Metal scrap dump site Sharada; CSB=Contaminated Soil [B] Stone crusher (quarry) Sauna; CSC=Contaminated Soil [C] Industrial waste dump site Sharada; SSD= Soil Sample [D] control (ecological study area Bayero University Kano); ND= Not Detected; WHO= World Health Organization

Iron (Fe), proved highest concentrations across the studied soil samples which defined the ferruginous nature of Kano urban soil. The highest mean concentration of Fe was recorded 311.02±0.04 mg/kg in soil sample A, and least concentrations were obtained in soil collected from side D 16.06±0.13 mg/kg. The high level of iron might be due to the fact that most of the scraps objects in the dumpsite are made up of Iron or Iron materials. Iron also ranking fourth most abundant element in the earth's crust (Wodaje and Alemayahu, 2017).

Zinc (Zn), The mean concentration of Zn varied across the four studied samples with the highest value recorded in soil sample collected from site A 112.04±0.04 mg/kg while the least was recorded 6.34±0.61mg/kg in soil sample collected from site B. Both the mean concentrations level of Zn from the three locations was higher than the control site D 6.10±0.13 mg/kg. All the concentrations of Zn from the studied soil sites are higher than USEPA, 2000 and WHO, 2016 permissible limit of 2.0 and 3.00 respectively. The abundance of Zn in dump site was reported by (Tariwari et al., 2016; Wunzami et al., 2020).

Cadmium (Cd), the concentration of Cd in the studied soils was presented in Table 4. The level of Cd ranged from 0.01±0.00-1.20±0.00 mg/kg. This clearly showed that the concentrations of cadmium across the experimental sampling sites were low but higher than WHO permissible limit of Cd on both water and soils for agriculture 0.003 mg/ml (Aneyo et al., 2016). The highest concentrations of Cd were recorded in soil sample collected from site A 1.20±0.00 mg/kg (Akpoveta et al., 2010). reported similar result of Cd in soils around metal scraps dump site. The analysis also recorded the presence and higher concentrations of Cd above WHO permissible limit in contaminated soil (Ogbodo et al., 2019; Usman et al., 2020).

Copper (Cu), the mean concentrations of Cu in the study soil collected from sites A, B and C are higher than that of D (control) sample and also higher than WHO permissible limit (1.000 mg/kg), soil sample collected from site A reveals highest level of Cu 208.62±0.01 mg/kg and the least was recorded from experimental soil collected from site B 20.02±0.10 mg/kg. The value was high than that of soil collected from control site 3.28±0.03 mg/kg. These result is in agree with the finding of both with the aim of decontaminating industrial and other waste dump site soils contaminated with HMs (Rinklebe et al., 2012; Abdulhamid et al., 2017; Ogbodo et al., 2019). The higher concentrations of Cu in both the studied sites were linked with the communal used of materials made up of Cu.

Nickel (Ni), the means concentrations of Ni ranged between 0.01±0.05 to 0.09±0.05 mg/kg in both soil samples collected from site C and A respectively. Across the study sites only soil sample collected from site A recorded mean value above permissible limits 0.09±0.05 mg/kg. The recommended safe limits by WHO for Ni in water and agricultural soils are 0.02 and 0.05ppm respectively (Aneyo et al., 2016). The low concentration of Ni in contaminated soil was also reported reported the high concentrations of Ni in contaminated soil while in contrast (Akpoveta et al., 2010; Rinklebe et al., 2012). The fluctuation of Ni concentration in various contaminated soil sites has a linked with the ages and the types of wastes. Nickel occurs in the environment at very low levels and the natural sources of atmospheric nickel are dust, volcanic emissions and the weathering of soils (Ambika et al., 2016; Al-lami et al., 2020).

Arsenic (As), **t**he highest level of As was recorded in the soil sample collected from site B 0.35±0.03 mg/kg which may likely be as a result of stones dust, and the least was recorded in soil sample collected from site C 0.24±0.02 mg/kg as showed in Table 4. These results were in agree with the findings of who recorded a low level of As in municipal waste dumpsite (Agbeshiea et al., 2020). Arsenic is gotten naturally and artificially as a result of weathered volcanic rocks, fossil fuels, agricultural chemicals, wood preservatives, medicinal products and industrial activities (Garelick et al., 2008).

Cobalt (Co), cobalt was recorded low across the soil sample sites, the highest concentration was recorded in experimental soil collected from site A (0.07±0.00 mg/kg) and the least was recorded from contaminated soil collected from site C 0.03±0.00 mg/kg. The post analysis results in Table 4 revealed 0.05±0.00 mg/kg that indicates slightly accumulation of Co by experimental plants species. These finding is in line with Solomon (2019) that recorded low Cobalt concentration in soil collected from different waste dump sites. Cobalt found naturally in the earth's crust.

Lead (Pb), the concentration of Pb in all the experimental soil samples varies and higher than WHO, permissible limits (0.1mg/kg). The highest concentrations were recorded 43.77±0.01 mg/kg in soil sample C while the least 0.07±0.03 mg/kg was recorded in soil sample B. Pb was not detected in the control soil sample. In soil sample C, the HMs concentration values decreased from 43.77±0.01 mg/kg to 8.03±0.00, showing that the plant species had the ability to extract and transfer Pb to various organs, see Table 4. The result of high level of Pb in dump sites is in agree with the finding of also recorded high level of Pb and other HMs in some dumpsite of Kano metropolis (Chukulobe and Saeed, 2014; Karkarna, and Mujahid, 2020). Low level of Lead in quarry contaminated soil was also reported by (Tiimub et al., 2015). The Pb notable sources in the environment are petroleum, electronic industries, battery; lead based paint, stained glass household dust and biocide preparation (Muhammad et al., 2020; Ekeleme et al., 2021). Lead can accumulate in the human body and may cause various health ailments. There has been a lot of attention paid to Pb levels in soil because it is well-known to cause adverse health effects, and is relatively widespread as a result of its historical use in many commercial products, from gasoline to paint (Mofor *et al.*, 2017). It can enter the human body through uptake of food (65%), water (20%) and air (15%) (Ruqia et al., 2015).

Chromium (Cr), the highest level of Cr was revealed in soil sample site C (4.63±0.02 mg/kg) while the lowest was recorded in soil sample site A (0.53±0.11 mg/kg) as shown in Table 4, all the values are above permissible limit (WHO, 2016). The concentration of Cr on studied soil site A, B, and C was higher than that of control soil sample 0.13±0.01 mg/kg. The results of high level of Cr in contaminated soils were in agree with the findings of while recorded the low concentration of Cr in different dumpsites soil within Kano metropolis (Abdulhamid et al., 2017; Solomon, 2019; Vasileios et al., 2021; Karkarna and Mujahid, 2020). Chromium is known to be a toxic metal that can cause severe damage to both plants and animals (WHO, 2000; Ambika et al., 2016).

3.3 *Geoaccumulation Index*

HMs geoaccumulation in the studied soil sample [A] shows heavily to extreme contamination with Zn, Fe, Pb, and Cu while Cd proof moderate to heavily contamination. Studied soil from site [B], however, exhibit various levels of geoaccumulation class, Ni showed strong contamination while Cu, Pb and Cr showed moderate to heavily contamination. Studied soil collected from site [C] proved extreme contamination with Pb, Cd and Cr mean while strong to moderately contaminated with Ni, Cu and Zn as presented in Table 5. Generally the Igeo status of the soil samples was firmly proof both the natural and anthropogenic sources of the contaminants. The negative values indicate the HMs contaminations of the sites are not from anthropogenic sources.

Table 5: The Igeo Class of studied HMs deduced from 0 -6 Muller Geoaccumulation Index

HMs	Site A	Site B	Site C		
Zn	3.61	-0.53	2.45		
Cd	2.00	-0.58	6.32	**I_{geo} class and level of contamination**	
Cu	5.41	2.02	2.03	Igeo≤0	*Uncontaminated*
Ni	0.58	-2.58	-2.58	0<Igeo<1	*Uncontaminated to moderately contaminated*
As	-0.71	-0.63	-1.13	1<Igeo<2	*Moderately contaminated*
Co	0.15	-0.17	-0.58	2<Igeo<3	*Moderately to Heavily contaminated*
Pb	8.12	-2.22	11.51	3<Igeo<4	*Strongly contaminated*
Fe	3.69	0.22	0.49	4<Igeo<5	*Heavily to extremely contaminated*
Cr	1.42	1.52	4.57	5< Igeo≥6	*Extremely contaminated*

I_{geo} Class: Adopted from Mueller (1969).

3.4 *HMs Accumulated in R. communis Organs*

The mean concentration results of accumulated HMs in various parts of *R. communis* were presented in Table 6-9. In soil collected from site A, the highest accumulation of Zn, Cu and Fe was recorded in leaves 60.02±0.01, 81.24±0.71 and 126.62±0.01 respectively. While Cd, Ni, As, Pb and Cr were recorded highest in the root. Co was not detected in all the organs of *R. communis* grown on soil site A, as shown in Table 6. On soil site B similar pattern of HMs accumulation in leaves was also observed, highest accumulation of Zn, Cu, and Fe 2.35±0.29, 6.78±0.72, and 8.85±0.29 respectively, while Ni was not detected in both the organs and Cr was recorded highest in the root see Table 7. With exception of Cr all the HMs are highly accumulated in leaves then other parts of the plants, Cd was not detected in the leaves of *R. communis* grown on soil sample C as showed in Table 8. While in Table 9, the highest concentration of Zn, Cu, and Fe are showed in leaves Cr, As, and Ni are highly concentrated in the roots of *R. communis* while Ni was not detected in the stem of *R. communis* grown on soil site D. The result showed the variations of HMs uptake and accumulation in different parts of *R. communis* grown across soil samples, which has to do with the level of concentration of HMs from various sites. The analysis reported the accumulations of Cd, Co, Ni, and Pb in various parts of *R. communis* cultivated from a scraps metals dumpsite (Yashim et al., 2016).

Table 6: Mean Values of HMs Concentration (mg/kg) accumulated in Different Parts of Experimental Plant organs grown on Soil Sample Site A.

Heavy Metals	**Plant Organs**			**Total**
	Roots	**Stem**	**Leaves**	
Zn	$28.60±0.02^{b}$	$8.56±0.01^{a}$	$60.02±0.01^{c}$	**$97.18±0.04^{d}$**
Cd	$0.04±0.01^{a}$	$0.01±0.00^{a}$	$0.01±0.00^{a}$	**$0.06±0.01^{a}$**
Cu	$48.07±0.02^{b}$	$38.02±0.01^{a}$	$81.24±0.71^{c}$	**$167.33±0.74^{d}$**
Ni	$0.04±0.01^{a}$	ND	ND	**$0.04±0.01^{a}$**
As	$0.07±0.01^{a}$	$0.04±0.01^{a}$	$0.06±0.01^{a}$	**$0.17±0.03^{a}$**
Co	ND	ND	ND	ND
Pb	$1.86±0.01^{a}$	$1.76±0.01^{a}$	$1.46±0.01^{a}$	**$4.08±0.03^{b}$**
Fe	$86.40±0.02^{a}$	$94.81±0.01^{b}$	$126.62±0.01^{c}$	**$307.83±0.04^{d}$**
Cr	$0.18±0.02^{a}$	$0.13±0.01^{a}$	$0.06±0.01^{a}$	**$0.37±0.04^{a}$**

All values along row with different superscript are significantly different from each other using one way ANOVA and pairs using Tukey's multiple comparisons (P<0.05).

HMs: Heavy Metals; ND: Not Detected.

Table 7: Mean Values of HMs Concentration (mg/kg) accumulated in Different Parts of Experimental Plant organs grown on Soil Sample Site B.

Heavy Metals	**Plant Organs**			**Total**
	Roots	**Stem**	**Leaves**	
Zn	$1.09±0.02^{a}$	$1.75±0.03^{a}$	$2.35±0.29^{b}$	**$5.19±0.34^{c}$**
Cu	$6.07±0.01^{a}$	$4.04±0.03^{b}$	$6.78±0.72^{b}$	**$16.89±0.76^{c}$**
Ni	ND	ND	ND	ND
As	$0.11±0.01^{a}$	$0.11±0.00^{a}$	$0.06±0.05^{a}$	**$0.28±0.06^{a}$**
Pb	$0.02±0.01^{a}$	$0.03±0.00^{a}$	$0.01±0.00^{a}$	**$0.06±0.01^{a}$**
Cr	$0.18±0.02^{a}$	$0.15±0.02^{a}$	$0.17±0.01^{a}$	**$0.50±0.05^{a}$**
Fe	$6.09±0.02^{a}$	$12.65±0.03^{c}$	$8.85±0.29^{b}$	**$27.59±0.34^{d}$**

All values along row with different superscript are significantly different from each other using one way ANOVA; and pairs using Tukey's multiple comparisons (P<0.05).

HMs: Heavy Metals; **ND**: Not Detected.

Table 8: Mean Values of HMs Concentration (mg/kg) accumulated in Different Parts of Experimental Plant organs grown on Soil Sample Site C.				
Heavy Metals	**Plant Organs**			**Total**
	Roots	**Stem**	**Leaves**	
Zn	13.25±1.03^{b}	11.45±0.48^{a}	20.67±0.01^{c}	**45.37±1.52^{d}**
Cd	0.06±0.01^{a}	0.03±0.01^{a}	ND	**0.09±0.02^{a}**
Cu	5.04±0.03^{a}	5.88±0.01^{a}	8.55±0.68^{b}	**19.47±0.72^{c}**
As	0.05±0.01^{a}	0.04±0.02^{a}	0.07±0.01^{a}	**0.16±0.04^{a}**
Pb	11.09±0.23^{a}	10.40±1.07^{a}	16.84±1.65^{b}	**38.33±2.95^{c}**
Cr	2.13±0.01^{a}	1.63±0.01^{a}	0.69±0.08^{a}	**4.59±0.10^{b}**
Fe	7.24±0.02^{a}	10.86±0.03^{b}	15.51±0.29^{c}	**33.25±0.34^{d}**

All values along row with different superscript are significantly different from each other using one way ANOVA and pairs using Tukey's multiple comparisons (P<0.05).

HMs: Heavy Metals **ND**: Not Detected.

Table 9: Mean Values of HMs Concentration (mg/kg) accumulated in Different Parts of Experimental Plant organs grown on Soil Sample Site D.					
		Plant Organs			
Heavy Metals	**Plants Species**	**Roots**	**Stem**	**Leaves**	**Total**
Zn	*R. communis*	1.16±0.08^{a}	1.62±0.05^{a}	2.85±0.53^{b}	**5.63±0.66^{c}**
Cu	*R. communis*	0.86±0.03^{a}	0.67±0.04^{a}	1.62±0.02^{a}	**3.15±0.09^{b}**
Ni	*R. communis*	0.02±0.00^{a}	ND	0.01±0.00^{a}	**0.03±0.00^{a}**
As	*R. communis*	0.12±0.05^{a}	0.08±0.03^{a}	0.11±0.05^{a}	**0.31±0.13^{a}**
Fe	*R. communis*	4.08±0.02^{a}	4.26±0.03^{a}	6.15±0.29^{b}	**14.49±0.34^{c}**
Cr	*R. communis*	0.08±0.02^{a}	0.03±0.01^{a}	0.02±0.00^{a}	**0.13±0.01^{a}**

All values along row with different superscript are significantly different from each other using one way ANOVA and pairs using Tukey's multiple comparisons (P<0.05). **HMs**: Heavy Metals; **ND**: Not Detected.

Figure 2 and 3, represent the chlorophyll contents and total dried biomass of *R. communis* grown across the studied soils respectively, for the chlorophyll contents the result was presented in the following increasing order 15 > 50.03 > 50.58 >52.58 μg/mm for the plants in soil A, B, D and C respectively. Plant grown in soil sample C proved the highest chlorophyll contents which have linked with the nutritional composition and proper growth of the plants in the soil. Proper growth and developments of plants determine the weight of its biomass, Figure 3 present the total dried plant biomass of *R. communis* grown across the studied soil. The highest was recorded on plants grown on soil collected from site C, 252.2 g while plants grown on soil sample A, showed least 46.82 g.

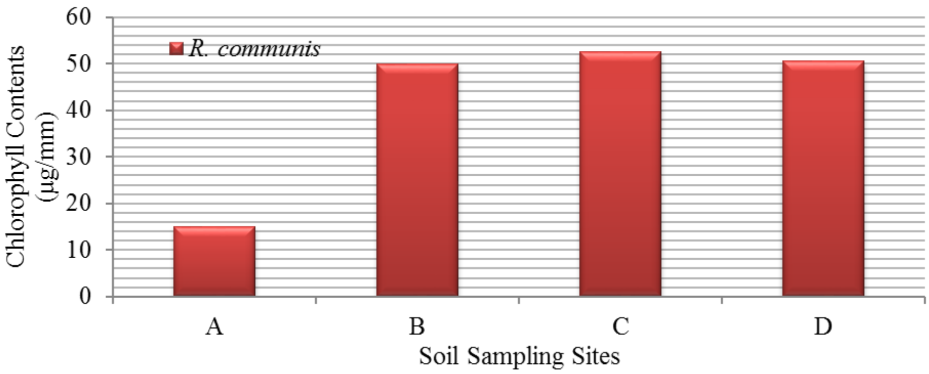


Figure 2: Mean Values of Chlorophyll Content (μg/mm) in *R. communis* Species across Soil Samples.

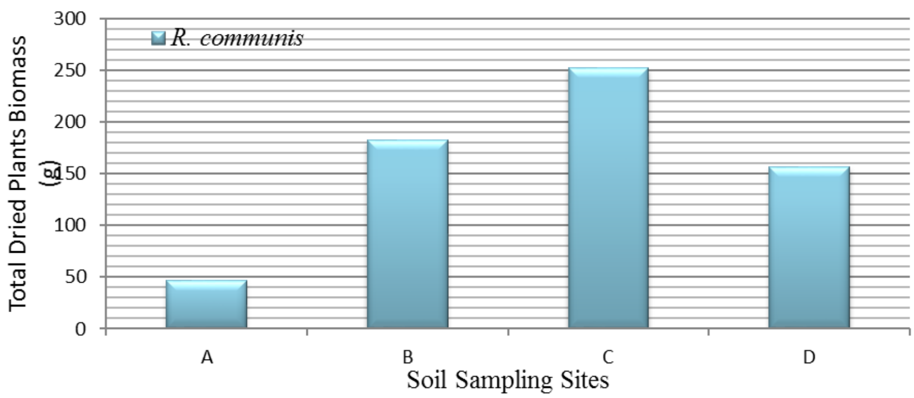


Figure 3: Total plants dried biomass (g) of *R. communis* grown across the study soil sites.

3.5 Bioaccumulation Factor and Translocation Factor

The bioaccumulation Factor and translocation factor R. communis was presented in Figure 4 and 5. The two biological indices indicate the efficiency of plants in up taking the HMs from soil and accumulating them into tissues. Bioaccumulation is a ratio of the concentration of HMs in shoots to that in roots. Translocation factor (TF) shows the efficiency of the plants in translocation the accumulated HMs from roots to shoots. "It is a ratio of the concentration of the HMs in shoots to that in roots" (Naz et al., 2022). *R. communis* showed low values of BAF, with the highest showed on soil site A on Pb, Fe, and Cd. With regard to TF the highest was observed in Fe on both soil sample A, B, and C while Zn proved highest TF in soil sample D see Figure 5. Plants with both BAF and TF greater than one have the potential to be used for phytoextraction (Nouri et al., 2011).

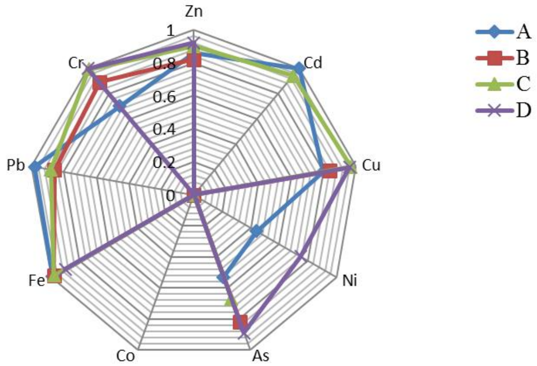
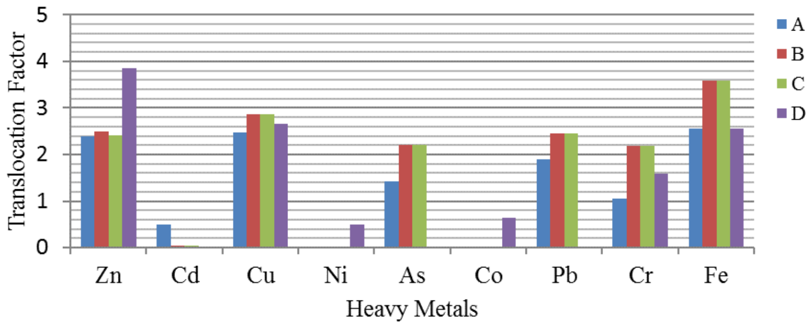


Figure 4: Bioaccumulation Factor (BAF) of studied HMs in *R. communis* species Grown across Soil samples using Radar Circle.



3.6 Soil Samples

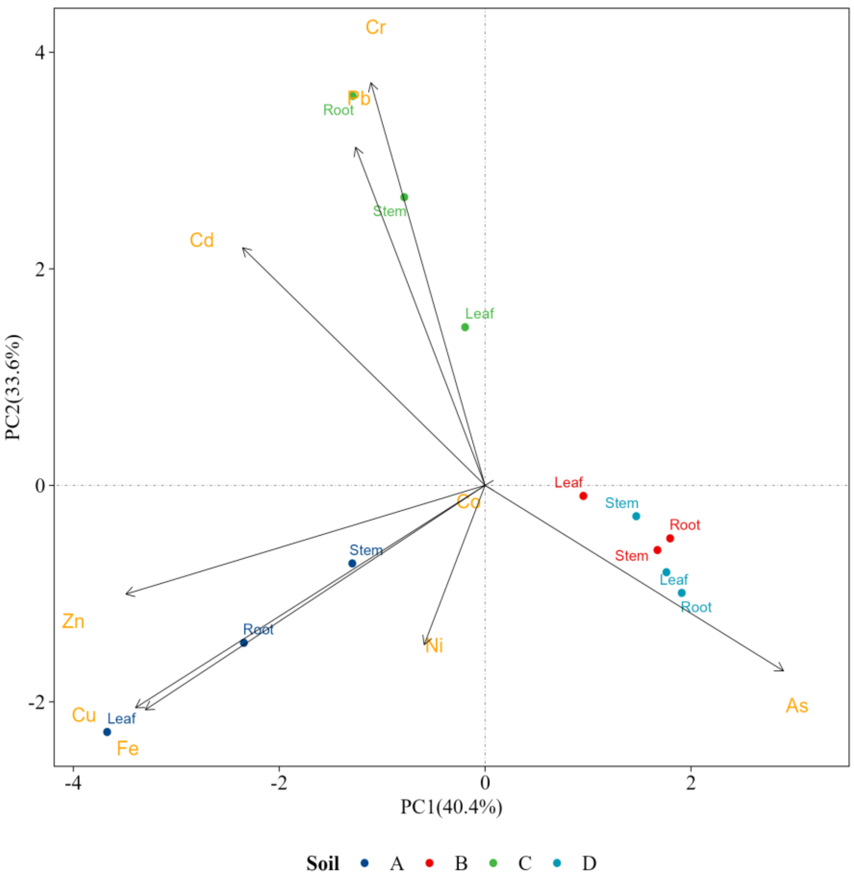


Figure 6: Reduction of multidimensional variables using Principal Component Analysis (PCA) biplot of Heavy Metals in *R. communis* organs grown across soil samples.

The principal component analysis (PCA) of the data obtained from the experiment involving *R. communis* found in all of the soil samples (A-D) revealed that Cr, As, Cu, and Fe were the biggest contributors to the variance of the first and second primary dimensions (components). Also, the first and second principal components accounted for more than 73% of the total variation. In the second dimension, the metal content of the species *R. communis* in all parts of the plant in soil sample C had a positive correlation with high levels of Pb and Cr. The metal content of all plant parts of the species in soil sample A correlated positively with high levels of Zn, Fe, and Cu in the first dimension. All parts of *R. communis* in locations B and D had a positive correlation with As in the first dimension, but it is negatively correlated with high levels of all heavy metals except As in the first and second dimensions in locations B and D.

4. Conclusion

Contamination of soil with HMs in urban Kano is of great concern due its potential impact on human and animal health. Sustainable and effective technologies are needed to protect the autochthonous biological lives. Hence phytoextraction is a highly promising technology whereby selected native plant species are used for the removal of HMs contaminant from the environment without the need for soil excavation or any other conventional treatments. The research work studied soils proved variation in physicochemical and concentrations of different HMs contaminants. The Igeo index defines the degree of individual HMs contaminants reaching from moderately - heavily - strongly - extremely contaminated. Concentrations of HMs in various parts of *R. communis*, which evaluated using BAF and TF, define the capacity of the plant for phytoextraction of HMs. The seedling raised on studied soil site C Proved high level of Chlorophyll content and high weight of dried biomass. Based on the toxicological point of view *R. communis* should not be used for food or medicine when grown in a contaminated environment. Screening for more endemic plants species are needed with potentials of phytoextraction for effective and inexpensive method for the heavy metals remediation

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