Accumulation and translocation of toxic elements from contaminated soils to plants, Nigeria: Implications for metal potential hazards to humans.

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Abstract

Soil pollution by heavy metals, their health effect on humans via the food chain are pressing issues of the environment caused by human activities. Plant's accumulation and translocation potentials were investigated to determine their suitability for phytoremedial purposes, and the potential of the edibles/vegetables to cause harm to humans when consumed. Plant and soil samples were collected, prepared, digested in acid mixture of H_2O_2 and HNO_3 for plants and $Li_2B_4O_7$ - $LiBO_2$ for soils and were analysed. These analyses were carried out to determine the concentration of these metals in soil, their accumulation and translocation in plant parts. The data acquired were evaluated using bioconcentration (BCF), translocation factor (TF), bioaccumulation coefficient (BAC), metal uptake efficiency (ME%) and hierarchical cluster analysis to determine hyperaccumulators, phytoextractors, phytostabilizers, metal source plants and metals that could be toxic to humans through intake of roots, grains/seeds, fruits and leaves as vegetables. ANOVA analysis revealed that the data were significant at $p < 0.05$. Correlation and cluster analyses were employed to understand the relationships between variables determined. From this study, *Colocasia asculenta* (CA), *Corchorus aestuans* (COA) and *Laportea aestuans* (LA) were hyperaccumulators of Co at various points. Arsenic has phytostabilizer plants from the study. COA and LA were phytostabilizers of Cd while Sida acuta was the only phytoextractor. The concentration of metals in the vegetables/edibles in roots, shoots and leaves were above permissible levels for Cr, Co and Cd. The metal uptake efficacy (%) were in this order Co (28.99 to 89.08) > Cd (21.74 to 50.96) > Cr (22.90 to 49.06) > and As (9.65 to 39.19).

1.0 Introduction

Trace (some toxic) metals occur naturally in all soils in low concentrations. However, the level of these metals have greatly increased due to human activities such as wastes generation (domestic and municipal), industries such as textile, battery and auto workshops, mining activities, agriculture etc (Lago-Vila et al., 2015; Mganga, 2014).Under elevated conditions in the environment, these toxic metals pose enormous threat not only to plants but also to humans via the food chain. This is because the metals are persistent in the environment, non-biodegradable and are easily transported from plants to animals and humans. While metals such as Co, Ni, Zn, Cu are essential nutrients to plants, others such as Hg, Cd, Cr have no known biological functions (Opaluwa et al, 2012; Mganga, 2014).

Discharged chemical and effluent wastes affect the environment by mobilization of hazardous constituents which contaminate soil, water and vegetation (Ahmed et al, 2010). Metal contaminations arising from industrial wastes, discharge and leachates into the soil are threats to resources, human health and other living organisms. Soil pollution is of global concern with increasing severity due to urban growth, industrialization and changing lifestyles. These soil pollution problems are visibly with us today, especially in developing countries like Nigeria. Land degradation is taking place today as a result of soil erosion, deforestation and soil pollution (Lago-vila et al, 2015).

The use of plants is an economically and ecologically friendly alternative to conventional techniques of decontamination/stabilization of toxic metal polluted soil sites (Suman et al., 2018). Plants have inherent ability to absorb toxic substances, including trace elements along with nutrient materials from the soil. The non-essential, toxic metals are known to cause plant toxicity and occur in various soluble and particulate materials which also affect their bioavailability and mobility. These toxic metals have the tendency to accumulate in soft tissues of living organisms (Rangnekar et al, 2013). Remediation of metal polluted soil is still a global challenge to both administrators and researchers due to the non-degradability of these metals in the environment. Phytoremediation, which is a harmless procedure that respect the environment and a biological technology that uses plants to remove contaminants from soil, has been on the search light due to its cost effectiveness and environmental harmonies (Ahmed et al, 2010; Lago-Vila et al, 2015). Metal pollution causes major environmental and human health problems and therefore needs our immediate attention for effective and affordable techniques of remediation from polluted soil. Phytoremediation uses plants to clean-up trace element contaminants and it is an environmentally friendly method. The uptake of these trace elements and accumulation varies from plant to plant and from species to species within a genus (Ahmed et al, 2010). This method uses plants to remove toxic elements from the contaminated soil through metal accumulation in harvestable shoot part or to immobilize metals in soil by root uptake, adsorption to root surfaces or precipitation in the rhizosphere. Reclaiming contaminated soil through plants and indeed native plants is most desirable and advantageous because of their survival rate, growth and reproduction under already polluted soil (Nazir et al; 2011).

Hyperaccumulator plants have the capacity to absorb and translocate metals from their roots to the shoots and equally have high tolerance for these metals without phytotoxicity symptoms (Suman et al, 2018). Hyperaccumulators require enormous energy for the mechanisms required to adapt to high metal concentrations in their tissues (Lago-Vila etal, 2015). Plants with potential for phytoextraction are capable of growing in soils with high degree of metals because of their large radicular system, high level of biomass production and are able to accumulate high concentration of metals in shoot (Lago-Vila et al, 2015). Phytoextraction means metal content reduction in soil, translocation to above-ground tissues and this technique is used to reduce damage caused to the soil. In cases where phytoextraction is not feasible, phytostabilization can be adopted. This means immobilizing the metals in the soil, stabilizing/detoxifying contaminated soils and thereby reducing the flow or distribution of contaminants into the environment (Suman et al., 2018). In phytostabilization method, the plants do not accumulate metals in their shoots. This also minimizes the risk in terms of food safety for vegetables and roots, seed/grains, fruits that are edible. Hyperaccumulator plants can take up concentrations of > 10,000.00mg/kg of Zn or Mn; 1,000.00mg/kg and above of As, Co, Cr, Cu, Ni, Pb, Sb, Se and Ti or 100mg/kg of Cd (Verbruggen et al, 2009).According to Lorestani et al., (2011), hyperaccumulator plants must also have TF or EF > 1 in addition to above criteria.

This research is hinged on the hypotheses that (i) the native plants are more adapted to the soil and pollutants (ii) these plants can accumulate and translocate metals from the polluted soil to the aboveground tissues (iii) some of these plants have the potential for removal and stabilization of these metal pollutants (iv) because of effective and efficient translocation to shoots and leaves (v) some of these plants if consumed by humans and animals could pose health hazards.

The objectives of this study are therefore, to (i) identify and determine metal concentrations in native plants and edibles/vegetables in study soil (ii) compare metal concentrations in soils and plants tissues (iii) determine the metal accumulation and translocation factors from soil to the aerial biomass of the plants (iv) evaluate their potentials for hyperaccumulation, phytoextraction and phytostabilization, (v) highlight plants with harmful effects if consumed in excess by humans.

Phytoremediation is therefore, needed to identify plants which remove metals from soil in large amount. Over time, land is made available for other socio-economic uses once the polluted level has been reduced to minimal and acceptable levels.

2.0 Materials And Methods

The area under study is a metropolitan City. The sources of wastes in the area include municipal and domestic wastes, hospital wastes, auto body and battery repair workshop wastes, textile and dying activities, agriculture and agricultural produce etc. Waste sites were surveyed and located for sample collection. The study area is between longitude 7°10'0"E and 7°12'0"E and latitude 7 °28'0"N and 7 °31'0"N.

2.1 Plant sample collection

Ten plant species were collected and the researchers ensured that different plant samples of each species have same physiology, identical size and appearance (Ng et al; 2018).Plant samples collected were representative of available plant species. The plant species collected from the contaminated sites were mostly edibles and vegetables. Some plants were sampled twice from two different sites while others were collected three and four times from different sites, respectively. Plant samples were collected carefully using a clean plastic hand trowel to dig the soil and were gently removed to ensure no part was lost (Rangnekar et al, 2013). The plant samples were washed thoroughly first with tap water and later with distilled water to remove adherent soil and contaminants. The plants were sectioned into roots, shoots and leaves and stored temporarily in self-sealing and well- labeled plastic bags. In the laboratory, all plant materials were oven-dried for 72 hours at 70°C to obtain a constant dry matter yield. The plants were crushed and homogenized in a mortar using

Fig i Sample location map of study area (after Ameh, et al., 2019)

pestle and were stored in sealed polyethylene bags ready for analysis (Yoon et al, 2006; Ahmed et al, 2010).

2.2 Soil sample collection

Soil samples were collected from the rhizosphere (0cm-20cm depths) at each previously sampled plant points. The samples were screened for pebbles, dirt, sticks etc. Equal subsamples of the soil were mixed or homogenized thoroughly and a composite sample taken (Baker and Brooks, 1989). The samples were oven-dried at 105°C for complete moisture removal and passed through 2mm sieve using a magnetic sieve shaker to collect the fine fraction for further analysis (Yoon et al, 2006).

2.3 Metal extraction from plants and soils

2.0grams of the powdered plant tissues were digested with H_2O_2 and HNO_3 in a microwave oven (Bell et al, 2000; Lago-Vila et al, 2014). This was continued till a minimal clear layer of acid was obtained. After cooling, the content was filtered through Whatman filter paper number 41. Final volume of 25ml was made in a clean volumetric flask using 0.25% of HNO_3 (Allen, 1989; Marin etal; 1993).

Total metal content in soil was determined by fusion method with $Li_2B_4O_7$ - $LiBO_2$. 1.0g of sample with 3.5g of $Li_2B_4O_7LiBO_2$ flux (50/50 w/w) and 1.0g of LiI in a platinum crucible (Hill, 2008). The mixture, a heated propane-perl induced machine was fused for 10-15minutes. The content of the crucible was poured into Teflon precipitate flask containing 100L of HNO_3 and magnetically shaken to dissolve the fused mixture. The mixture was transferred to a 500ml flask and made up to volume with 5% HCL. The filtrate of both plants and soil were analyzed for metal content using EDX3600B X-ray Fluorescence Spectrometer (Skyray Instruments Inc., USA) at Nanotechnology and Advanced Materials, National Agency for Science and Engineering Infrastructure (World Bank Assisted Project) Centre, Akure, Nigeria.

The analytical range of elements by EDX3600B metal analyser is between (Mg, Z = 12) and Uranium (U, Z = 92) with high resolution and accuracy of 0.05% and detection limit of 0.01ppm.The pure silver sample was used to calibrate the instrument before use (Aksoy et al. 2014).

Each sample of plants and soil were digested in replicates for consistency of results. Blanks were run in replicates to check the precision of the method with each set of sample (Rangnekar et al, 2013). The standard reference materials for Cr, Cd, As and Co (Merck-E grade, Germany) were used for calibration and quality assurance. The analytical data, quality of metals were ensured through replicate analysis and comparing with standard reference materials. The obtained results were within ± 2.05–2.85% of certified values. The mean recovery of 98–99.95% was achieved for different metals.

2.4 Data evaluation methods

(i) Bioconcentration faction (BCF): This is the metal uptake capacity from soil to plant The BCF was calculated as metal concentration in the plant root, shoot and leaves to metal concentration in soil (Ghosh et al; 2005; Mganga et al; 2014; Lago-Vila et al; 2015).

(ii) Translocation factor (TF): Translocation factor indicates preferential partitioning of metals to shoot and Plants with higher translocation factor have greater accumulation The TF was calculated as the ratio of metal concentrations in plant's shoot and leaves to concentration of metal in corresponding

root (Gupta et al, 2008; Singh et al, 2010; Brooks and Baker, 1989; Yanhong et al, 2013). Translocation of metals from roots to other plant parts is useful in monitoring metal contamination and selection of metal accumulator or tolerance species (Singh et al, 2010). This index also shows which plant that can harm humans when the edible parts are consumed.

(iii) Bioaccumulation Coefficient (BAC): is dependent on the soluble fraction of metals in soil (Ahmed et al, 2010). The BAC is calculated as the ratio of metal concentration above ground parts of plants (shoot & to metal concentration in soil on dry weight (Iya et al, 2018; Anwar et al, 2010).

(iv) Enrichment factor (EF1): is calculated as the ratio of plants leaf concentration to soil concentration (Branquinho et al., 2006)

(v) Metal uptake efficacy (%): is the ratio of metal accumulated in shoot/ total metal concentration removed from the soil media ×100 (Ng et al., 2018)

(vi) ANOVA and Hierarchical cluster analyses: The ANOVA, correlation and hierarchical analyses were performed using SPPS version 20. All the data generated by ANOVA in this study were significant at $p < 0.05$. The correlation matrix based on Pearson's correlation coefficient was used to display relationships between variables. Only variables between + 1 and − 1 were used (Yang et al., 2009).

Hierarchical cluster analysis was used to group similar variables. Evaluations of similarities were based on the average linkage between groups. Cluster analysis was performed on the normalized data sets by means of the Ward's method, using squared Euclidean distances as a measure of similarity (Laluraj et al., 2005). Objects were grouped such that similar objects fall into the same class. Hierarchical clustering joins the most similar observations and successively the next most similar observations (Lokhande et al., 2008). The levels of similarity at which observations were merged were used to construct the dendogram. A short distance indicates that the two objects were similar, whereas a long distance shows dissimilarity. Hierarchical cluster using dendograms identifies relatively homogeneous groups of variables with similar properties and combines clusters until only one is left (Praveena et al., 2007).

3.0 Results And Discussions

Chromium (Cr)

Cr concentrations in soils from the waste dumps in the study area ranged from 19.00 in site 4 to 118.00mg/kg in site 7 with standard error of 5.32 and standard deviation of 27.66 (Tables 1a and b). According to Rudnick and Gao (2003), the upper continental crust limit of Cr in soil is 92.00mg/kg; 2.00mg/kg (Vinogradov, 1954) and 42.00mg/kg by Kabata- Pendias, 2001 (Table 1b). The average concentration of Cr in soils from study area were higher than the uncontaminated references. The elevated value of Cr observed may be due to pollution from the dumps. In a similar study, 1366 ± 49mg/kg to 2689 ± 82mg/kg of Cr were recorded in soil (Lago-Vila et al., 2015). The accumulation content of Cr in roots varied from 2.00mg/kg in *Amaranthus hybridus* in site 3 to 120.00mg/kg in *Laportea aestuans* in site 7. The standard deviation and error were 26.70 and 5.14 respectively (Table 1b and Fig. 2a). Compared to the soil concentrations of Cr in study area, the level of Cr in roots were higher in three locations. On the average, Cr concentrations in soil were all higher than in roots (Table 1a and Fig. 2a). In another study, 19.63 ± 1.79mg/kg and 29.49 ± 3.40mg/kg were accumulated in roots of *Festuca rubra L*. and *Juncus sp.L* respectively (Lago-Vila et al, 2015).

Table ia Concentration of Cr (mg/kg) in soils and plant tissues

*Short code for plants name

Table ib Summary statistics of Cr in soil and plant tissues

Variable	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil	19.00	118.00	51.38	5.32	27.66
Root	2.00	120.00	32.00	5.14	26.70
Shoot	1.00	102.00	29.26	6.13	31.86
Leaf	.00	70.00	14.67	3.15	16.38
BCF	.07	1.18	.69	.06	.29
TF	.08	2.50	.91	.12	.62
BAC	.00	1.89	.48	.08	.43
TFI	.00	1.33	.48	.06	.35
EFI	.00	.59	.26	.036	.19

Table ic Uncontaminated soil and vegetable standard values

Element mg/kg(soil)	Rudnick and Gao, 2003	Vinogradov, 1954	Vinogradov, 1954	Kabata-Pendias, 2001	Bradford et al., 1996	Papadopoulos et al., 2015	Element mg/kg (vegetable)	WHO, 1996	WHO/FAO, 1993	Podlesakova et al., 2002
Cr	92.00	2.00	80.00	42.00	-	64.00	Cr	1.30	-	-
Co	17.00	8.00	10.00	7.00	14.90	40.00	Co	0.02	-	6.00
As	05.00	05.00	05.00	05.00	0.80	-	As	0.20	-	2.00
Cd	0.10	-	-	-	0.36	1.400	Cd	0.02	1.00	1.10

Table id Sampled plants and their edible parts

Scientific name	Edible part
Amaranthus hybridus	Grains as food crop and leaves as vegetable
Amaranthus viridis	Seed and leaves as vegetable
Abelmoschus esculentus	Green seed pod
Cucurbita maxima	Seed, fruit and leaves as vegetable
Colocasia asculenta	Corms, roots (coco yam) and leaves as vegetable
Corchorus aestuans	Leaves as vegetable
Laportea aestuans	Leaves as vegetable
Physalis angulata	Fruits, the leaves as vegetable
Sida acuta	Not edible but medicinal
Zea mays	Grains/seeds
*ONLY *Sida acuta* is NOT edible but medicinal in the region	

According to Iya et al, (2018), the highest accumulation of Cr in the root of *A. wilkesiana* was 101.23 ± 2.92mg/kg (Table 1a and Fig. 2a). The shoot content of Cr in plants varied from 1.0mg/kg in *Amaranthus viridis*, (site 3) to 102.00mg/kg in *Laportea aestuans* in site 7 (Table 1). Iya et al (2018), observed the highest concentration of 76.93 ± 1.27mg/kg of Cr in *A. wilkesiana* shoot. Singh et al (2010), recorded Cr values in the range of 2.54 to 0.08mg/g in plant's shoot. These were both lower than the range obtained from this study. This is an indication of higher accumulation and translocation of Cr to the shoots by plants in the study area compared to previous works. Hyperaccumulators of Cr must concentrate up to 0.10% of Cr and TF or EF > 1

Fig iia Average concentration (mg/kg) of Cr in soil and plant tissues

(Verbruggen et al, (2009). Mongkhonsin et al, (2011); Reeves and Baker, (2000); Lorestani et al., (2011) and Tappero et al, (2007) to be considered hyperaccumulator of Cr based on, (i) that Cr concentration in shoot be > 50mg/kg (ii) that the concentration of Cr in aerial biomass is 10–500 times greater than in the non-metallophyte (0.2-5mg/kg of Cr), (iii) TF or EF > 1 and (iv) that Cr concentration in the shoot is greater than in the roots. Based on (i, iii and iv) definitions, *Amaranthus viridis* at site 7 (100mg/kg), *Abelmoschus esculentus* site 7 (100mg/kg); *Laportea aestuans* (102.00mg/kg of Cr) and *Sida acuta* (80.00mg/kg of Cr) at site 1 were all hyperaccumulators of Cr. The intake of Cr by the leaves were generally lower compared with the stem and root (Table 1 and Fig. 2a) According to Cirua et al., (2005), Cr is predominantly immobilized in the roots with much less Cr in leaves. The Cr concentration ranged from 70.00mg/kg in *Abelmoschus esculentus*, (site 7) to 1.00mg/kg (sites 3 and 1) in *Amaranthus hybridus* and *Cucurbita maxima* at site 2 (Table 1b). Mellem et al (2012) recorded Cr accumulation of 17.0 ± 1 to 118.0 ± 1 in *A. dubius* leaves from a similar study. The WHO, 1996 permissible limit of Cr in leaves or vegetables is 1.30mg/kg (Table 1c). This suggests that the edibles/vegetables among sampled plants may have excess of Cr (Table 1c and 1d). This may not be safe for human intake as the leaf concentrations among plants were < 1.30mg/kg in only three locations. Cr in the body may result in acute kidney failure, long term risk for lung cancer, contact dermatitis etc (Mediolla et al., 2008).

The BCF, TF and BAC for shoots and leaves

The BCF were all less than 1 for Cr except at sites 1, 7 and 3 for *Corchorus aestuans, Laportea aestuans* and *Sida acuta* where BCF > 1 were observed (Table 1 and Fig. 2b). This shows that most plant roots were not tolerant to Cr accumulation from the soil. This is in agreement with the finding of Ciura et al., (2005) where they states that translocation of Cr from roots to shoots is extremely limited. The BCF ranged from 0.07 to 1.18 in study area (Fig. 2b). In *R. acetosa*, BCF range of 0.15 to 0.24 was observed while in *U. dioica*, BCF varied from 0.02 to 0.04 (Balabanova et al; 2015). The only phytoextractor of Cr in the area was *Sida acuta* at site 3. Plants with BCF > 1, TF or EF < 1 were suitable for phytostabilization of Cr. Therefore, COE (site 1) and LA were phytostabilizers of Cr. The TF values for Cr were slightly higher in most sampled points than the BCF. Contrary to Cr soil-root accumulation, the plants under study tolerated and accumulated Cr from root to the shoot. This is contrary to Ciura et al (2005), that accumulation in roots were 100-fold higher than shoots. The TF of

Fig iib Average Cr variations in plant tissues

Cr from the study ranged from 0.08 to 2.50. This indicates relative ability to accumulate Cr in above ground tissues. Mellem et al, (2012) observed TF range of 0.5 to 1.1 for Cr. Also Singh et al, (2010), recorded TF value of 0.73 for Cr in a similar study. The BAC, which is the root to leaf translocation and soil to leaf accumulation were mostly < 1 at most points. These suggest relatively lower ability of the plants to translocation and accumulation Cr in leaves of plant species under investigation. The efficacy of Cr uptake ranged from 22.90% in ZM to 49.06% in CA. This value is below the average metal uptake for Cr (Table 1a).

Table ie Correlations among variables

	Soil	Root	Shoot	Leaf	BCF	TF	BAC	TFone	EFone
Soil	1	.594	.717*	.619	− .170	.311	.238	.344	.135
Root	.594	1	.674*	.436	.656*	− .102	.439	− .171	.315
Shoot	**.717***	**.674***	1	.761*	.225	.649*	.810**	.513	.635*
Leaf	.619	.436	**.761***	1	.026	.550	.481	.718*	.777**
BCF	− .170	**.656***	.225	.026	1	− .284	.458	− .411	.389
TF	.311	− .102	**.649***	.550	− .284	1	.698*	.881**	.582
BAC	.238	.439	**.810****	.481	.458	**.698***	1	.437	.737*
TFone	.344	− .171	.513	.718*	− .411	**.881****	.437	1	.647*
EFone	.135	.315	**.635***	**.777****	.389	.582	**.737***	**.647***	1

*. Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level.

At 0.01 level of significant, shoot-BAC (r = .810), leaf-EFone (r = .777) and TF-TFone (r = .881) showed very high relationship. This is a reflection of the fact that between the two variables above, there seems to be no difference between the concentration of metals accumulated and translocated from one variable to the other (Poniedzialek et al., 2010). Given the level of significant at 0.05, soil-shoot (r=-717), root-shoot (r = .674),root-BCF (r = .656), shoot-leaf (r = .761), shoot-TF (r = .649), shoot-EFone (r = .635), leaf-TFone (r = .718), TF-BAC (r = .698), BAC-EFone (r = .737) and TFone-EFone (r = .647) correlations were revealed (Table 1e). The relationship at 0.05 level is strong but at 0.01, it is stronger. It means that between the pair of variables, there exist a good connectivity. That is accumulations and translocations to other plants parts were good (Table 1e).The negative correlation (soil-shoot) indicate accumulation but reduced biomass due to soil contamination and low shoot tolerance to Cr.

Fig iic Cluster analysis of variables

The dendogram consist of two clusters. Cluster one is a union of TF-TFone, shoot-BAC, leaf-EFone and soil alone. Soil shows the greatest dissimilarity to all the variables. This by implication means that the concentrations of metals in soils were not proportional to that in plants part. In the same cluster, TF-TFone, shoot-BAC and leaf-EFone showed decreasing similarities in this order. The pair of variables with the greatest similarity shows that the metal content in the pair were not different in terms of their concentrations and what was translocated. Cluster two is an association of only root-BCF. The highest degree of dissimilarity in this cluster is between root-BCF. This dissimilarity suggests that the metal content of one variable has no relationship with the content of another variable in the same pair (Fig. 2c).

Cobalt (Co).

Co concentrations in soil samples range from 1536.67mg/kg in site 1 to 3240.47mg/kg in site 6 (Table 2a and b). The Co in uncontaminated soil is 7.00mg/kg (Kabata- Pendias, 2001); 14.90mg/kg (Bradford et al, 1996) and 40.00mg/kg (Papadopoulos et al, 2015). The concentrations cited are way below the study area concentration. This could suggest soil pollution from the wastes dumps in the area (Table 2a). The root accumulated the highest concentration of Co (612.00mg/kg) in *Colocasia asculenta* and the least (0.00mg/kg) in AH, AV, AE, CM, LA and PA at various points (Table 2a and b). The shoot on the other hand recorded the highest accumulation of Co (1215.0mg/kg) in *Laportea aestuans* and the least value of 0.00mg/kg in *Amaranthus viridis* at location 7. Over all, the shoot accumulated more Co than any other plant tissue (Table 2b).This shows that Co is readily absorbed by roots and transported to the shoot. Sometimes also, Co can be accumulated higher in shoots even though its concentration in soil is low (Ciura et al, 2005). The highest Co concentration in leaf (152.00mg/kg) was recorded in *Zea mays* while *Amaranthus hybridus* recorded 0.00mg/kg of Co as the least concentration. This is possible because *Zea mays* grow rapidly and have high biomass production (Suman et al, 2018). The permissible value of Co in vegetables is 0.02mg/kg (WHO, 1996) and 6.00mg/kg (Podlesakova et al, 2002). Both limits are lower than the average Co in vegetables from the area. All the values recorded in the leaves were higher than the permissible level except at four locations (Table 1c and 1d). Food safety with respect to Co contents in vegetable intake require attention

Fig iiia Average Co concentration (mg/kg) in soil and plant tissues

even though Co is an essential nutrient for both plants and humans (Table 2c). Co has been implicated for causing cardiomyopathy, polycythemia and cancer (Huu et al, 2010).

Table iia Concentration of Co (mg/kg) in soils and plant tissues.

*Short code for plants name

Table iib Summary statistics of Co in soil and plant tissues

Variable	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil	1536.67	3240.67	2333.32	109.35	568.21
Root	.00	612.00	102.15	30.52	158.60
Shoot	.00	1215.00	291.11	85.86	446.14
Leaf	.00	152.00	27.00	5.75	29.90
BCF	.00	.19	.04	.01	.06
TF	.00	24.47	3.08	1.20	6.24
BAC	.00	.79	.14	.04	.23
TFl	.00	20.00	.99	.73	3.82
EFl	.00	.06	.01	.00	.01

From the study data, *Colocasia asculenta; Corchorus aestuans* (sites 2 &1); *Laportea aestuans* (sites 1and 7) were all hyperaccumulators of Co and are therefore suitable for phytoremediation of Co contaminated soil in the area (Table 2a). The minimum, maximum values of Co in soil and tissues are presented in table 2b with their respective standard deviation and error. In some sites, the plant leaves revealed higher accumulation of Co than in the roots. This may suggest a situation whereby shoot to leave translocation of Co is better than soil to roots accumulation. CA, COA, and AE, CM, LA, PA, SA and ZM (one site each) that accumulated and translocated more Co to above parts are plants that are suitable for phytoremediation. Where this metal is in excess in vegetables/edibles, it can also become toxic to humans. In a similar study, the leaves accumulated more of Co, followed by stem and then the roots. *A. wilkesiana* recorded 2.92 to 87.87mg/kg in leaves; 81.63mg/kg in shoot and 50.19mg/kg in roots (Iya et al, 2018). Also, 5.17 to 8.17mg/kg and 0.92 to 1.10mg/kg were observed in shoots of *Festuca rubra L.* and *Juncus sp.L* respectively. In the roots of *Festuca*, 19.63 to 77.04mg/kg and in *Juncus*, 25.53 to 29.49mg/kg were observed (Lago-Vila et al, 2015).These results are in contrast to the earlier observation by Iya et al, (2018).

The BCF, TF, BAC for both shoots and leaves

The BCF for Co were all < 1 in the study area. This suggests limited accumulation of Co by the roots from the soil. This may suggests that the roots were excluders of Co (Table 2a and b). Interestingly too, the translocation factors for Co were very high in some locations. Translocation factor ranged from 0.23 in *Laportea aestuans* to as high as 24.47 in *Corchorus aestuans* (Tables 2a, 2b and Fig. 3b). The BAC for plants were all < 1. The root to leaf translocations were > 1 (in three sampled plants at three locations). Soils to leaf accumulations were all < 1(Table 2a and Fig. 3b). These observations indicate high translocation but low accumulation in their respective tissues.

Fig iiib Average Co variations in plant tissues

The TFs in the study area were contrast with TFs of < 1 recorded for *Festuca* and *Juncus.* The current result is also in contrast with BCF recorded in roots of *Festuca* and *Juncus* which were 1. The BAC for shoots agrees with the < 1 values obtained for *Juncus sp. L* (Lago-Vila et al, 2015). From this study, no plant is suitable as phytoextractor and phytostabilizer of Co but high values of TFs were recorded in some plant's shoot. Metal uptake for Co is highest among the metals under study. ME for Co ranged from 28.99 to 89.08% (Table 2a).

Table iic Correlations among variables									
Variable	Soil	Root	Shoot	Leaf	BCF	TF	BAC	TFone	EFone
Soil	1	.292	.235	− .152	.163	− .089	− .240	− .086	− .303
Root	.292	1	.729*	.464	.984**	− .158	.041	− .283	.440
Shoot	.235	.729*	1	.123	.694*	.355	.446	− .264	.167
Leaf	− .152	.464	.123	1	.537	− .129	− .081	− .119	.926**
BCF	.163	.984**	.694*	.537	1	− .169	.061	− .316	.539
TF	− .089	− .158	.355	− .129	− .169	1	.112	.496	.051
BAC	− .240	.041	.446	− .081	.061	.112	1	− .132	− .099
TFone	− .086	− .283	− .264	− .119	− .316	.496	− .132	1	− .082
EFone	− .303	.440	.167	.926**	.539	.051	− .099	− .082	1
*. Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level .									

The correlation between root-shoot(r = .729) and shoot-BCF (r = .694) were the only relationship revealed at significant level of 0.05. The two pairs of correlations were strong. This may suggest that the roots accumulated and translocated Co proportionally to the shoot. At 0.01 level, the root-BCF (r = .984), and leaf-EFone (r = .926) revealed very strong correlation. It signifies that the concentrations of metals in each of these variables were not significantly different. Apart from these four pairs, all other variables showed less significant correlations (Table 2c).

Two clusters were extracted. Cluster two is a union between TF-TFone at a distance > 10. This distance means that the two variables have very little in common in terms of Co content. Cluster one showed greater similarities between root-BCF, leaf-EFone and root-shoot. Within the same cluster, BAC and soil recorded the highest dissimilarities within the cluster (Fig. 3c). The more the similarities among variables, the more the equality in metal content of the variables and vice versa.

Fig iiic Cluster analysis of variables.

Arsenic (As)

The As in soil from study area ranged from 6.27 to 44.00mg/kg. According to Kabata-Pendias & Pendias (1992; 2001), the limit for As in unpolluted soil is 05 to 20mg/kg and 5.00mg/kg by Bowen, (1979). The background concentration of major and trace elements in California soils is 0.80mg/kg (Bradford et al, 1996). The range observed from the study area clearly showed elevated levels of As in sampled soils due to waste dumps (Tables 4a &b). The highest content of As in roots (60.00mg/kg) was recorded in *Abelmoschus esculentus* in site 4. The lowest concentration of As (1.00mg/kg) in roots was found in *Colocasia asculenta* (Table 4a, 4b and Fig. 4a). As accumulated in shoot varied from 1.00mg/kg to 52.00mg/kg. In leaves also, As recorded was between 1.00mg/kg to 9.00mg/kg (Fig. 5a). The average of this range in leaves is higher than 0.20mg/kg limit of WHO, (1996) and 2.00mg/kg by Podlesakova et al., (2002) (Table 1c and 1d). As is a known cause of systemic hypertension, anemia, liver necrosis, kidney failure and acute leukemia (Adriana, et al, 2008;Violante et al, 2010). Excess of it in edibles/vegetables may not be safe for consumption (Table 1c and 1d). As accumulation was highest in roots, followed by shoot and lastly leaf (Table 4a and Fig. 4a). In another study, the roots of Rumex

Fig iv a Average concentration (mg/kg) of As in soil and plant tissues

Table iva Concentration of As (mg/kg) in soils and plant tissues.

*Short code for plants name

Table ivb Summary statistics of As in soil and plant tissues

Variable	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil	.00	44.33	17.58	3.12	16.20
Root	1.00	60.00	19.52	3.42	17.75
Shoot	.00	52.00	9.44	2.02	10.51
Leaf	.00	9.00	3.41	.49	2.55
BCF	.00	11.99	1.30	.43	2.23
TF	.00	3.00	.73	.15	.77
BAC	.00	5.24	.74	.22	1.16
TFl	.00	2.25	.48	.12	.64
EFl	.00	1.12	.23	.05	.28

acetosa accumulated < 0.25 to 1.18mg/kg and the shoot < 0.25 to 0.94mg/kg. In the same study, < 0.53 to 0.94mg/kg and < 00.25 to 0.90mg/kg were accumulated in the root and shoot of *Urtica dioica* respectively (Balabanova et al, 2015). These are lower than observed values in the present study. According to Mellem et al, (2012), *A. dubius* accumulated between 7.00-126.00mg/kg, 13.00-201.00mg/kg and 4.00-188.00mg/kg respectively in roots, shoots and leaves. The above values are however, higher than what was obtained from this study (Table 4a and Fig. 4a).

The BCF, TF and BAC for roots, shoots and leaves

The soil to root BCF for *Amaranthus hybridus* (sites 1, 3 &5), *Abelmoschus esculentus, Corchorus aestuans* (site 1), *Laportea aestuans, Physalis angulata* (site 2), *Sida acuta* (site 1 & 3) *and Zea mays* (site 3) were all > 1. The corresponding TFs were < 1 except *Amaranthus hybridus* that is > 1 in site 1 (Table 4a and Fig. 4a). Only *Amaranthus hybridus* (site 1) can serve as both phytoextractor and stabilizer of As. Other plants were only suitable for phytostabilization of As. The TFs < 1 indicates preference of these plants to storing and accumulation of As in their roots. This property observed in most of these plants make the edibles/vegetables suitable for consumption. Also, BCFs > 1 indicate that more As is accumulated in plants than in soil as seen among few plants (Nonglak

Fig ivb Average As variation in plant tissues

et al, 2011; Hosman et al, 2017). The BCF in the study varied from 0.01 to 11.99. The TF from root to shoot ranged from 0.08 to 2.50. The BAC ranged from 0.07 to 5.24. The root to leaf translocation varied from 0.02 to 2.25 (Table 4a and Fig. 4b). While the ability of these plants to accumulate As in root and shoot were significant in AE, COE, LA, PA, SA and ZM, the studied plants also showed good degree of root to leaf translocation in CM and COA. The recorded TFs from the study were lower than 2.4 to 2.8 in *A. dubius*. The BCF observed were higher (on average) than the 1.0 to 5.7 BCF recorded in *A. dubius* (Mellem et al, 2012). The likely hood of harm from consumption of any of the edibles/vegetables due to As is remote (Table 1c and 1d). Metal intake efficiency for As varied from 9.65 to 39.19%. This value is the least among studied metals (Table 4a).

Table ivb Correlations among the variables

Variable	Soil	Root	Shoot	Leaf	BCF	TF	BAC	TFone	EFone
Soil	1	.780**	.249	.472	.096	− .480	− .045	− .488	− .269
Root	**.780****	1	.741*	.246	.642*	− .576	.468	− .676*	.051
Shoot	.249	**.741***	1	− .087	.887**	− .327	.879**	− .532	.438
Leaf	.472	.246	− .087	1	− .295	− .247	− .300	.000	.356
BCF	.096	**.642***	**.887****	− .295	1	− .420	.878**	− .570	.289
TF	− .480	− .576	− .327	− .247	− .420	1	− .274	.914**	− .025
BAC	− .045	.468	**.879****	− .300	**.878****	− .274	1	− .501	.519
TFone	− .488	**− .676***	− .532	.000	− .570	**.914****	− .501	1	− .019
EFone	− .269	.051	.438	.356	.289	− .025	.519	− .019	1

**. Correlation is significant at the 0.01 level. *. Correlation is significant at the 0.05 level.

The soil-root (r = .780), shoot-BCF (r = .887), shoot-BAC (r = .879), BCF-BAC (r = .878) and TF-TFone (r = .914) at 0.01 level have very strong relationships. These relationships show that the pairs of variables does not discriminate in accumulation and translocation to other parts of the plants. That is, nothing

within the pair that hinders metal transportation and have about the same concentrations of accumulated and translocated metals. At $p < 0.05$, root-shoot ($r = .741$), root-BCF ($r = .642$) and root-TFone ($r=-.676$), recorded strong relationships. It also shows proportionality in the content of metal among pairs of variables (Table 4b).

Two clusters were extracted. Cluster one consist of TF-TFone alone. The similarity between the pair was very strong. In cluster two, the strongest similarity was between shoot-BAC. Lesser similarity was recorded between soil-root. Also, between BCF-EFone, and soil-leaf were other degrees of similarities in decreasing strength. The greatest dissimilarity was observed between root-BAC (Fig. 4c). These similarities were also revealed in the correlation (Table 4b)

Fig ivc Cluster analysis of variables

Cadmium (Cd).

The concentrations of Cd recorded in soils from this study were 1.53mg/kg to 16.67mg/kg (Tables 5a and b). According to Rudnick and Gao (2003), Cd limit in uncontaminated soil is 0.10mg/kg. This limit is in contrast and lower than the values obtained from this study (Table 5a). The European Commission, Luxembourg Council directive (1986), limit of Cd in soil is 0.20mg/kg. The range from the study is higher than the European Commission value (Table 5b). Based on other studies such as Papadopoulos et al, (2015); Bradford et al, (1996), the soil contents of Cd were 1.40mg/kg and 0.36mg/kg respectively. The range from this study was also higher than these benchmarks.

Fig va Average Cd concentration (mg/kg) in soil and plant tissues

The accumulated Cd ranged from 1.00mg/kg to 18.00mg/kg in sampled roots. The shoots recorded 1.00mg/kg to 10.00mg/kg of Cd. The leaves on the other hand revealed accumulated range of 1.00mg/kg to 5.00mg/kg. These results showed that more Cd was accumulated in roots than the shoots and leaves (Table 5a and Fig. 5a).This is in agreement with Ciura et al, (2005) finding that Cd is readily absorbed by roots and transported to other parts. However, this study is in contrast to their observation that Cd distribution among plants parts are regular. Balabanova et al, (2015) in their study recorded Cd concentration of 0.05 to 0.09mg/kg and 0.03 to 0.07 respectively in roots and shoots of Rumex acetosa. According to Singh et al (2010), Cd content in roots was 1.48mg/kg and 1.22mg/kg was recorded in shoots. These results are in contrast to the observed values for plant parts under investigation (Table 5a and Fig. 5a). This relatively higher than the unpolluted soil limit in Cd concentration may not be unconnected with the pollution from the dumps.

Table va Concentration of Cd (mg/kg) in soils and plant tissues

*Short code for plants name

Table vb Summary statistic of Cd in soil and plant tissues

Variable	Minimum	Maximum	Mean		Std. Deviation
	Statistic	Statistic	Statistic	Std. Error	Statistic
Soil	1.53	16.67	7.83	1.12	5.83
Root	.00	18.00	5.26	.97	5.02
Shoot	.00	10.00	4.37	.58	3.03
Leaf	.00	6.00	1.93	.30	1.54
BCF	.00	6.00	1.93	.30	1.54
TF	.00	6.00	1.24	.31	1.61
BAC	.00	5.23	1.06	.27	1.38
TFl	.00	2.00	.41	.09	.47
EFl	.00	1.41	.42	.08	.42

The concentration of Cd varied from 1.0mg/kg-5.0mg/kg in leaves. The range of Cd from the study area is higher than 0.02mg/kg WHO (1996) limit; the 1.00mg/kg WHO/FAO (1993) and 1.10mg/kg by Podlesakove et al's (2002) permissible limits in edibles/vegetables (Table 1c and 1d). Eating any of these plants as vegetables/edibles may not be healthy as there are no known mechanisms of ridding the body of Cd. Cadmium has been implicated in kidney disorder, bone disease, heart diseases, bronchitis, lung cancer, cancer emphysema etc (Plumlee and Ziegler, 2005)

The BCF, TF and BAC for roots, shoots and leaves

The BCF for Cd varied from 0.16 in *Amaranthus hybridus* (site 6) to 5.23 in *Laportea aestuans* (site 1). The TF varied from 0.25 in *Physalis angulata* to 6.00 in *Sida acuta* (Table 5b and Fig. 5b). Therefore, *Amaranthus hybridus* (site 1 and 4), *Abelmoschus esculentus* (site 4) and *Laportea aestuans* (site 1) are potential species for phytoextraction of Cd from the soils. The BCF > 1, TF and BAC < 1 have also been used to evaluate phytostabilization of metals

by plants (Sudmoon et al, 2015; Lorestani et al, 2011). From the current study, *Amaranthus viridis* (site 1); *Abelmoschus esculentus* (site 4); *Cucurbita maxima* (site 5); *Corchorus aestuans* (site 6); *Physalis angulata* (site 2); *Sida acuta* (site 4) and *Zea mays* can all serve as phytostabilizers of Cd in soils (Table 5a). The BAC ranged from 0.06 to 5.23. This also implies that these plants have potential for translocation and accumulation of Cd above-ground tissues. This indicates that Cd is easily absorbed by roots and transported to the shoots (Nazir et al, 2011). The roots to leaves TF and soil to leaf accumulation were mostly less than < 1 except in four plants at various locations (Fig. 5b). This implied inefficiency in translocation and accumulation abilities of the leaves compared to the shoots. The leaves recorded reasonable level of Cd. Four plants recorded EF > 1, an indication of enrichment of Cd in the sampled plants. The metal uptake efficacy of Cd ranged from 21.74 to 50.96%. This value is slightly higher than that of Cr. The Co ME% value is the highest (28.99 to 89.08%).

Fig vb Average Cd variation in plant tissues

Table vc Correlations among variables

Variable	Soil	Root	Shoot	Leaf	BCF	TF	BAC	TFone	EFone
Soil	1	.179	− .002	.636*	− .477	− .176	− .799**	− .392	− .578
Root	.179	1	.720*	.482	.104	− .263	− .293	− .832**	.176
Shoot	− .002	**.720***	1	.453	.340	.151	.167	− .541	.397
Leaf	**.636***	.482	.453	1	− .226	− .213	− .560	− .304	.066
BCF	− .477	.104	.340	− .226	1	− .205	.580	− .005	.486
TF	− .176	− .263	.151	− .213	− .205	1	.559	.147	− .120
BAC	**− .799****	− .293	.167	− .560	.580	.559	1	.363	.390
TFone	− .392	**− .832****	− .541	− .304	− .005	.147	.363	1	.237
EFone	− .578	.176	.397	.066	.486	− .120	.390	.237	1

*. Correlation is significant at the 0.05 level. **. Correlation is significant at the 0.01 level.

At the significant level of 0.01, only soil-BAC (r=-.799) and root-TFone (r=-.832) recorded very strong correlations. This negative correlation indicates active Cd accumulation but reduction in biomass due to soil contamination and low plant tolerance to Cd (Poniedzialek et al.,2010) At P < 0.05 level, soil-leaf (r = .636), and root-shoot(r = .720) displayed strong correlations. Pairs of variables with strong correlation reflected unhindered ability to proportionally accumulate and translocate metal from soil-leaf and from root to shoot. This is irrespective of whether Cd is lower in soil (Table 5c).

Fig vic Cluster analysis of the variables

Two clusters were revealed. Cluster one is an association between root-shoot, soil-leaf and soil-root (Fig. 6c). The strongest similarity in the cluster was between root-shoot, followed by soil-leaf and lastly soil-root. In cluster two, BCF-BAC and BCF-EFone were extracted. At a greater distance, TFone and TF were linked to this cluster. From the two clusters, root-shoot, soil-leaf, BCF-BAC and BCF-EFone, the strength of similarities displayed decreases in this order. Root-shoot showed uninhibited mobility of Cd. Soil-leaf also showed a lesser mobility. Followed by these two was BCF-BAC displaying good degree of Cd mobility (Fig. 6c).

Conclusively, this investigation has shown that Co has three hyperaccumulator plants. As has no hyperaccumulator and phytoextractor but phytostabilizers. Cd has only Sida acuta as phytoextractor at site 3 and COA and LA as phytostabilizers. AH (sites 1 and 4), AE, LA (site 1) were all phytoextractors of Cd. Few other plants were also phytostabilizers of Cd. Cr and Co. Edible parts/vegetables from some of the plants may have excess of Cr, Co and Cd. It is strongly recommended that these edibles/ vegetables should not be consumed by humans until further investigation. The metal uptake efficacy (%) were in the order Co (28.99 to 89.08) > Cd (21.74 to 50.96) > Cr (22.90 to 49.06) > and As (9.65 to 39.19).

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2. Conflicts of Interest. Not applicable
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5. Authors Contributions. All Authors contributed one way or the other, from beginning till now.
6. Ethical approval. Not applicable
7. Consent to participate. Not applicable
8. Consent for publication. Not applicable.

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Figures

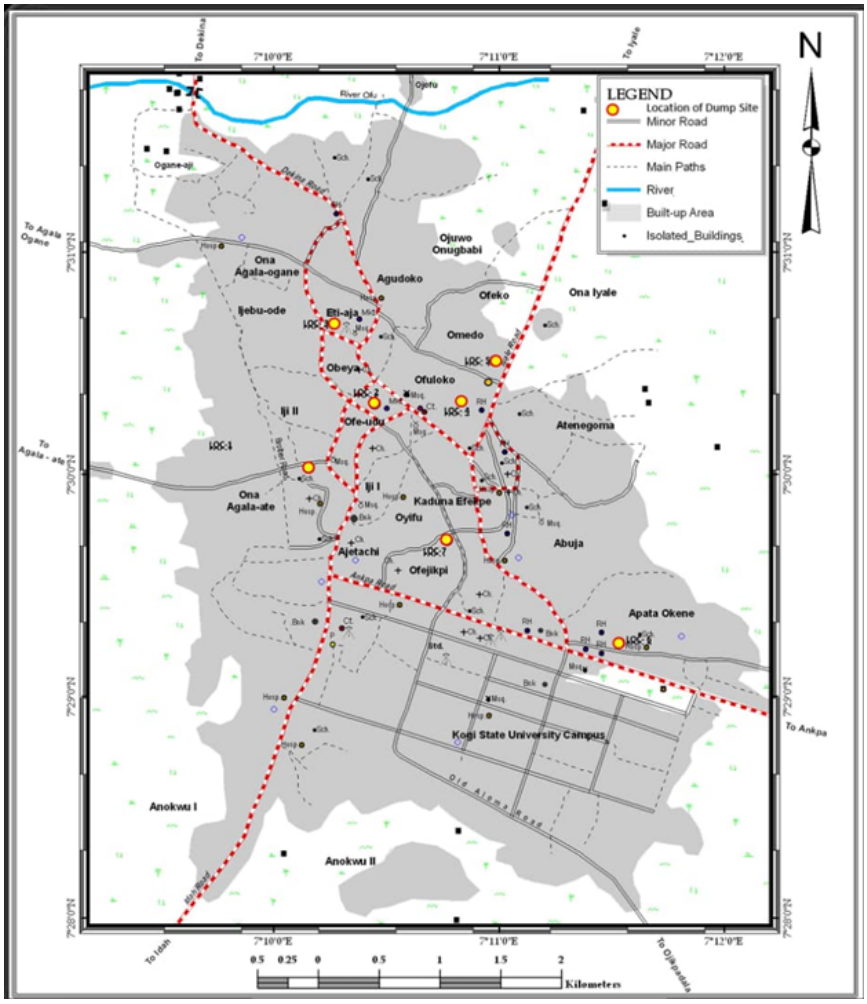

Figure 1

Sample location map of study area (after Ameh, et al., 2019)

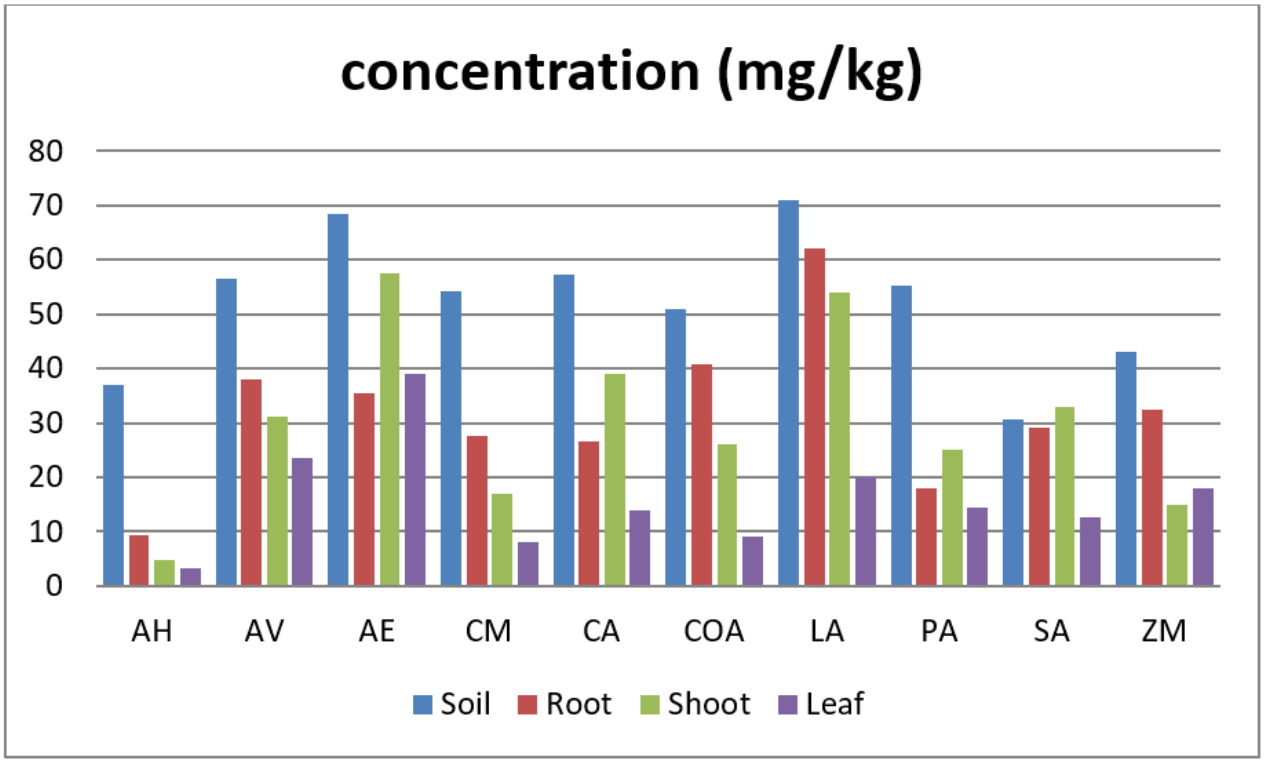

Figure 2

Average concentration (mg/kg) of Cr in soil and plant tissues

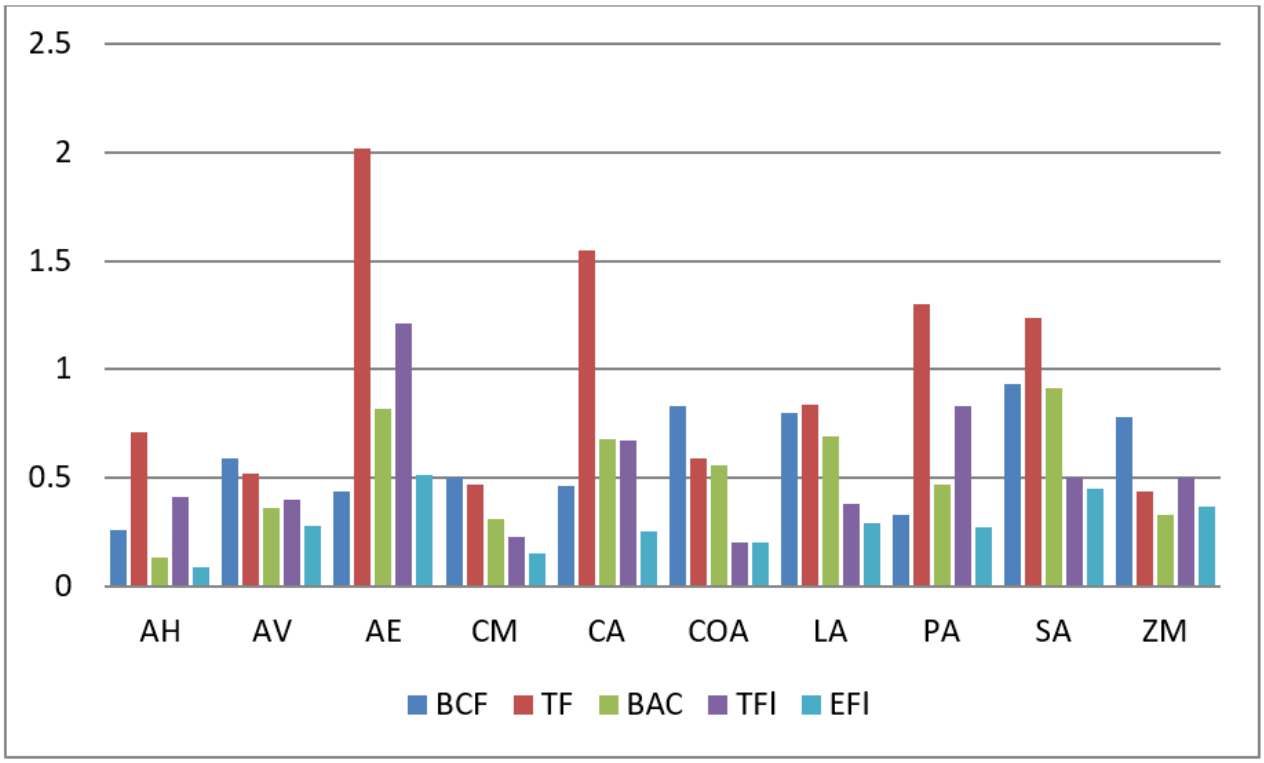

Figure 3

Average Cr variations in plant tissues

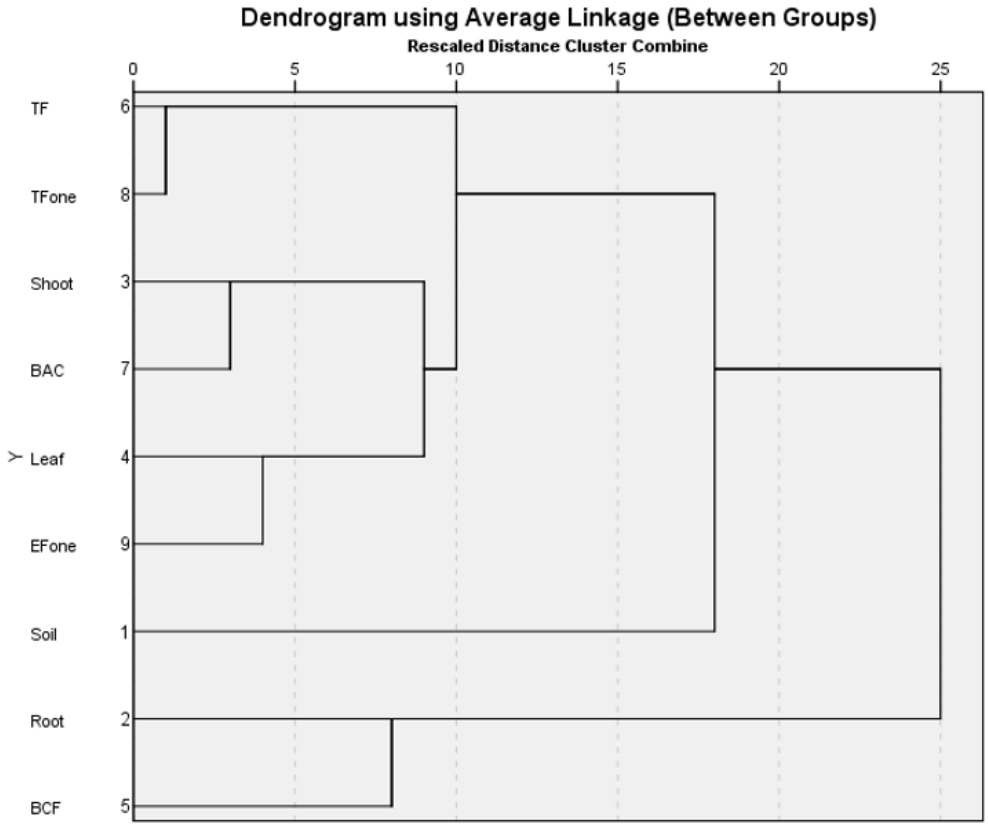

Figure 4

Cluster analysis of variables

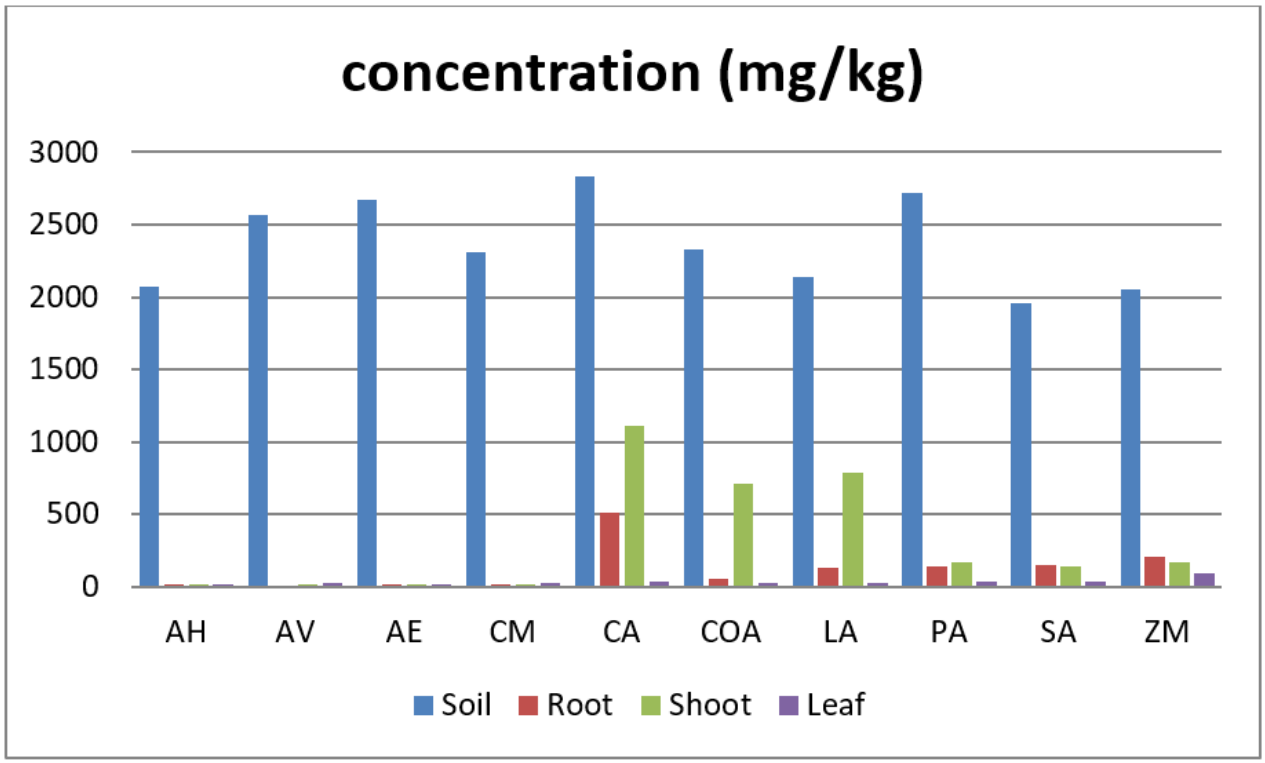

Figure 5

Average Co concentration (mg/kg) in soil and plant tissues

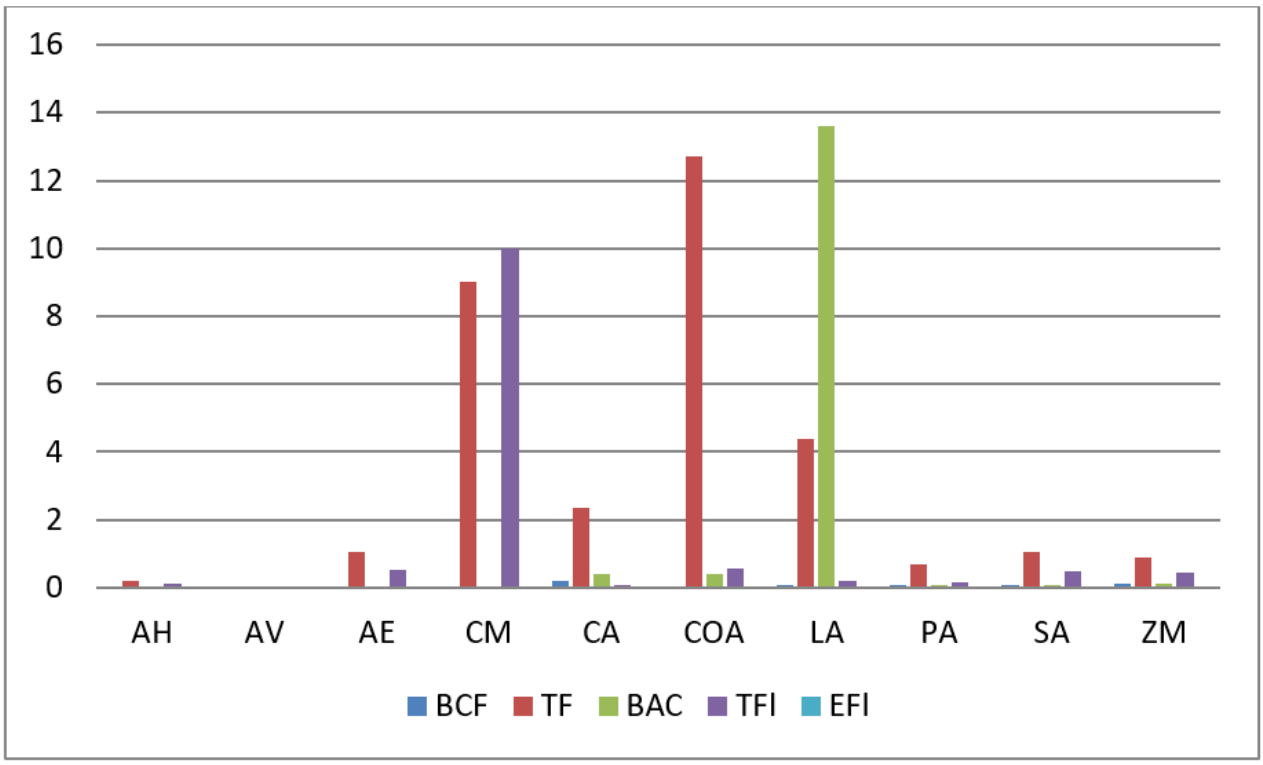

Figure 6

Average Co variations in plant tissues

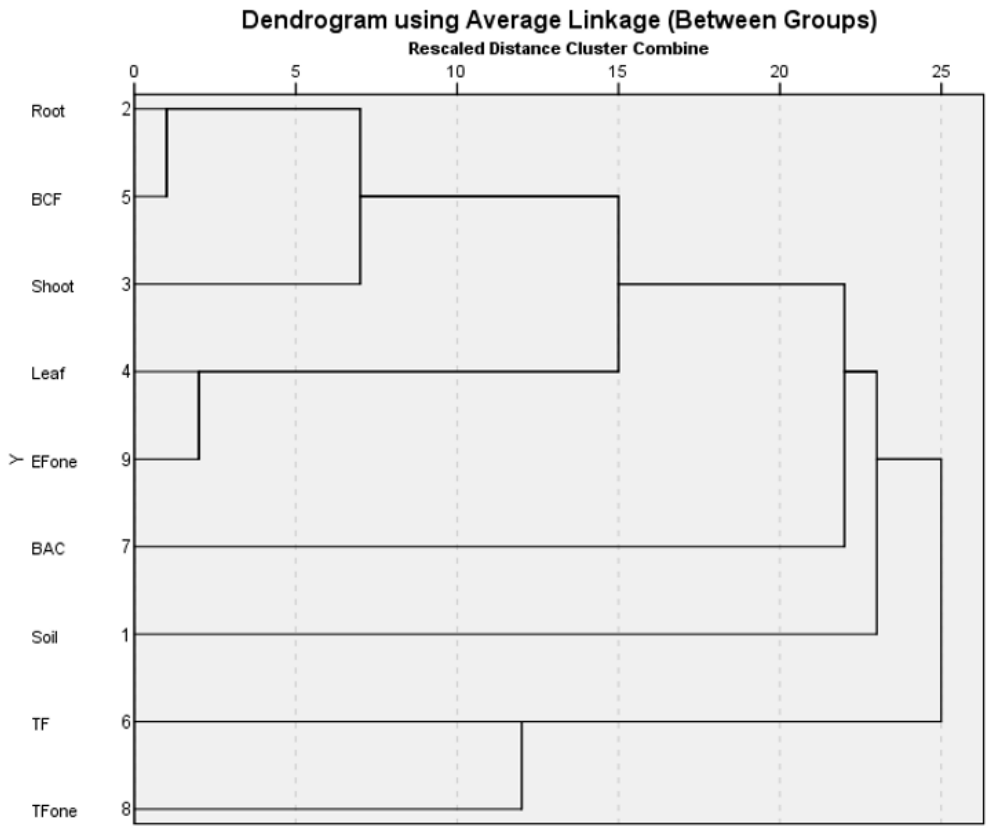

Figure 7

Cluster analysis of variables

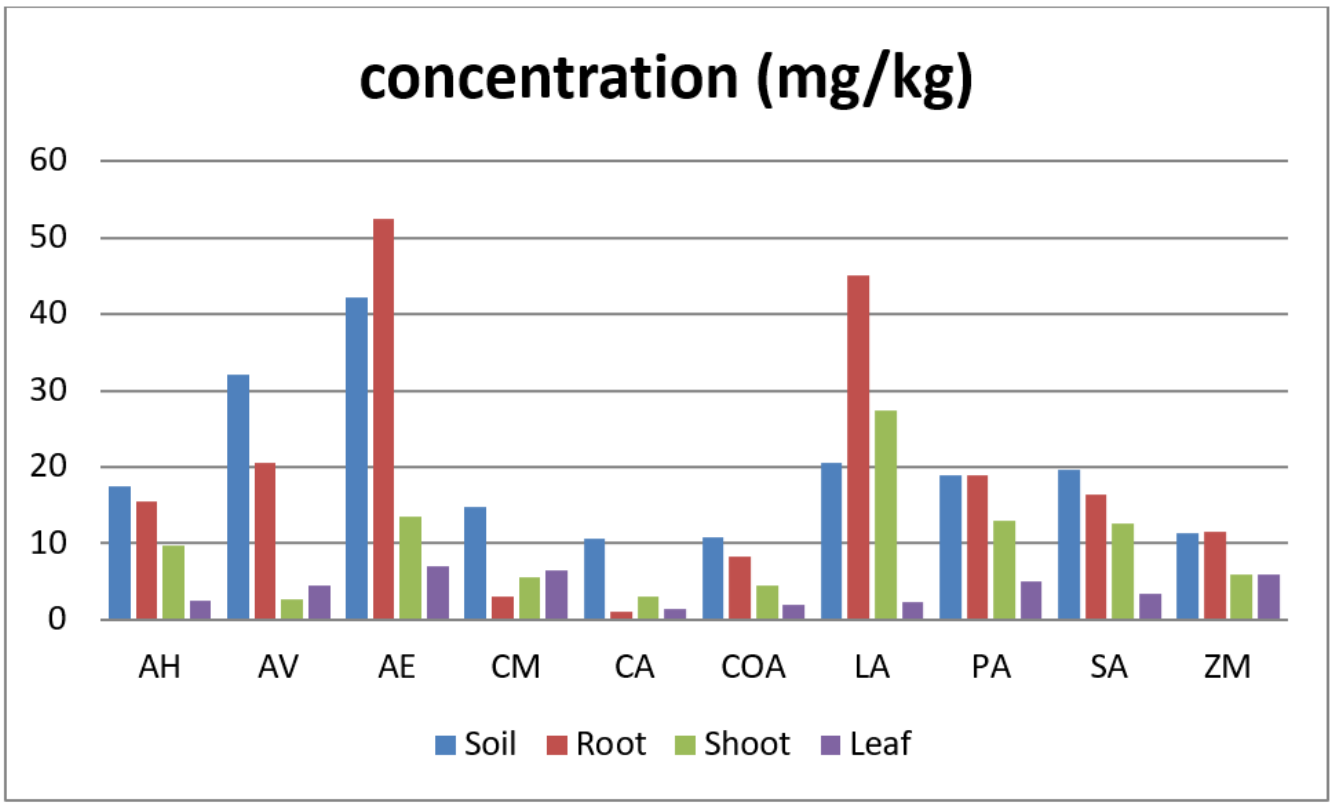

Figure 8

Average concentration (mg/kg) of As in soil and plant tissues

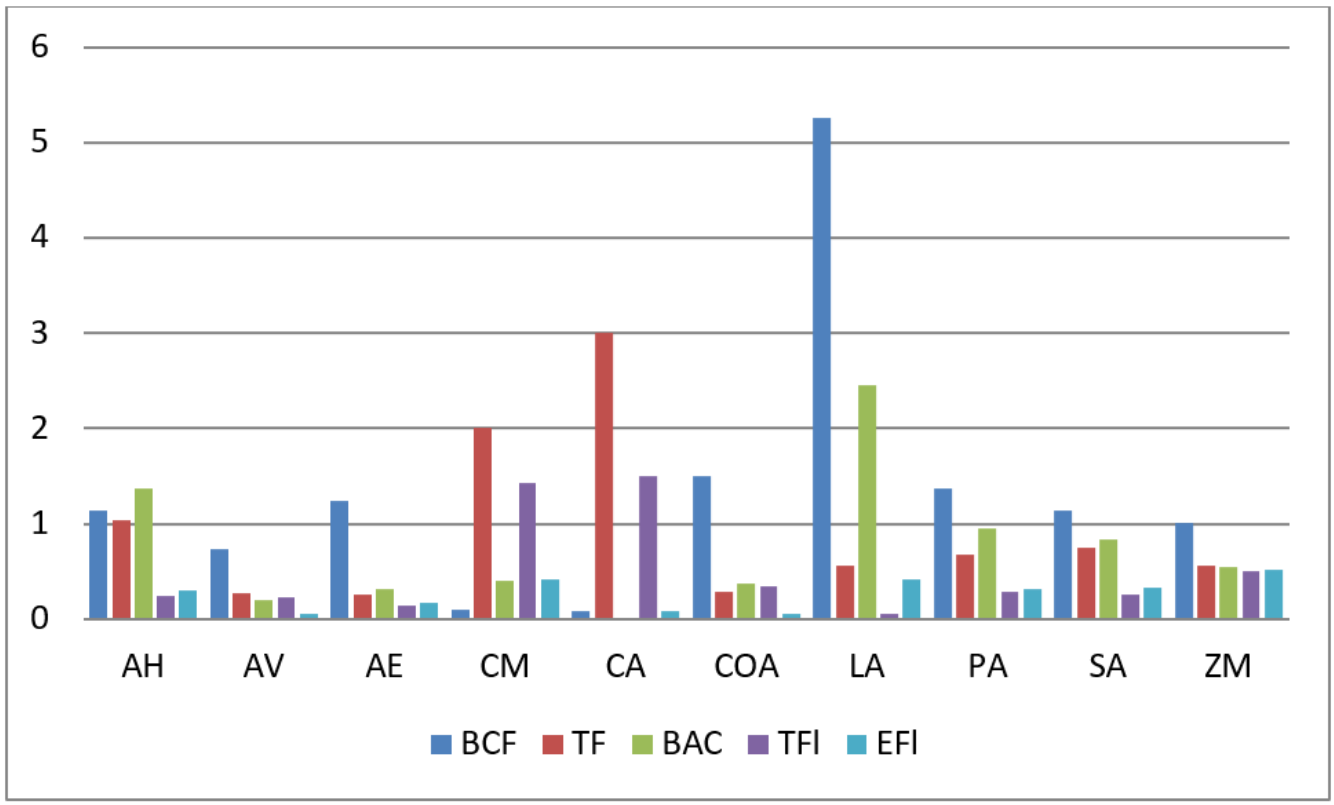

Figure 9

Average As variation in plant tissues

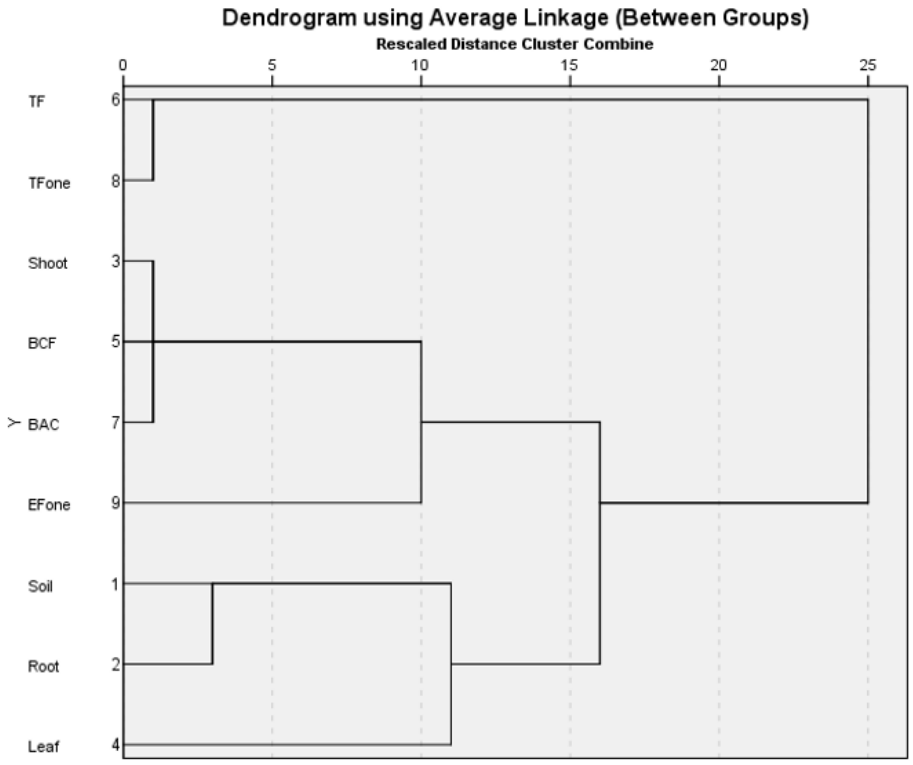

Figure 10

Cluster analysis of variables

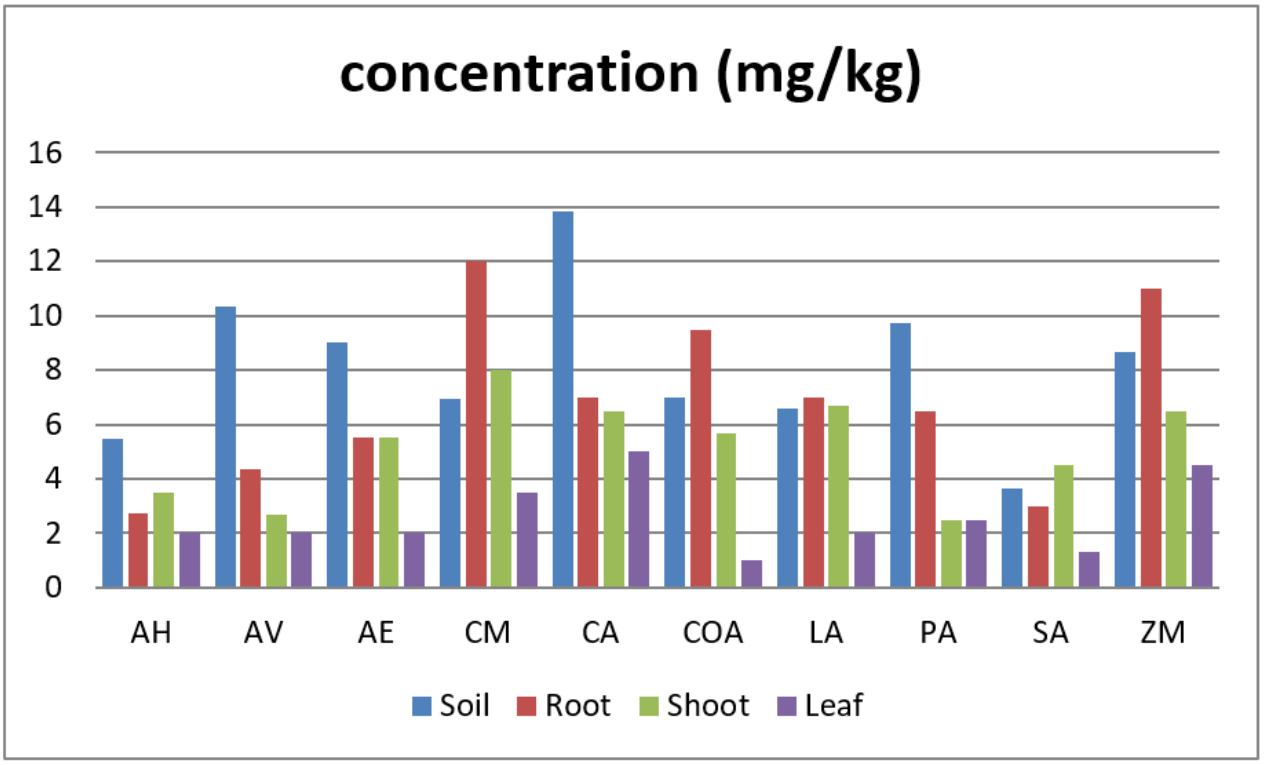

Figure 11

Average Cd concentration (mg/kg) in soil and plant tissues

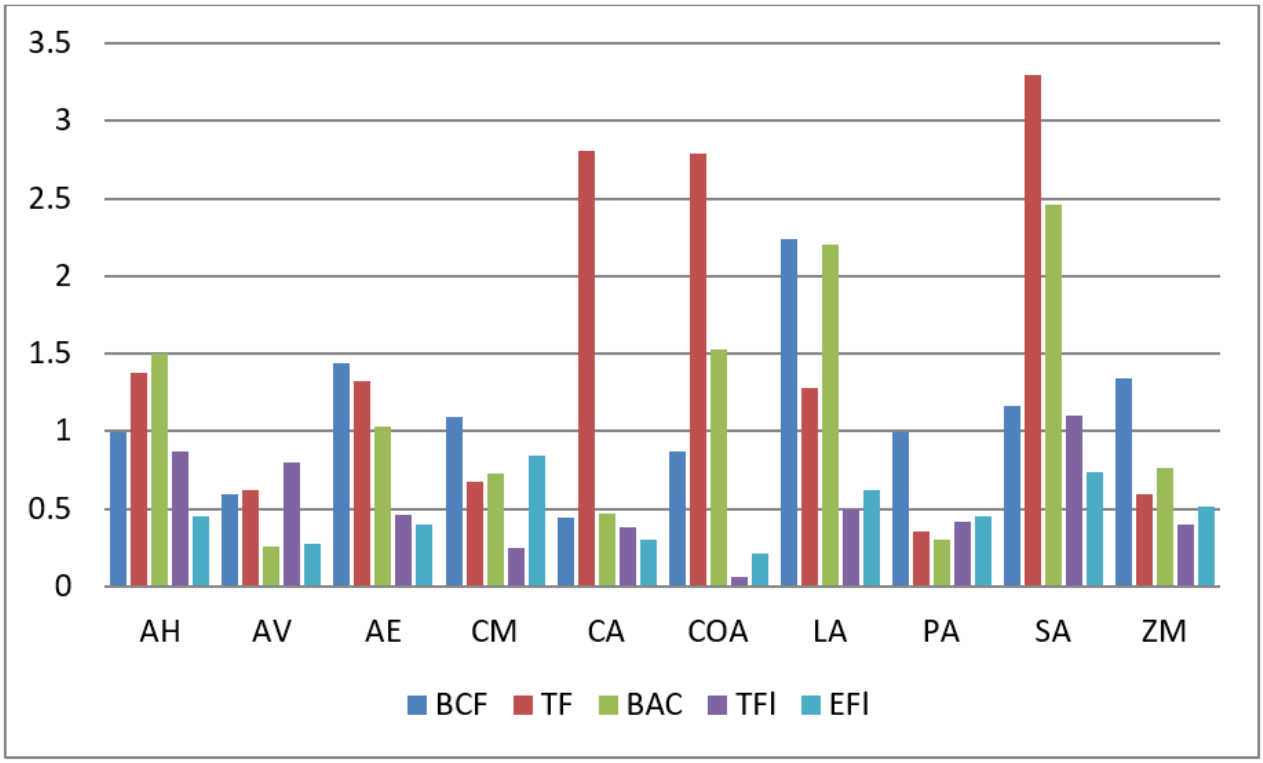

Figure 12

Average Cd variation in plant tissues

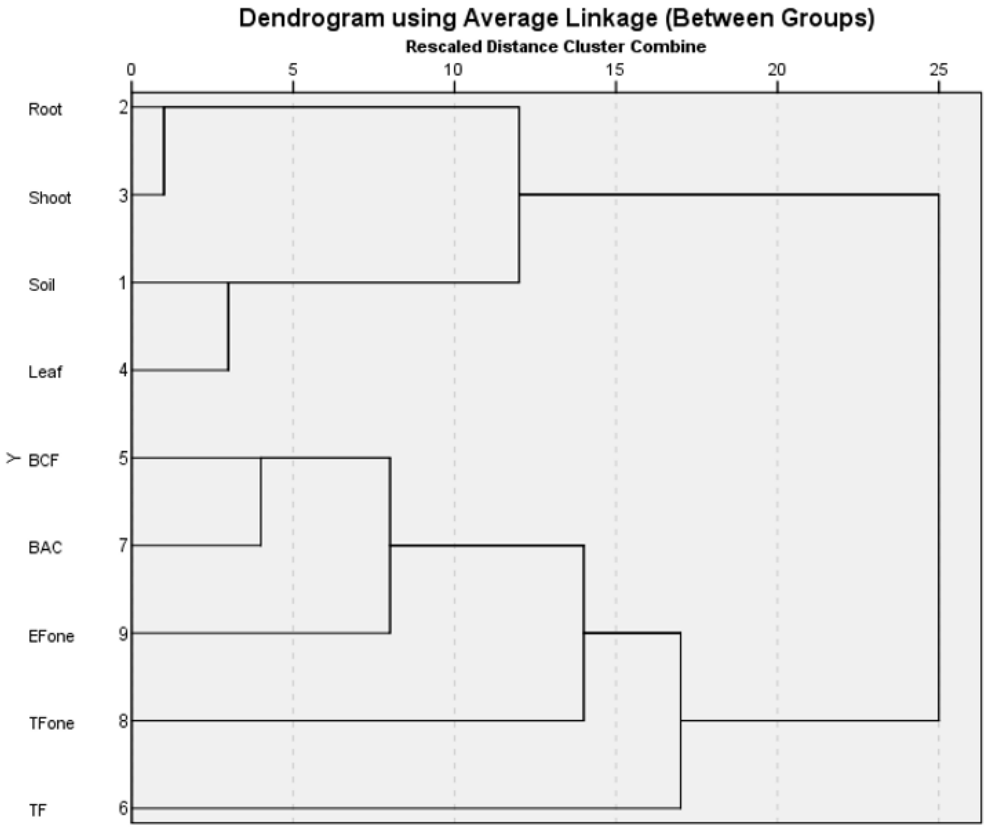

Figure 13

Cluster analysis of the variables