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PHYTOREMEDIATION OF HEAVY METALS USING SPINACH (*Amarantus spinosa*) GROWN ON CONTAMINATED SOILS

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ABSTRACT: *This work was designed to assess the phytoremediation ability of Spinach (Amarantus spinosa) grown on two different soils (contaminated soil obtained from Chalawa Industrial Estate, Kano, and control soil obtained from Biological Garden of Umaru Musa Yar'adua University, Katsina). Concentrations (mg/Kg) of Cr, Fe, Mn, Ni, Pb, and Zn were determined using atomic absorption spectrophotometry (AAS). Biological concentration factors (BCFs) and translocation factors (TFs) were calculated. The mean levels of metals obtained ranged widely from 0.23 mg/kg Ni to 1971.37 mg/kg Fe. Highest mean levels of Cr (97.74 mg/kg), Fe (1971.37 mg/kg), Mn (78.22 mg/kg), Zn (170.60 mg/kg) were contained in the leaf of the spinach samples, whereas Ni (1.98 mg/kg) and Pb (14.24 mg/kg) were contained in the root of the spinach samples. The results showed a significant level ($p<0.05$) of all the metals analysed in the spinach samples grown on the polluted soil compared with those grown on the control soils. Amongst the metals, Ni and Pb were found to have the lowest (0.50) and highest (7.57) BCF values respectively. The lowest and highest TF values were found to be on Cr (0.32) and Zn (1.17) respectively. Consequently, Higher BCF and TF values were found for Pb and Zn and this resulted in greater extraction ability of Pb and Zn. The spinach ability to extract Fe and Ni was found to be poor.*

KEYWORDS: Phytoremediation, Heavy Metals, Contaminated Soil, Vegetable, Spinach.

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INTRODUCTION

The generic term 'Phytoremediation' consists of the Greek prefix Phyto (plant), attached to the Latin root Remedium (to correct or remove an evil) (Sadowsky, 1999). Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environment (Greipsson, 2011). It can be used for removal of heavy metals and radionuclides as well as for organic pollutants (such as polynuclear aromatic hydrocarbons, polychlorinated biphenyls, and pesticides) (Ali *et al.*, 2013). It is a novel, cost-effective, efficient, environment- and eco-friendly, in situ applicable, and solar-driven remediation strategy (Saier & Trevors, 2010; Kalve *et al.*, 2011; Sarma, 2011; Singh & Prasad, 2011; Vithanage *et al.*, 2012).

Phytoremediation is an alternative to engineering procedures that are usually more destructive to the soil (Greipsson, 2011). Phytoremediation technology is a relatively recent technology with research studies conducted mostly during the last three decades (1990 onwards) (Ali *et al.,* 2013). The establishment of vegetation on polluted soils also helps prevent erosion and metal leaching (Chaudhry *et al.*, 1998).

Major environmental concern due to disposal of industrial and urban wastes generated by human activities is the contamination of soil. Controlled and uncontrolled disposal of waste, accidental and process spillage, mining and smelting of metalliferous ores, and sewage sludge application to agricultural soils are responsible for the migration of contaminants into non-contaminated sites as dust or leachate and contribute towards contamination of our ecosystem (Ghosh & Singh, 2005).

Nyamangara and Mzezewa (1999) implicated land disposal of sewage and industrial effluents as the chief source of heavy metal enrichment of pasturelands and agricultural fields. Heavy metals contamination in agricultural soils from wastewater irrigation is of serious concern due to its implications on human health (Sharma *et al.*, 2010).

Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals (Ghosh & Singh, 2005).

Green plants have an enormous ability to uptake pollutants from the environment and accomplish their detoxification by various mechanisms (Ali *et al.,* 2013). This technology can be applied to both organic and inorganic pollutants present in soil (solid substrate), water (liquid substrate) or the air (Salt *et al.*, 1998; Raskin *et al.*, 1994).

Most of the conventional remediation technologies are costly to implement and cause further disturbance to the already damaged environment (Alloway & Jackson, 1991).

The physico-chemical techniques for soil remediation render the land useless for plant growth as they remove all biological activities, including useful microbes such as nitrogen fixing bacteria, mycorrhiza, fungi, as well as fauna in the process of decontamination (Burns *et al.*, 1996).

Plants which offer multiple harvests in a single growth period (like *Trifolium spp*.) can have a great potential for phytoextraction of heavy metals (Ali *et al.*, 2012).

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It is interesting to notice that there are plants that survive, grow and reproduce on natural metalliferous soils as well as on sites polluted with heavy metals as a result of anthropogenic activities (Rascioa & Navari-Izzo, 2011).

Discovery of hyperaccumulator species has further boosted this technology (Ghosh & Singh, 2005). Among all the plant species, certain cultivars of *Brassica juncea* (Indian mustard) had the highest shoot Pb accumulation as well as an ability to accumulate and tolerate Cd, Cr, Ni, Zn, Cu (Kumar *et al.*, 1995).

A study by Onyedika, and Okon (2014) reveals that green spinach accumulated the heavy metals at varying concentrations. Cd, Pb and Zn were highly mobile in green spinach from soil to leaves through roots and stem. It was also noted that bioaccumulation of heavy metals by green spinach is affected by the soil pH and the green spinach is a potential hyperaccumulator especially in soils with low pH values.

Lawal and Audu (2011) recorded high levels of Ni, Pb and Cr to be the highest in spinach, although their concentrations are below the NAFDAC limits.

Thlaspi caerulescens is generally referred to as a well-known Zn/Cd hyperaccumulator, which can accumulate and tolerate up to 10,000 mg kg^{-1} of Zn and 100 mg kg^{-1} of Cd in shoots (dry matter) without showing any symptoms of toxicity (Escarré *et al.*, 2000).

Although there are over 400 species of hyperaccumulator plants (Baker *et al*., 1989) and more are still being sought, very few studies have tested the feasibility of natural hyperaccumulators or other potential plants for phytoextraction performance under field conditions (Zhuang *et al*., 2007).

This study was carried out with the aim to assess the phytoextraction potentials of spinach grown on the metal accumulated soils of Chalawa Industrial Estate, Kano, Kano State, Nigeria and to evaluate the phytoextraction efficiency of Cr, Fe, Mn, Ni, Pb and Zn.

MATERIALS AND METHODS

Site Description

The global location of Chalawa Industrial Estate is between latitude (11^0 54^I 03^{II}) North of the equator and longitude (08^0 25^I 21^{II}) East of the Greenwich Meridian in Kumbotso Local Government Area, Kano State, Nigeria. It is the industrial hub of Kano State where most of the industrial plants including tannery, agrochemicals, textiles, etc. are located. The industrial plants are big and occupy a very large number of landmass (Udofia, 2018).

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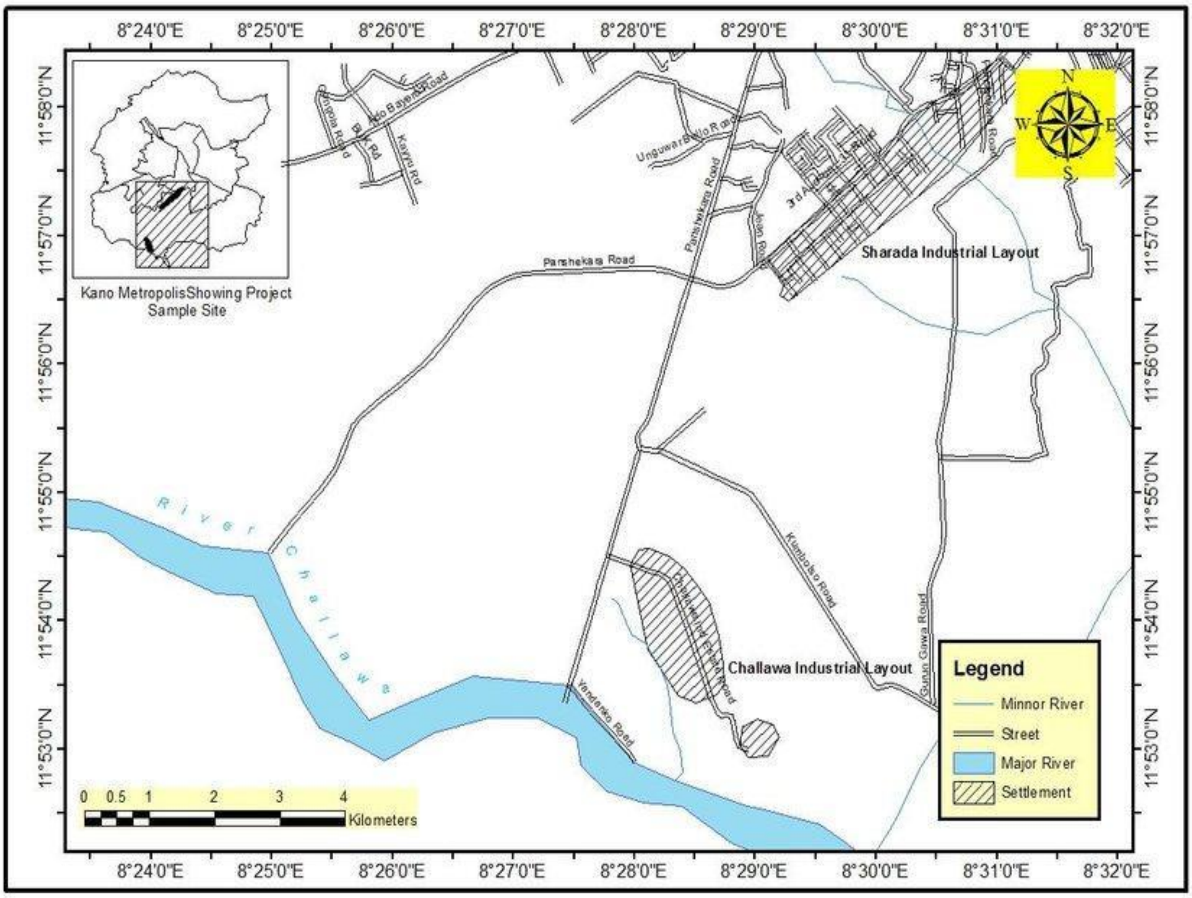

Figure 1. Map of Challawa Industrial Estate showing the study site

Experimental Design

The field work was conducted using a pot experiment. Two (2) separate treatments (control and polluted) were designed to contain ten (10) replicates of perforated plastic pots sized 12 cm × 20 cm each. 2.00 kg of homogenized soil from UMYU biological garden was used in each pot in the control treatment and 2.00 kg of homogenized soil from the study site was used in each pot in the polluted treatment. Equal volumes of polluted water and tap water were used to moisten the soils in the polluted treatment and control treatment respectively prior to sowing the seeds. Continuous irrigation with equal volumes of waters was maintained for the optimum germination and growth of the plants. The seeds germinated within 2 to 3 weeks and continuous irrigation was maintained for 3 consecutive months until the plants were fully grown and matured. The experiment was terminated after three months and plants were harvested.

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Table 1: Levels of heavy metals (mg/Kg) and pH of soils and waters of the treatments (mean ± SD, n = 5)

Parameters	Control treatment		Polluted treatment	
	Soil	Water	Soil	Water
Cr	11.88±8.24	0.22±0.14	1297.00±94.01	5.13±1.20
Fe	2572.28±306.39	3.82±2.01	4244.39±519.50	19.34±8.64
Mn	23.68±5.45	0.15±0.04	37.90±4.31	0.18±0.09
Ni	1.34±0.39	0.06±0.02	1.91±1.01	0.07±0.05
Pb	2.03±1.39	0.01±0.00	2.36±0.67	0.02±0.02
Zn	7.63±3.39	0.31±0.14	64.92±28.57	0.78±0.09
pH	6.33±0.39	6.05± 0.70	5.24±0.15	7.03±0.63

$P < 0.05$

The experiment was conducted in a poly house to maintain ideal temperature, protection from invaders (rodents and insects) and to control contamination by rainfall (Krzepilko, Zych-wezyk & Mplas, 2015). Plants were harvested, washed with clean water, air-dried and taken in a newspaper to the laboratory for further treatment and analysis.

Plant, Soil and Water Analysis

Analytical grade reagents and deionised water were used throughout the experiment. All glass and plastic wares used were washed with liquid soap, rinsed with water, soaked in 10% nitric acid for 24 hours, rinsed thoroughly with deionised water and dried to ensure that no contamination occurs (Abdullahi *et al.*, 2009)

Plant samples were washed thoroughly with deionized water to remove surface dust and soil, divided into root, stem and leaf, dried at 60°C for 24 hours until completely dry, weighed, and ground to <0.5 mm. About 1.0 g of finely ground tissue of plant subsamples was digested with concentrated HNO_3 (16 mol dm^{-3}) (Markert 1993; Aksoy *et al.*, 2005). The sample solutions were filtered through a Whatman filter paper into screw capped plastic bottles prior to the analysis. The soil samples were digested using 20.00 cm^3 of (1:1) HNO_3/HCl acid mixture. The resulting digest was cooled and quantitatively filtered into a 50 cm^3 volumetric flask using a Whatman filter paper number 540. Water was then added to the volume (Ogundiran & Osibanjo, 2008). The water samples were digested with concentrated HNO_3. The digest was filtered into a 50 cm^3 volumetric flask through Whatman filter paper number 42. The solution was made to volume with water and transferred into capped plastic bottles before analyses (Kebbekus & Mitra, 1998).

Quality control was addressed by routinely analyzing blank samples for plant, soil and water prepared during digestion.

All the sample solutions prepared were used for the determination of Chromium, Iron, Lead, Manganese, Nickel and Zinc at their respective wavelengths using Atomic Absorption Spectrophotometer (AAS) Model: 210VGP.

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Phytoextraction Efficiency

The phytoextraction efficiency was evaluated using two indices namely bioconcentration factor (BCF) and transformation factor (TF).

The bioconcentration factor (BCF) was calculated by the following equation:

$$BCF = \frac{Metal\ concentration\ (mg/Kg)\ in\ root}{Metal\ concentration\ (mg/Kg)\ in\ soil}$$

The translocation factor (TF) was calculated using the following equation:

$$TF = \frac{Mean\ metal\ cancentration\ (mg/kg) in\ shoot\ \ (Roots\ + Bolbs/Stems\ + Leaves)}{Metal\ concentration\ (mg/kg)\ in\ roots}$$

(Tukura *et al.*, 2012).

Table 2: Concentrations of Cr, Fe, Mn, Ni, Pb and Zn in root, stem and leaf of spinach (*Amarantus spinosa*) grown in control and polluted treatments (mean ± SD, mgKg^{-1}, n = 10)

Treatment	Plant's parts	Cr	Fe	Mn	Ni	Pb	Zn
Control	root	32.21±7.78^a	1486.10±419.07^a	44.17±0.73^a	0.23±0.36^c	7.78±0.73^b	92.06±13.63^a
	Stem	11.49±1.37^b	451.10±48.05^b	8.98±0.15^b	0.44±0.22^b	10.59±3.44^a	10.36±1.18^b
	Leaf	25.48±7.18^a	682.72±272.01^b	46.47±1.13^a	0.64±0.29^a	9.60±0.31^a	34.18±10.51^b
Polluted	root	86.56±8.64^a	1728.26±445.96^a	67.12±1.04^a	1.98±1.22^a	14.24±11.38^a	114.26±22.30^a
	Stem	69.86±19.83^b	462.94±201.68^b	18.68±0.16^b	1.40±1.16^a	11.70±9.83^a	13.63±1.18^b
	Leaf	97.74±7.74^a	1971.37±50.09^a	78.22±2.40^a	1.35±1.02^a	12.40±4.76^a	170.60±10.34^a

Data with different letters in the same column indicate a significant difference at $p < 0.05$ according to the least significant difference (LSD) test.

Statistical Analysis

All analytical results were performed as the average of 10 replicates. Descriptive statistics were made using SPSS 22.0 and Excel (Microsoft Inc.) software packages.

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RESULTS AND DISCUSSION

Metal Accumulation in Plant Tissues

The results of the analysis are shown in Table 1, 2 and 3. Results in Table 1 showed that the mean pH of the control soil samples and the polluted soil samples were found to be slightly acidic (6.33 ± 0.39) and acidic (5.24 ± 0.15) respectively. These inferred that absorption of the metals by plants is feasible since, at low pH, nutrients become soluble and plants can readily extract them (Michael & Arjun, 2010). Conversely, the mean pH of the control water samples and polluted water samples were found to be slightly acidic (6.05 ± 0.70) and neutral (7.03 ± 0.63) respectively. The soil metal mean concentrations ranged from Ni (1.34 ± 0.39 mg/kg) to Fe (2572.28 ± 306.39 mg/kg) in the control soil and from Ni (1.91 ± 1.01 mg/kg) to Fe (4244.39 ± 519.50 mg/kg) from the polluted soil. However, the mean concentration of metals in water ranged from Pb (0.01 ± 0.00 mg/L) to Fe (3.82 ± 2.01 mg/L) from the control water samples and from Pb (0.02 ± 0.02 mg/L) to Fe (19.34 ±8.64 mg/L) from the polluted water samples. The mean concentration of metals in roots, stems and leafs are presented in Table 2. The mean accumulation of the metals range from Ni (0.23 mg/Kg) to Fe (1971.37 mg/Kg). From the results in Figure 1, the general trend for the mean levels of metal analyzed in spinach samples from both the control and polluted treatments showed that: Fe > Zn > Cr > Mn > Pb > Ni. This observation is somewhat similar to that (Fe > Zn > Mn > Ni > Pb > Cu > Co > Cr) shown by Audu and Lawal (2006).

However, the individual mean metals accumulations goes as: Cr accumulation varied from 11.47 mg/kg from control treatment to 97.74 mg/kg from polluted treatment in stem samples. Fe accumulation varied from 451.10 mg/kg in stem samples from the control treatment to 1971.37 mg/kg in leaf samples from polluted treatment. Mn accumulation varied from 8.98 mg/kg in stem samples from control treatment to 78.22 mg/kg in leaf samples from polluted treatment. For Ni, the accumulation ranged from 0.23 mg/kg from control treatment to 1.98 mg/kg from polluted treatment both in the root samples. Pb had a similar accumulation trend with Ni and it ranged from 7.78 mg/kg from the control treatment to 14.24 mg/kg from polluted treatment both in the root samples. Zn accumulation ranged from 10.36 mg/kg in stem samples from control treatment to 170.60 mg/kg in leaf samples from polluted treatment.

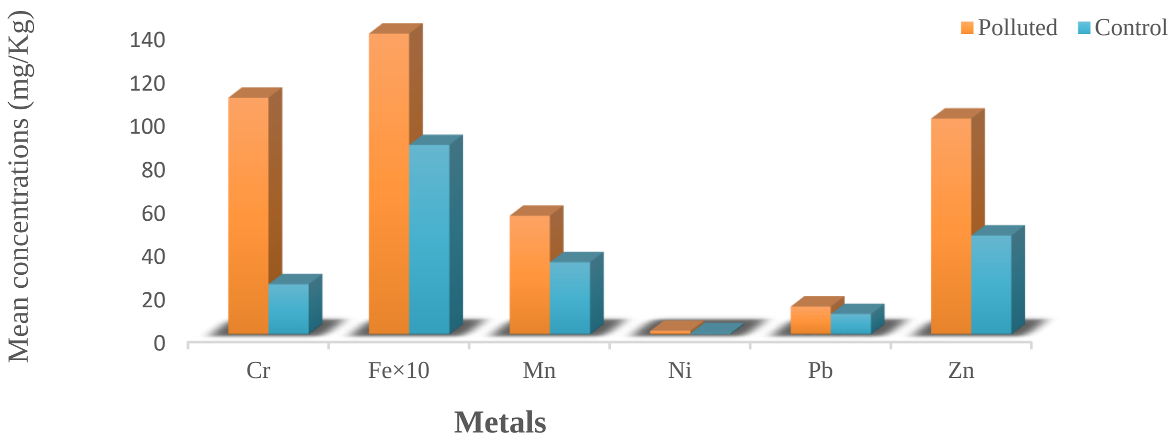

Figure 1: Showing the total mean levels of metals in control treatment and polluted treatment.

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The general sequences for the metals mean accumulations by spinach parts are: For Cr and Mn, Leaf > Root > Stem; for Fe, Ni and Zn, Root > Leaf > Stem; for Pb; Stem > Root > Leaf.

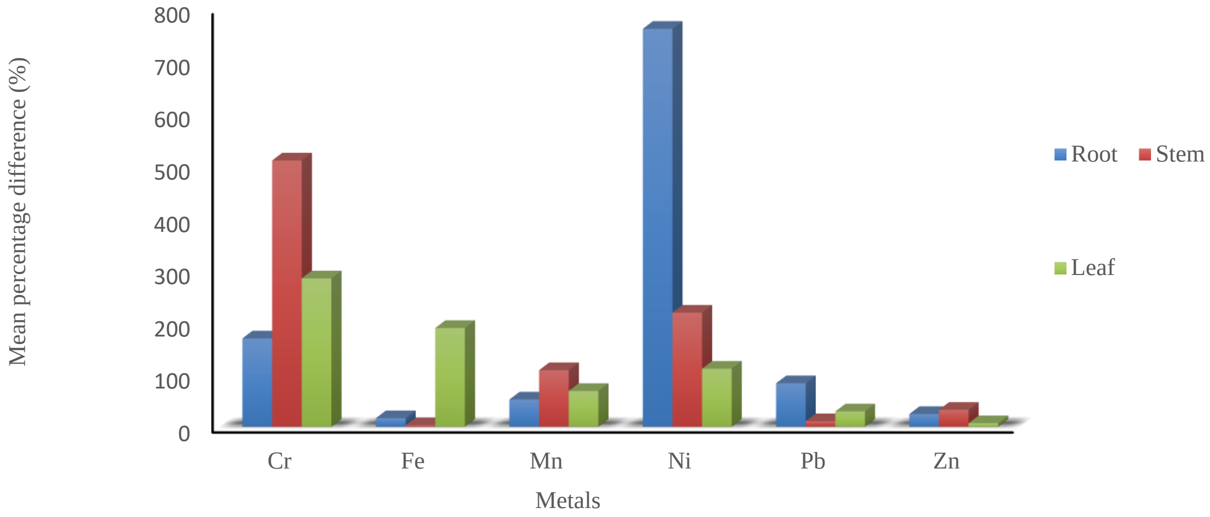

Figure 2: Mean percentage difference (%) between the metal content of spinach samples in the control treatment and those in the polluted treatment.

Mean Percentage Difference

The results also showed that the mean percentage difference between the metals contents in the polluted treatment and those in the control treatment with respect to parts (root, stem and leaf) indicated a sequence: Ni > Cr > Zn > Mn > Fe > Pb. The sequence showed relatively low percentage difference for essential metals (such as Mn and Fe) which recorded 76.10% and 69.22% difference respectively, and high percentage difference for toxic metals (such as Ni and Cr) which recorded 363.33% and 320.47% difference respectively (Fig 2).

Bioconcentration Factor (BCF) and Translocation Factor (TF)

Table 3 shows the bioconcentration factors (BCF) and translocation factors (TF) of spinach for all the metals. The BCF values ranged from 0.50 (Ni) to 7.57 (Pb). Whereas the TF values ranged from 0.32 (Cr) to 1.17 (Zn). The sequence for the BCFs showed that Pb > Zn > Cr > Mn > Fe > Ni. Pb recorded the highest BCF (7.57) against the finding of Zhuang *et al.* (2007) where in all the eight tested plants Pb recorded BCF values below 0.2. Zn also recorded a high BCF value of 6.19 which is somewhat similar to the figure recorded by Zhuang *et al.* (2007), where the Zn BCF value is up to 6.30. These indicate that spinach had no difficulties in mobilizing Pb and Zn in the root zones because of these relatively high BCF values. In this study, only Pb and Zn had the TF values each greater than one (> 1). This indicates that spinach had no difficulties in mobilizing Pb and Zn in the root zones as well as translocating same to the shoot parts possibly due to the hyperaccumulation characteristics which is in line with the findings of Onyedika and Okon (2014), where they conclude that 'Pb and Zn were highly mobile in green spinach from soil to

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leaves through roots and stem.' Metal uptake and translocation of an element from roots to shoots is basically linked to the element speciation, soil pH, and other factors (Zhuang *et al.*, 2007).

Table 3 Bioconcentration factor (mean BCF) and translocation factor (mean TF) of Cr, Fe, Mn, Ni, Pb and Zn, of spinach (*Amarantus spinosa*) grown on control and contaminated soils

Metals	BCF	TF
Cr	1.50	0.32
Fe	0.84	0.57
Mn	1.16	0.80
Ni	0.50	0.49
Pb	7.57	1.14
Zn	6.19	1.17

CONCLUSION

This study demonstrated that spinach could extract Pb, Zn, Cr and Mn considerably from metal contaminated soil. Higher BCF and TF values were found for Pb and Zn and this resulted in greater extraction ability of Pb and Zn. The spinach ability to extract Fe and Ni was found to be poor.

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REFERENCES

Abdullahi, M. S., Uzairu, A., & Okunola, O. J. (2009). Quantitative Determination of Heavy Metal Concentrations in Onion Leaves. *Int. J. Environ. Res*, *3*(2), 271–274.

Ali, H., Khan, E., & Anwar, M. (2013). Phytoremediation of heavy metals — Concepts and applications. *Chemosphere*, *91*(7), 869–881. https://doi.org/10.1016/j.chemosphere.2013.01.075.

Ali, H., Naseer, M., & Sajad, M. A., (2012). Phytoremediation of heavy metals by Trifolium alexandrinum. *Int. J. Environ, Sci. 2,* 1459–1469.

Alloway, B. J. & Jackson, A. P. (1991). The behavior of heavy metals in sewage- sludge amended soils. *Sci. Total Environ. 100,* 151-176.

Audu, A. A., & Lawal, A. O. (2006). Variation in Metal Contents of Plants in Vegetable Garden Sites in Kano Metropolis ABSTRACT : J. Appl. Sci. Environ. Mgt., 10(2), 105–109

Baker, A. J. M., & Brooks, R. R. (1989). Terrestrial higher plants which hyperaccumulate metallic their distribution, ecology and phytochemistry. *Biorecovery, 1,* 81-126.

Article DOI: 10.52589/AJENSR-JPCC0GFF
DOI URL: https://doi.org/10.52589/AJENSR-JPCC0GFF

Burns, R. G., Rogers S. & McGhee, I. (1996): In Contaminants and the Soil Environment in the Australia Pacific Region. (Ed.) Naidu, R., Kookana, R. S., Oliver, D. P., Rogers S. and McLaughlin M. J.), – Kluwer Academic Publishers, London.

Chaudhry, T. M., Hayes, W. J., Khan, A. G., & Khoo, C. S. (1998). Phytoremediation-focusing on accumulator plants that remediate metal-contaminated soils. *Austraaslian Journal of Ecotoxicology. 4,* 37-51.

Escarré, J., Lefebre, C., Gruber, W., LeBlanc, M., Lepart, J., Riviere, Y., et al. (2000). Zinc and cadmium hyperaccumu- lation by Thlaspi caerulescens from metalliferous and nonmetalliferous sites in Mediteranean area: Implications for phytoremediation. New Phytologist, 145, 429–437.

Ghosh, M., & Singh, S. P. (2005). A rewiew on phytoremediation of heavy metals and utilization of it's biproducts. *Asian Journal on Energy and Environment, 6*(4), 214-231.

Greipsson, S. (2011). Phytoremediation. *Nature Education Knowledge, 3*(10), 7.

Kalve, S., Sarangi, B. K., Pandey, R. A., & Chakrabarti, T. (2011). Arsenic and chromium hyperaccumulation by an ecotype of Pteris vittata-prospective for phytoextraction from contaminated water and soil. *Curr. Sci. 100,* 888–894.

Kebbekus, B. and Mitra, S. (1998) Environmental Chemical Analysis, Chapman & Hall, New York.

Krzepiłko, A., Zych-wężyk, I., & Molas, J. (2015). Alternative ways of enriching the human diet with iodine, *9*(2), 167–171. https://doi.org/10.5604/18982395.1186500

Kumar, P. B. A. N., Dushenkov, V., Motto, H., & Raskin, I. (1995). Phytoextraction.the use of

Lawal, A. O., & Audu, A. A. (2011). Analysis of heavy metals found in vegetables from some cultivated irrigated gardens in the Kano metropolis, Nigeria, *3*(June), 142–148.

Michael P, Arjun H. 'Soils': In Encyclopedia of Earth. 2010. Accessed 15 December, 2012. Available: http://www.eoearth.org/article/soil.

Nyamangara J., Mzezewa J. (1999). The effects of long-term sludge application on Zn, Cu, Ni and Pb levels in clay loam soil under pasture grass in Zimbabwe. Agric. *Ecosyst. Environ,* 73:199-204.

Ogundiran, M. B. and Osibanjo, O. (2008). Heavy Metal Concentrations in Soils and Accumulation in Plants Growing in a Deserted Slag Dumpsite in Nigeria. *African Journal of Biotechnology.* 7(17):3053-3060.

Onyedika, M., & Okon, E. (2014). Bioaccumulation and Mobility of Cadmium (Cd), Lead (Pb) and Zinc (Zn) in Green Spinach Grown on Dumpsite Soils of Different pH Levels, *4*(December), 85–91.

Plant to remove heavy metals from soil. *Environ. Sci. Technol. 29*, 1232-1238.

Rascio, N., & Navari-izzo, F. (2011). Heavy metal hyperaccumulating plants : How and why do they do it ? And what makes them so interesting ? *Plant Science*, *180*(2), 169–181. https://doi.org/10.1016/j.plantsci.2010.08.016

Raskin, I, Kumar, P. B. A. N., Dushenkov, S. & Salt, D. (1994). Bioconcentration of heavy metals by plants. *Current Opinion Biotechnology 5,* 285-290.

Sadowsky, M. J. (1999). In Phytoremediation: Past promises and future practices. – Proceedings of the 8th International Symposium on Microbial Ecology. Halifax, Canada; pp. 1-7.

Saier, M. H., & Trevors, J. T. (2010). Phytoremediation. *Water Air Soil Pollut. 205*, 61–63.

Salt, D. E., Smith, R. D., & Raskin, I. (1998). Phytoremediation. – Annu. Rev. Plant Physiol. *Plant Mol. Biol. 4,* 643-668.

Sarma, H. (2011). Metal hyperaccumulation in plants: a review focusing on phytoremediation technology. *J. Environ. Sci. Technol. 4,* 118–138.

Article DOI: 10.52589/AJENSR-JPCC0GFF
DOI URL: https://doi.org/10.52589/AJENSR-JPCC0GFF

Sharma, R.K., Singh, A., Agrawal, M., and Marshell, F.M. (2010). Risk Assessment of Heavy Metal Toxicity through Contaminated Vegetables from Wastewater Irrigated Area of Varansi, India. *Tropical Ecology*. 51:375-387.

Singh, A., & Prasad, S. M. (2011). Reduction of heavy metal load in food chain: technology assessment. *Rev. Environ. Sci. Biotechnol. 10*, 199–214.

Udofia, L. E. (2018). Pollution Potential of Effluent from Challawa Industrial Layout and its Influence on the Water Quality of River Challawa , Kano , Nigeria.

Vithanage, M., Dabrowska, B. B., Mukherjee, B., Sandhi, A., & Bhattacharya, P. (2012). Arsenic uptake by plants and possible phytoremediation applications: a brief overview. *Environ. Chem. Lett. 10*, 217–224.

Zhuang, P., Yag, Q. W., Wang, H. B., & Shu, W. S. (2007). Phytoextraction of Heavy Metals by Eight Plant Species in the Field, 235–242. https://doi.org/10.1007/s11270-007-9412-2.

Article DOI: 10.52589/AJENSR-JPCC0GFF
DOI URL: https://doi.org/10.52589/AJENSR-JPCC0GFF