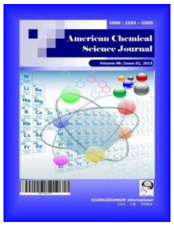

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Phytoremediation Potentials of Common Nigerian Weeds for the Purpose of Cleaning up a Lead-Zinc Derelict Mine

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Six common Nigerian weeds namely *Helianthus annus*, (Sunflower), *Imperala cylindrical* (Sword grass), *Sida acuta burn* (Broom weed), *Gossypium* spp (Cotton), *Eleusine indica* (Goose grass) and *Chromoleaeceae Odarata* (Siam weed) grown around Enyigba lead mines were investigated within a period of two years (2008-2010) for their abilities to remove heavy metals from the soils of the derelict mines. X-ray Fluorescence (XRF) spectrometric method was used to determine the concentrations of arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb) and zinc (Zn) in the top and sub soils and also in the roots, stems and leaves of the studied plants. The Pollution Indices (PI) of the soil was evaluated as well as the Bioaccumulation Factors (BAF) and Translocation Factors (TF) of the weeds and they were used to determine the phytoremediation potentials of the weeds. The results obtained revealed the mean concentrations (mg/Kg) of metals in the studied plants were of the range: Pb (12.62 – 417.2); As (0.38 – 2.26); Cd (8.46 – 144.6); Cu (32.81 – 420.40); Cr (30.2 – 184.2); Zn (0.26 – 16.87); Mn (12.94 – 155.80) and Ni (3.86 – 47.42). Levels of heavy metals in *Chromoleaeceae odorata* and *Imperata Cylindrical* were significantly higher than in the other weeds. Higher accumulation of metals was observed in roots than in the stems and the leaves. High BAF and TF (<1) observed in some of the studied plants suggest that they could be employed as efficient phytoremediation

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agents in cleaning up polluted soil. Statistical analysis of variance (ANOVA) at $P<0.05$ showed variations in the heavy metal levels between and within groups while Fisher's Least Significant Difference (LSD) Correlation analysis identified a strong relationship between the investigated plant and soil samples. Pollution Indices of metals in the studied soil sample in addition to the Bioaccumulation Factors and Translocation Factors of the studied weeds are important parameters to evaluate plants phytoremediation potentials.

Keywords: Phytoremediation; heavy metals; weeds; pollution index; bioaccumulation factor; translocation factor.

1. INTRODUCTION

Increasing industrialization has lead to extraction and distribution of mineral substances from their natural deposits [1]. Unlike other pollutants, heavy metals are non-biodegradable and they have the tendency to bioaccumulate and biomagnify from one trophic level to another [2]. Heavy metals, at different sites, have been mined, smelted, or used in other industrial processes. The tailings, smelter slag and other wastes left behind often pollute the agronomic soil and also surface and ground water. Heavy metal contamination can be carried with soil particles swept away from the initial areas of pollution by wind and rain [3-4]. In many Nigerian cities and rural areas, there is inefficient environmental control system which results to contamination of immediate surroundings and the ground water with heavy metals [5]. This is the reason why this present study was carried at Enyigba lead-zinc derelict in Ebonyi State, Nigeria where farmers are still actively cultivating their crops around the mine waste.

Phytoremediation is a plant based bioremediation technologies which employs the engineered use of green plants and their associated micro biota for the in-situ treatment of contaminated soil and ground water [6]. The process is environmentally friendly and takes advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant storage / degradation abilities of the entire plant body. Phytoremediation is cost-effective, and aesthetically pleasing as the plants can be easily monitored and metals absorbed by the plants may be extracted from harvested plant biomass and then recycled. The major disadvantage of phytoremediation is that it is limited to the surface area and depth occupied by the roots. Moreover it relies on natural cycle of plants and therefore takes time [7].

Single Pollution Index (PI) is often used to determine the level of the pollutant in the environment by comparing the concentration of the pollutant to the allowable maximum limit of regulatory bodies such as World Health Organisation (WHO) [8]. Bioaccumulation factor (BAF) is the ability of the plant to accumulate the heavy metals with respect to the metal concentration in the ecosystem [9]. For a plant to be an efficient phytoremediation tool in the contaminated soil, the BAF have to be higher than one. Translocation factor is the plant's ability to translocate heavy metal from root to harvestable aerial part. When values of BAF>1 and/or TF >1 is obtained, it indicates a preferential partitioning of metals from soil to root and from root to shoot respectively [10]. TF and BAF values of the studied weeds are strong indices of their phytoremediation potential [11].

The aims of this study are in two fold; first is to determine the levels of heavy metals in the investigated soils and establish the Pollution Index (PI). Second is to determine levels of heavy metals in the weeds and from the data, evaluate their Bioaccumulation Factor (BAF) and Translocation Factor (TF) which suggest their phytoremediation potential [12].

2. METHODOLOGY

2.1 Collection and Preparation of Soil and Plant Samples

2.1.1 Soil

From each sampling site, composite top and sub soil samples were collected and labeled at 0-30 cm (n=6) and 60-90 cm (n=6) depths respectively. The samples were air-dried, ground mechanically with stainless steel soil grinder and sieved to obtain < 2 mm fraction. 30 g sub-sample was drawn from the bulk (< 2 mm fraction) and reground with laboratory mortar and pestle to obtain < 200 µm fraction. Further drying was done in an open inert vessel in a muffle furnace at 105ºC for 2 hours so as to remove soil moisture, after which the samples were cooled in desiccators [13].

2.1.2 Plant

Plant samples were collected within Enyigba lead-zinc mine derelict and were authenticated at Applied Biology Department of Ebonyi State University. Nigeria. The roots, stems and leaves of the studied plants were separated in each case and the components were cut into pieces. The plant tissues were cleaned to remove dust, soil and other particles by putting them through a three step washing sequence [14]. First they were washed with water, then with P-free detergent and followed by de-ionized water. The samples were air dried, and placed in a dehydrator at approximately 80ºC for 48 hours so as to stop enzymatic activity. The samples were mechanically grounded into fine powdery with the aid of an agate mortar and were further dried at 65ºC in an oven to obtain a constant. The samples were appropriately stored in treated plastic bottles for XRF analysis.

2.2 X-ray Fluorescence (XRF) Analyses of Heavy Metal in Plant and Soil Samples

A 13mm pellet of the each sample was formed using CAVER model manual palletizing machine at a pressure of 6 - 8 torr. Procedure for XRF was followed to determine the concentrations of metals in the soil and plant samples in accordance with Shefsky [15]. A voltage of 25KV and current of 50 μA produced from X-ray tube was used to bombard the sample in XRF system for 18 minutes at 1000 counts. Si-Li detector was used to detect the characteristic X-ray of the metals and their corresponding concentrations were computed in the read out device. In addition to metal concentration, the pH, percentage of Organic Matter and percentages of sand, silt, and clay of the soil were determined using Orion 920A pH meter; Walkley & Black method and Hydrometer method respectively [16].

2.3 Statistical Analysis

The samples were assayed and analyzed in triplicates and data generated from XRF were reported as Mean±Standard Error. One way analysis of variance (ANOVA) and Fisher's Least Square Difference (LSD) were used to determine significant difference within and between groups, considering a level of significance of less than 5% (P<0.05) and from the generated data, PI, BAF and TF were calculated.

3. RESULTS

The following tables present the results of XRF analyses and the PI, BAF and TF calculated from the generated data. Tables 1 and 2 deal with soil [17] and the rest deal with weeds.

4. DISCUSSION

Table 1 shows a comparison of the concentrations of the metals with the US-EPA Regulatory Limits (US-EPA, 1993). Only Pb, Ni and Cd from the Enyigba top soil exceeded the limits with their pollution index (PI) indicated in the order, Pb (2.7) > Cd (1.5) > Ni (1.1). The overall pollution status of soils of Enyigba mine derelict was calculated as 1.96 and this value indicated that Enyigba soils were polluted and it agrees with Chukwuma [18] and Nweke [19]. Soils with PI > 1are known to affect plants, animal and ultimately distort the food chain they support [20]. Table 2 shows the soil characteristics by their organic matter, sand, silt and clay contents. The percentage of organic matter content was 1.34% and this is comparable to results obtained by Okoronkwo [21]. Organic matter content increases with decrease in pH and an increase in metal concentrations [22]. Table 3 shows the levels of heavy metals in the plants and they did not follow a particular trend. However in most cases heavy metal concentrations were found to be higher in the root than in the stems and leaves. *Chromoleaeceae odarata* significantly accumulated high concentrations of Pb, Cd, Cu, Cr Mn and Ni (at p<0.05) compared to other weeds. Low bioaccumulation factors (BAF < 1) were generally observed for all the investigated heavy metals except Cr (Table 4). Bioaccumulation factor is known to decrease with increasing metal concentration in the soil [23]. High BAF values of Cr were obtained for *Chromoleaeceae odarata* (57.7), *Sida acuta burn* (52.8), *Eleusine indica* (23.2) and *Helianthus annus* (15.5). Based on classification of plants into excluders and accumulators, all the studied weeds can be considered as accumulators of Cr [24-26]. Table 5 revealed low translocation factors (TF < 1) of As and Cu which was observed in all the weeds. TF = 1 was observed for Cd, Zn and Ni in *Imperata cylindrical*; Zn and Mn in *Chromoleaeceae odarata* and Mn in

Helianthus tuberosus. However, high Translocation Factors (TF > 1) was observed in *Chromoleaeceae odarata* (1.42) for Pb and Ni (1.10); in *Imperata cylindrical* for Mn (1.03) and in *Helianthus annus* (1.09) for Cr. A key trait of metal hyperaccumulators is the efficient metal transport from roots to shoots, characterized by the TF >1 one [27]. Higher levels of heavy metals of 10 – 500 times the levels in normal uncontaminated plants have been recorded and these hyperaccumulators are known to concentrate the pollutants in a minimum percentage which varies according to the pollutant involved. Indian mustard has been used to remediate lead contaminated land [28].

Table 1. XRF mean concentrations (mg/kg) of heavy metals in soil of Enyigba mine derelict and their pollution indices, (Ave pH = 6.5±0.29) (Oti, 2015)

Metal	Topsoil	PI	Subsoil	PI	US-EPA
As	4.8 ± 1.8	0.06	2.12 ± 1.6	0.03	75*
Cd	126.0 ± 42	1.5	28.8 ± 6.2	0.34	85
Cu	812.2 ± 141.2	0.19	322.2 ± 12.2	0.07	4300
Cr	2.12 + 0.2	–	1.02 + 0.2	–	
Mn	424.0 ± 50.4	–	120.0 ± 44.0	–	
Ni	82.6 ± 22.0	1.1	34.8 ± 8.2	0.46	75
Pb	1116.8 ± 43.2	2.7	91.7 ± 16.7	0.22	420
Zn	995.2 ± 82.4	0.13	322.0 ± 62.4	–	7500

** Values refer to metal concentration in typical soils (Miroslav & Vladimir) [29],*
PI = Pollution index was calculated using C_{soil} / $C_{USEPA\text{-}standard}$ where C is concentration of metal

Table 2. Properties of soil from Enyigba mine derelict (Oti, 2015)

Properties	(n = 3)
Sand (%)	61.28 ± 5.2
Silt (%)	7.12 ± 0.8
Clay (%)	31.60 ± 2.6
Organic Matter (%)	1.34 ± 0.5

Table 3. XRF level of heavy metals of non-edible weeds from Enyigba mine (n=3)

			Heavy metals concentration (mg/kg)							
Botanical name	**Common name**	**Plant parts**	**Pb**	**As**	**Cd**	**Cu**	**Cr**	**Zn**	**Mn**	**Ni**
Imperata cylindrical	Sword grass	Leaves	53.22	0.38	66.42	340.1	46.3	11.24	53.26	56.41
		stem	68.40	0.35	66.48	312.2	56.2	14.25	62.82	61.30
		Root	128.6	0.62	66.40	366.4	113.2	14.26	61.08	61.34
Sida acuta burn	Broom weed	Leaves	12.62	ND	24.26	42.82	164.2	12.62	32.48	3.86
		stem	14.84	ND	22.82	46.26	112.4	12.04	36.26	4.88
		Root	22.65	ND	34.64	52.88	170.2	13.26	42.68	8.94
Helianthus annus	Sunflower	Leaves	18.61	1.12	12.63	122.6	32.6	0.89	12.94	11.82
		stem	42.85	1.49	14.81	168.8	42.9	1.27	13.06	14.87
		root	84.68	2.26	22.67	222.6	71.3	2.32	13.12	15.20
Gossupium spp	Cotton	Leaves	24.85	0.88	8.46	32.81	33.4	6.46	40.18	25.92
		stem	32.23	1.12	18.41	44.43	32.9	8.08	42.06	27.14
		root	66.81	1.48	26.42	46.26	30.2	8.82	45.88	34.16
Eleusine indica	Goose grass	Leaves	24.83	ND	43.28	76.44	44.7	0.28	17.32	6.98
		stem	26.75	ND	52.24	86.48	49.2	0.26	21.44	8.23
		root	29.86	0.62	60.49	102.2	52.8	0.48	23.38	12.72
Chromoleaeceae odarata	Siam weed	Leaves	417.2	0.46	122.2	420.4	98.2	16.42	155.8	47.42
		stem	234.2	1.22	102.6	224.8	122.4	16.85	80.28	44.27
		root	164.5	1.88	144.6	264.1	184.2	16.87	80.18	40.19

Table 4. Bioaccumulation factors (TF = C_{shoot}/C_{soil})

Botanical name	Common name	Pb	As	Cd	Cu	Cr	Zn	Mn	Ni
Imperata cylindrical	Sword grass	0.06	0.07	0.53	0.38	2.45	0.01	0.13	0.72
Sida acuta burn	Broom weed	0.01	-	0.18	0.06	52.8	0.01	0.09	0.06
Helianthus annus	Sunflower	0.04	0.31	0.12	0.21	20.2	0.00	0.03	0.18
Gossupium spp	Cotton	0.03	0.23	0.15	0.06	15.5	0.00	0.10	0.33
Eleusine indica	Goose grass	0.024	-	0.42	0.11	23.2	0.00	0.05	0.10
Chromoleaeceae odarata	Siam weed	0.21	0.25	0.82	0.28	57.7	0.02	0.65	0.54

Table 5. Translocation factors (TF = C_{shoot}/C_{root})

Botanical name	Common name	Pb	As	Cd	Cu	Cr	Zn	Mn	Ni
Imperata cylindrical	Sword grass	0.53	0.56	1.00	0.85	0.49	1.00	1.03	1.00
Sida acuta burn	Broom weed	0.65	-	0.66	0.87	0.66	0.91	0.85	0.55
Helianthus anus	Sunflower	0.51	0.66	0.65	0.76	0.60	0.55	1.00	0.98
Gossupium spp	Cotton	0.48	0.76	0.70	0.96	1.09	0.92	0.92	0.79
Eleusine indica	Goose grass	0.90	-	0.86	0.85	0.93	0.54	0.92	0.65
Chromoleaeceae odarata	Siam weed	1.42	0.65	0.71	0.85	0.66	1.00	1.00	1.10

5. CONCLUSION

Based on high TF and BAF values, *Chromoleaeceae odarata* has a greater potential to clean up Pb and Ni contaminated soil than the rest of the studied weeds, while *Imperata cylindrical* and *Helianthus annus* have the potential to clean up Mn and Cr contaminated soils respectively.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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