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Full Length Research Paper

Changes in soil properties and plant uptake of heavy metals on selected municipal solid waste dump sites in Ile-Ife, Nigeria

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In a study to evaluate the contributions of open municipal waste dump to soil heavy metals contamination and the modification of other soil physical and chemical parameters, soil samples were collected at various depths from the vicinity of major dump sites in Ile-Ife (latitudes 7°27´and 7°32´ , longitudes 4° 22' and 4° 29'), Nigeria. The samples when analyzed, showed that soils in the vicinity of dump sites had significantly higher pH regime compared to the control soil. Soils of the dump sites were found to be enriched with the heavy metals (Zn, Cu and Cd) more than the adjacent soils (control) but were still within tolerable /critical level with the exception of Pb which had a high value of 109.7 ugg-^{1} above the critical value of 100 ugg-^{1}. There was significant relationship between the soil heavy metal content and plant uptake. Transfer factor (TF) expressed as the ratio of the heavy metal concentration in plants to that of soil varied significantly amongst the dump sites and also amongst the species of the heavy metals. The ten years old dump sites recorded the highest TF value ranging from 0.29 for Zn to 4.05 for Pb. The study therefore showed that changes in physico-chemical characteristics at dump sites could be attributed to interactions of different soil properties rather a single factor.

Key words: Heavy metal contamination, seasonal changes, soil pH, soil texture, specific adsorption mechanism, transfer factor, food chain.

INTRODUCTION

Soil is a vital resource for sustaining basic human needs, a quality food supply and a livable environment (Wild, 1995). It serves as a sink and recycling factory for both liquid and solid wastes. Municipal solid waste has been found to contain appreciable quantity of heavy metals such as Cd, Zn, Pb, and Cu, all which may eventually end – up in the soil and are leached down the profile (Alloway and Aryes, 1997). This qualifies municipal solid wastes among the principal sources of heavy metals in the environment. Other identifiable sources include atmospheric deposition, manure and fertilizers, pesticides and industrial discharge (Holgate, 1979). The concern about these heavy metals is that they are not biodegradable and may therefore accumulate in the environment. Thus, one of the development challenges facing this decade is how to achieve a cost effective and environmenttally sound strategies to deal with the global waste crisis facing both the developed and developing countries (Parker and Corbilt, (1992), Jensen (1990); NEST (1991); Oyediran (1994) and Alloway and Aryes (1997). The crisis has threatened the assimilative and carrying capacity of the earth, which is our life support system.

Studies on heavy metals (density >5.54 gcm^{-3}) in ecosystem have shown an indication of a silent epidemic of environmental metal poisoning of ever increasing metals in sub humid tropical soils (Nriagu, 1988; Shuman, 1999). With increasing pressure on agricultural and the proliferation of urban and peri-urban farming, waste dump sites are becoming attractive because of their rich deposits of organic matter and plant nutrients. Although the nutrient content of wastes makes them attractive as fertilizers, land application of many industrial wastes and sewage is constrained by the presence of heavy metals, hazardous organic chemicals, salts, and extreme pH

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Table 1. Distribution of soil physical and chemical properties in the surface (0 - 15 cm) across the different open waste dump sites in dry season.

Age of site (years)	PH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				cmol/kg			
4	7.5a	62.7a	17.3a	20.0ab	6.2a	3.1a	0.59ab	14.9a	10.4a
7	7.3a	71.7a	10.0bc	18.3b	4.5ab	1.7b	0.57ab	14.5a	8.5ab
10	6.6ab	68.7a	11.7bc	19.7ab	5.0ab	1.8b	0.65a	14.3a	8.8ab
20	7.3a	70.7a	14.0ab	15.7b	5.0ab	2.7ab	0.51b	10.3a	7.3b
Control	6.0b	66.3a	8.0c	25.7a	3.0c	1.9b	0.57ab	11.8a	4.2c

Means with the same letters are not significantly different at $p<0.05$ according to Duncan Multiple Range Test.

(Cameron et al., 1997). Most edible crops are indiscriminate in their extraction of nutrients from the soil and thus will extract the non-desirable heavy metals alongside the required essential nutrients. This may predispose the populace to heavy metals through the consumption of such agricultural products thereby serving as a point of entry of heavy metals into the food chain. This calls for the need with regards to their impact on soil properties and as a potential source of introduction of contaminants into the food chain. This is better achieved by monitoring the sources and the pathway of heavy metals from the dump site through edible vegetables into human. Therefore, the objective of this study was to examine the effects of municipal solid waste open dump site on soil physic-chemical properties and identify the possible pathway for the transfer of heavy metals from these sites into the food chain.

MATERIALS AND METHODS

The study area is located in Ife East Local Government area (Figure 1) of Osun State in Southwest Nigeria, which lies between latitudes 7°27´ and 7° 32' and longitudes 4° 22' and 4° 29'. The geology of the area forms a complex pattern of coarse and fined grained gneisses. The soil is derived from material of the old basement complex, which is mainly made up of granitic metamorphosed sedimentary rock. A total of 90 soil samples were collected from four open waste dump sites and a forest site opposite the dump sites as the control across two seasons. Samples were collected in February representing dry season and in September (for wet season) in 2005. Each sample site was divided into four quadrants each 3 m^2 and a total of 9-15 cores soil per quadrat were collected from three of the four quadrats randomly at different depths of 0 - 15, 15 - 30 and 30 – 50 cm using a stainless steel Dutch auger in composite replicate. The soil samples were thoroughly mixed in clean plastic buckets before sub samples were collected, taken to the laboratory, air dried and sieved through 2 mm sieve. Fresh leaves and corm of *Xanthosoma* species (cocoyam) were harvested, oven dried at 60º C for 48 h. The dried samples were ground to pass through a 2 mm sieve and prepared for chemical analysis after wet digestion. The plant samples were analyzed for Cd, Pb, Zn and Cu using a Perkin Elmer Atomic Absorption Spectrophotometer (AAS).The soil samples were equally analysed for the following parameters: organic matter, particle size, exchangeable cations, pH and heavy metals content. Soil organic matter was determined using the Walkley and Black method (Walkley and Black, 1934), particle size distribution was determined by the hydrometer method using sodium hexametaphosphate as the dispersant (Bouyoucous, 1962), exchangeable bases were extracted with ammonium acetate at pH 7 and the Ca, Na and K contents of the extracts were determined with a Jenway flame photometer while the Ca, and Mg contents were determined using AAS. The soil pH was measured as described by Hendershot et al. (1993). Heavy metals were extracted using a mixture of 1 ml HNO_3 and 3 ml of HCl (*aqua regia*) and the content heated on a hot plate in a fume cupboard to dryness at 1000°C, allowed to cool and leached with 0.5 M HCl before analysis using a Perkin Elmer Atomic Absorption Spectrophotometer (AAS).

Plant uptake of heavy metals was expressed as proportion of heavy metals in plant tissue per tissue dry weight. The transfer ratio of heavy metals to plant tissues was computed as the ratio of the concentration of the metals in plants to that in soil as described by Oyedele et al. (1995).

Statistical analysis

Analysis of Variance was carried out using PROC ANOVA subroutine of SAS (SAS, 1998) site and seasons as the effects while season/site interactions were computed for the different parameters. The means of soil properties were separated using the Duncan's multiple range test (DMRT) at 5 % level of significance ($P < 0.05$).

RESULTS AND DISCUSSION

Physical and chemical composition

The mean distribution of the soil properties at various depths on the different open waste dump sites are summarized in Tables 1 - 6. The soil pH differed signifycantly among the dump sites and from one season to other. The topsoil (0 - 15 cm) pH across the dump sites ranged from 6.0 to 7.5 units in the dry season and from 6.3 to 7.7 units in the wet season. These values are expected as most soils in the tropics have their ranging from acidic to slightly neutral (Alloway and Aryes, 1997). These values were however significantly higher on the average compared to the control site. This may be attributed to the buffering effect of soil organic matter against pH change in addition to the release of basic cations during the organic matter decomposition. This trend is repeated in the three sampling depths with the exception of the control where the pH decreased with

Table 2. Distribution of soil physical and chemical properties in the surface (0-15 cm) across the different open waste dump sites in wet season.

Age of site (years)	pH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				cmol/kg			
4	7.7a	64.7a	16.0a	19.3ab	2.7b	1.5b	0.98a	12.5ab	7.3a
7	7.1b	63.3a	14.7a	22.0a	3.1a	1.7b	0.75ab	13.8ab	6.1ab
10	7.4ab	61.7a	15.3a	23.0a	3.5a	1.5b	0.75ab	14.2ab	6.7ab
20	7.3ab	69.3a	14.7a	16.0b	3.6a	2.3b	0.99a	9.7b	5.5b
Control	6.3c	69.0a	9.3b	22.0a	2.3b	4.0a	0.49b	18.8a	5.3b

Means with the same letters are not significantly different at p<0.05 according to Duncan Multiple Range Test.

Table 3. Distribution of soil physical and chemical properties in the sub-surface (15 - 30 cm) across the different open waste dump sites in dry season.

Age of site (years)	PH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				cmol/kg			
4	7.6a	62.3b	17.0a	20.7bc	5.9a	2.5a	0.67ab	18.7a	9.6a
7	7.4a	70.3ab	9.3b	20.3bc	4.5ab	2.0a	0.56b	13.3ab	8.5ab
10	6.9a	63.3b	12.0ab	24.7ab	4.8ab	2.0a	0.71a	13.0ab	7.8b
20	7.5a	73.0a	11.7ab	15.3c	3.0bc	2.0a	0.57b	12.3b	6.4bc
Control	5.4b	63.7b	6.3c	29.7a	1.9c	2.1a	0.61ab	12.5b	3.5c

Means with the same letters are not significantly different at p<0.05 according to Duncan Multiple Range Test.

Table 4. Distribution of soil physical and chemical properties in the sub-surface (15 - 30 cm) across the different open waste dump sites in wet season.

Age of site (years)	pH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				cmol/kg			
4	7.7a	62.0b	18.0a	20.0ab	4.2a	1.4b	0.91ab	15.3a	5.9bc
7	7.2a	68.0ab	12.3ab	19.7ab	2.9b	1.5b	1.15a	11.7b	5.9bc
10	7.4a	61.3b	13.0ab	25.3a	3.9ab	2.8a	0.96ab	10.5b	6.5b
20	7.4a	71.3a	12.7ab	16.0b	3.6ab	1.8b	1.08a	13.5ab	5.3c
Control	5.8b	64.3ab	16.0b	7.7c	1.1c	2.2ab	0.59b	15.3a	7.0a

Means with the same letters are not significantly different at p<0.05 according to Duncan Multiple Range Test.

Table 5. Distribution of soil physical and chemical properties in the sub-surface (30 - 50 cm) across the different open waste dump sites in dry season

Age of site (years)	pH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				μg/g			
4	7.6a	55.3b	16.0a	28.7b	4.7a	3.7a	0.90a	15.3ab	10.4a
7	7.3a	61.7ab	14.0ab	24.3b	3.6a	3.3a	0.52b	12.2b	9.5a
10	7.2a	64.0ab	9.0b	27.0b	4.4a	2.3ab	0.67ab	20.5a	8.4ab
20	7.3a	70.3a	14.7ab	15.0c	3.7a	2.4ab	0.59b	10.5b	6.4b
Control	5.3b	53.0c	3.7c	43.3a	1.3b	3.7a	0.62ab	17.2ab	3.4c

Means with the same letters are not significantly different at p<0.05 according to Duncan Multiple Range Test.

increasing soil depth. Soil pH is an important parameter that directly influences sorption/desorption, precipitation/dissolution, complex formation and oxidation reduction reactions. As observed by Mclean and Bledsoe

Table 6. Distribution of soil physical and chemical properties in the sub-surface (15 - 30 cm) across the different open waste dump sites in wet season.

Age of site (years)	pH	Sand	Silt	Clay	Organic matter	K	Na	Ca	Mg
		%				µg/g			
4	7.7a	58.3ab	16.3a	25.3b	3.9ab	1.5ab	0.96ab	10.5ab	5.9a
7	7.1a	55.7ab	12.3ab	32.0ab	2.1b	1.8ab	1.04a	11.3ab	6.4a
10	7.4a	57.7ab	12.0ab	30.3ab	4.2a	1.9ab	0.75b	8.7b	6,7a
20	7.4a	69.3a	17.3a	13.3c	1.8c	2.5a	1.09a	14.3a	6.4a
Control	5.8b	58.7ab	4.7c	40.3a	1.3c	2.2a	0.67b	13.3a	6.8a

Mean with the same letters are not significantly different at p<0.05 according to Duncan Multiple Range Test.

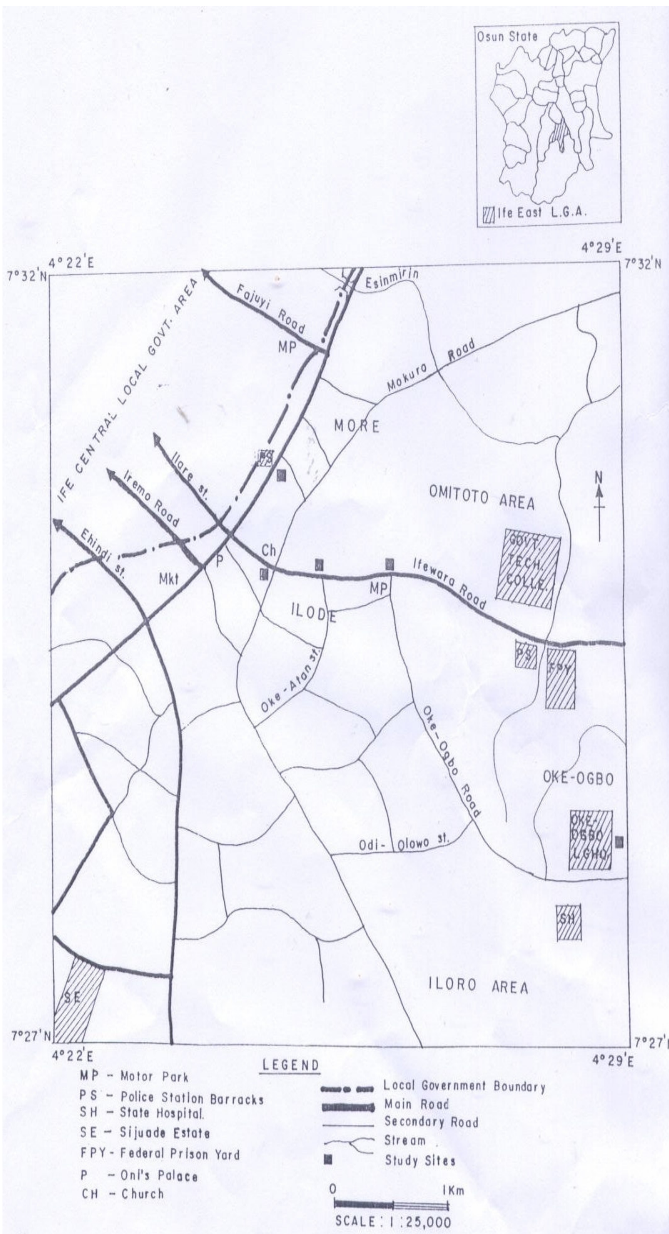

Figure 1. Map of Ife central local government showing the study sites.

(1992) the maximum retention of cationic metals occurs at pH > 7 while anionic occurs at pH < 7.

The textural composition of the soils did not differ significantly with sites and across the two seasons. This is expected as soil texture is mainly inherited from the soil forming parent materials. The soils percentage of sand and silt generally decreased with increasing depths, while the clay contents increased down the profile. Kadeba (1978) demonstrated the importance of clay as a parameter for predicting the exchange capacity of the subsoil. The soil organic matter (SOM) content of the surface (0 -15 cm) soil ranged from 3.0 to 6.2% in the dry season and from 2.7 to 4.2% in the wet season. Meanwhile, the SOM content in the sub-surface (15 – 30 cm) depth ranged between 1.9 to 5.9% in the dry season and from 1.1 to 4.2% in the wet season. The significantly higher SOM contents of the soils in the dry season compared to the wet season is because the lower soil moisture contents during the dry season retards the activities of the microorganisms involved in the organic matter decomposition thereby accumulating more organic matter in the dry season. The SOM content of the control site was significantly lower compared to the waste dump sites. The organic matter content of the subsoil plays an important role in adsorption reaction in the soil thereby preventing pollutants from reaching ground water sources (Alloway and Aryes, 1997; Puls et al., 1991; Mclean and Bledsoe, 1992). Clay along with SOM accounts for a great percentage of the total cation exchange site. The soils' concentrations of exchangeable bases significantly differ across soil depths, between the seasons and among the dump sites. This may not be unconnected to the heterogeneous nature of wastes received by different dump sites, which is expected to impact differently on soil properties. Dry season mean values were slightly higher than the wet season values for Ca, Mg and K which can be attributed to the leaching of these cations down the profile by rainfall (Wong et al., 2005). It was observed further that the soil content of most of the exchangeable bases reduced down the profile on most of the dump sites. This is apparently because the cations are concentrated in the organic matter rich surface soil that is mixed with waste materials at different stages of decomposition

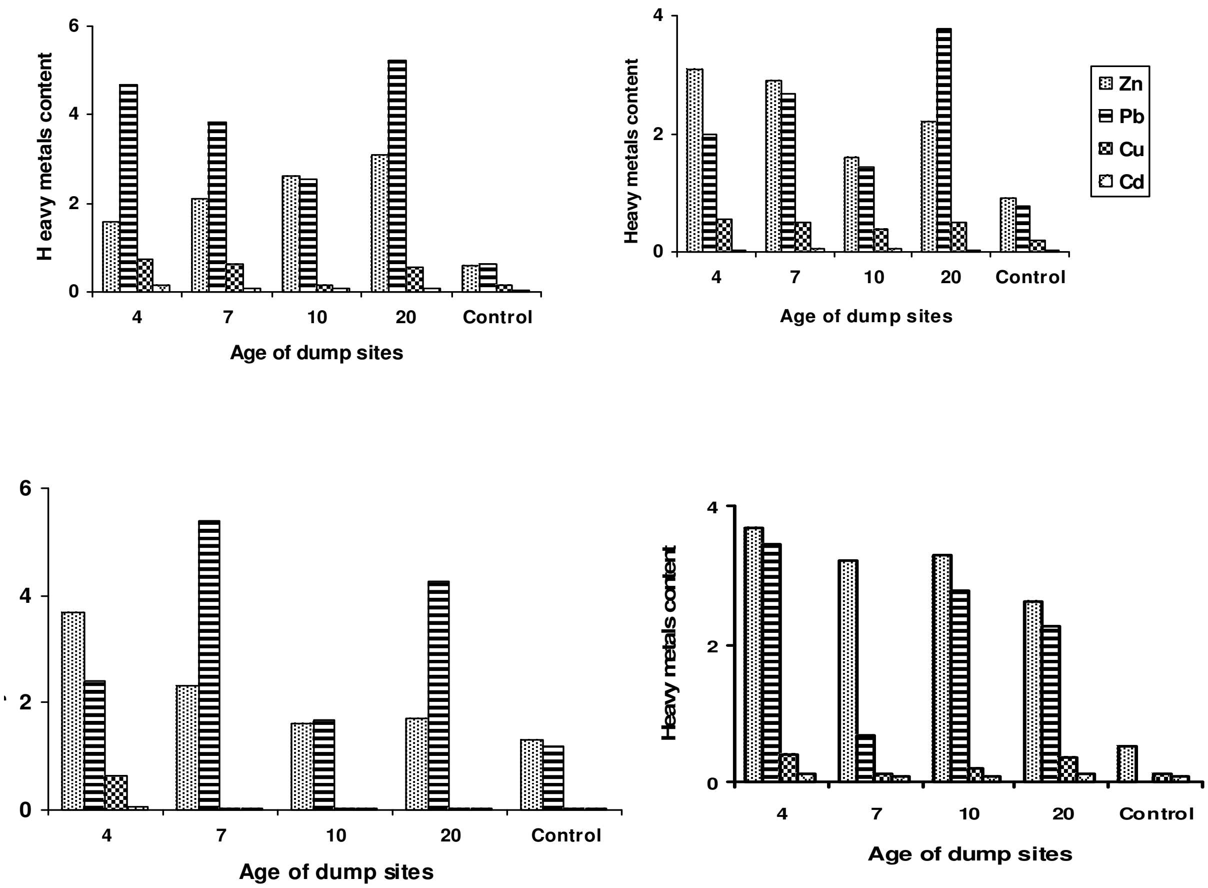

Figure 2. Influence of the age (years) of dump site on the distribution of heavy metals (µg/g soil) in the topsoil (0-15 cm) during (a) the wet season, (b) dry season and on subsoil (15 – 30 cm) during (c) wet season and (d) dry season.

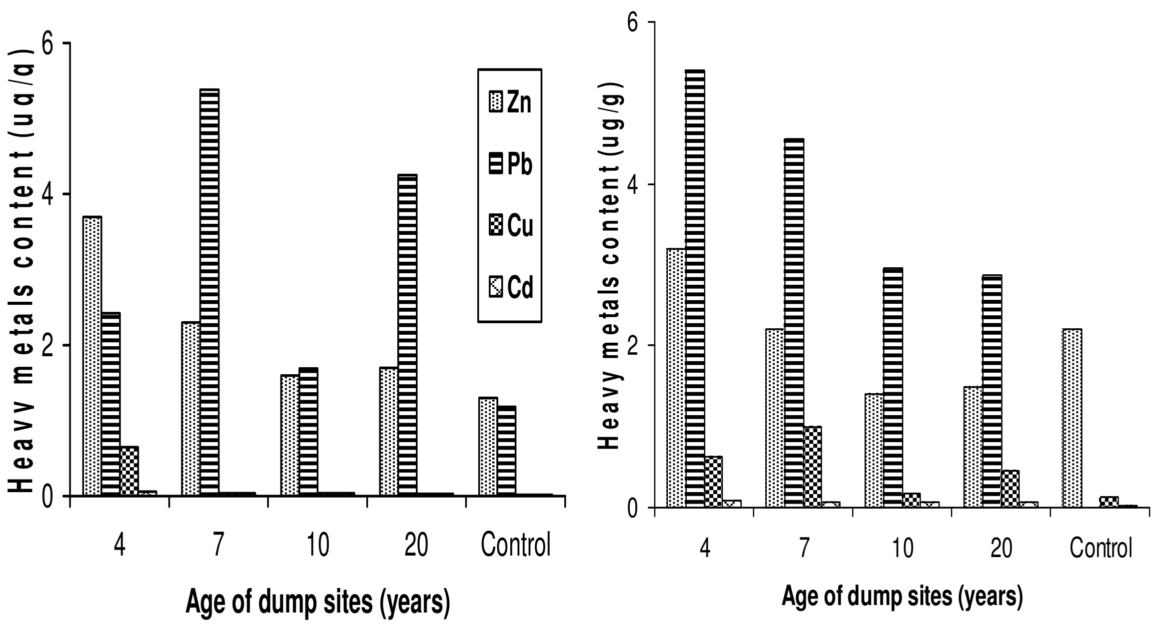

Figure 3. Influence of the age (years) of dump site on the distribution of heavy metals (µg/g soil) in the subsoil (30 - 50 cm) in the dry season.

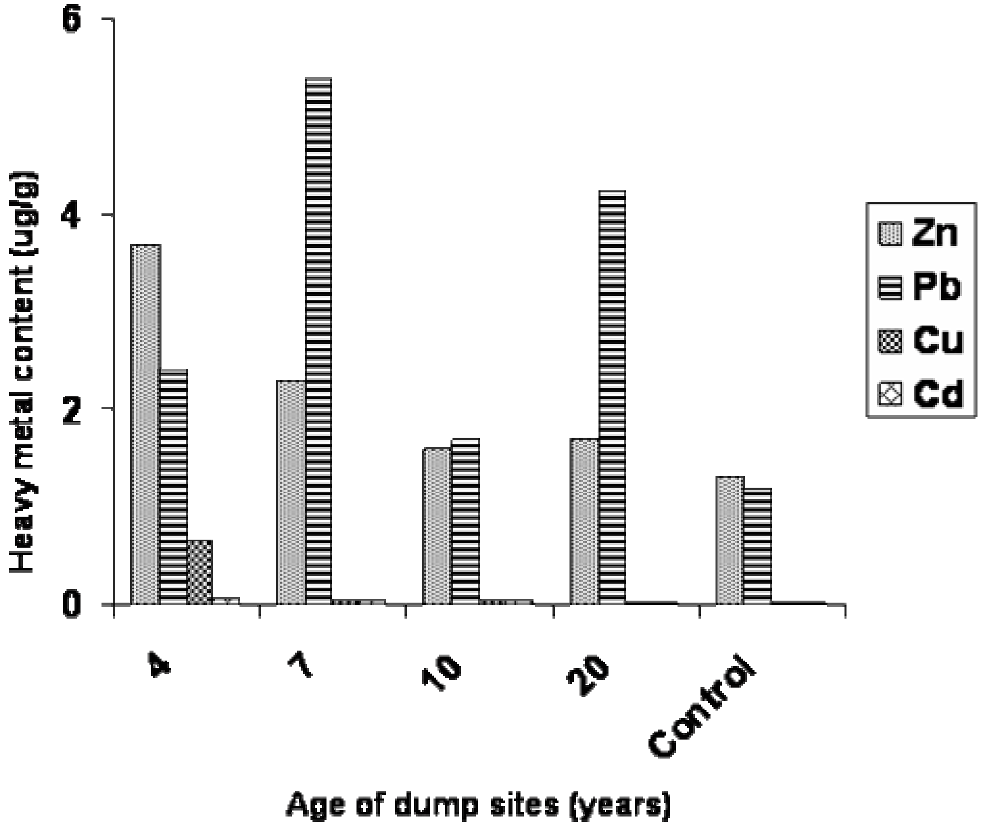

Figure 4. Influence of age of dump site on the distribution of heavy metals (µg/g soil) in the subsoil (15-30 cm) during the dry season.

which continuously release the cations.

Heavy metals contents

The soil distribution of heavy metals in the surface (0 - 15 cm) is shown in Figures 2 and 3. The figures showed that the soil heavy metals content was significantly lower on the control site with no waste, while the oldest dump site which was about 20 years old had the highest concentration of heavy metals. In the dry season (Figures 2, 4 and 6) heavy metals showed variability with depths from one dump site to the other. Lead for instance increased with depth from 37.9 ugg^{-1} in the topsoil to 42 ugg^{-1}Pb in the subsoil on the oldest site. In the wet season (Figures 3, 5 and 7), Pb ranged from 46.8 $µgg^{-1}$ in the topsoil to 102.1 $µgg^{-1}$ Pb in the subsoil above the critical value of 100 ugg^{-1} (Kabata-Pendias and Pendias, 1984). On the other dump sites, Pb reduced with increased depth which was in line with studies by Oyedele et al. (1995), Alloway and Ayres (1997); Bada et al. (2001) and Amusan et al. (2003). The results further showed that the significant differences in the distribution of Cu and Zn in the wet season could be attributed to leaching conforming to observations of earlier studies by Hodgson (1963), Alloway and Ayres (1997), McBride (1981) and Loneragan et al. (1981). In this study however, the concentrations of Cu and Zn decreased with increasing soil depth which is an indication of their low mobility. This is in line with earlier studies by Hodgson (1963) and Alloway and Ayres (1997) who both observed that Cu and Zn are among the least mobile of the trace elements. Cavallaro and McBride (1978) suggested that Cu might be retained in the soil through exchange and specific adsorption mechanism. Hickey and Kittrick, (1984); Kuo et al. (1983); and Tessier et al. (1980) found out that the greatest percentage of the total Zn in polluted soils were readily adsorbed by clay minerals. The behaviour of heavy metals in the soil all depends on the soil pH, properties of metals, redox conditions, soil chemistry, organic matter content, clay content, cation exchange capacity and soluble ligands in the surrounding fluid. The pH of the soils under study generally hovers around the slightly acidic to neutral range and may be responsible for the relative immobility of the heavy metals in the soils. Heavy metals are generally more mobile in the soil in the acidic pH range.

Heavy metals contents of plant tissues

The uptake of heavy metals by cocoyam on the waste

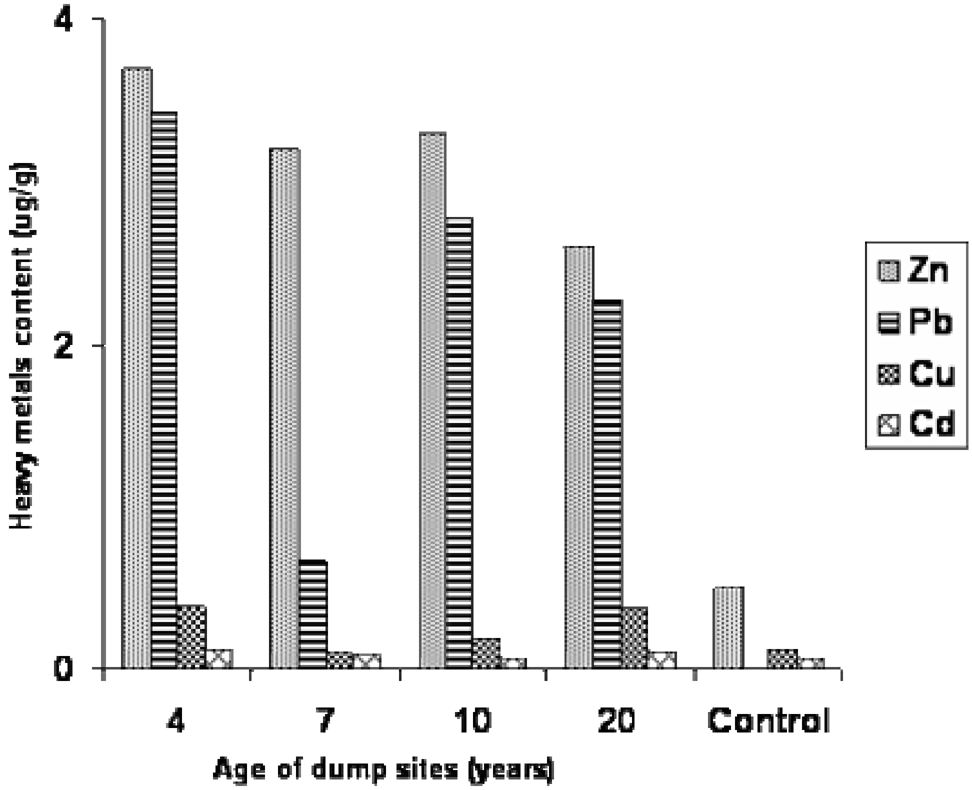

Figure 5. Influence of age of dump site on the distribution of heavy metals (µg/g soil) in the subsoil (15-30 cm) during the wet season.

Table 7. Comparison of the heavy metals contents (µg/g) of cocoyam leaves among the different dump sites

Age of site (years)	Zn	Cd	Cu	Pb
	µg/g			
4	2.08	0.03	0.23	17.43
7	3.40	0.06	0.04	2.45
10	0.52	0.05	0.59	85.65
20	0.8	0.05	0.23	48.95
Control	1.03	0.04	0.05	0.52

Table 8. The transfer factor of heavy metals from soils of dump sites to cocoyam plants

Age of site (years)	Zn	Cd	Cu	Pb
	µg/g			
4	0.75	0.27	0.40	0.18
7	1.36	0.86	0.09	0.09
10	0.29	0.6	2.57	4.05
20	0.33	0.63	0.5	1.42
Control	0.50	0.80	0.33	0.05

dump sites are shown in Table 7. Uptake of Pb was highest compared with other heavy metals analyzed. This ranged from 0.52 µg g^{-1} in control site to 85 µg g^{-1} in the 10 years old dump site. The least uptake of Zn by cocoyam (0.52 µg g^{-1}) was observed on the 10 year old dump site while the highest uptake of 3.40 µg g^{-1} was obtained on the 7 year old dump site. There were also significant differences in the uptake of Cd among the sites. There was no significant difference in the uptake of Cd in the control site and the 4 years old dump site which had the least uptake, while the highest Cd uptake was again obtained on the 7 year old dump site. The uptake of Cu was least on the control site and highest on the 10 year old dump site.

Transfer factor of heavy metals

To be able to determine the extent of heavy metals contamination of the soil, an enrichment factor was computed. This was expressed as the ratio of the concentration of the metals in plants (Table 8) to that in soil according to the method by Oyedele et al. (1995). The transfer factor (TF) varied significantly among the dump sites and among the species of the heavy metals. The least TF values were recorded on the control site. It varied from 0.05 units for Pb to 0.80 units for Cd. The 10 year old dump recorded the highest TF value which ranged from 0.29 for Zn to 4.05 for Pb. The TF values recorded in this study is an indication of the potentials of

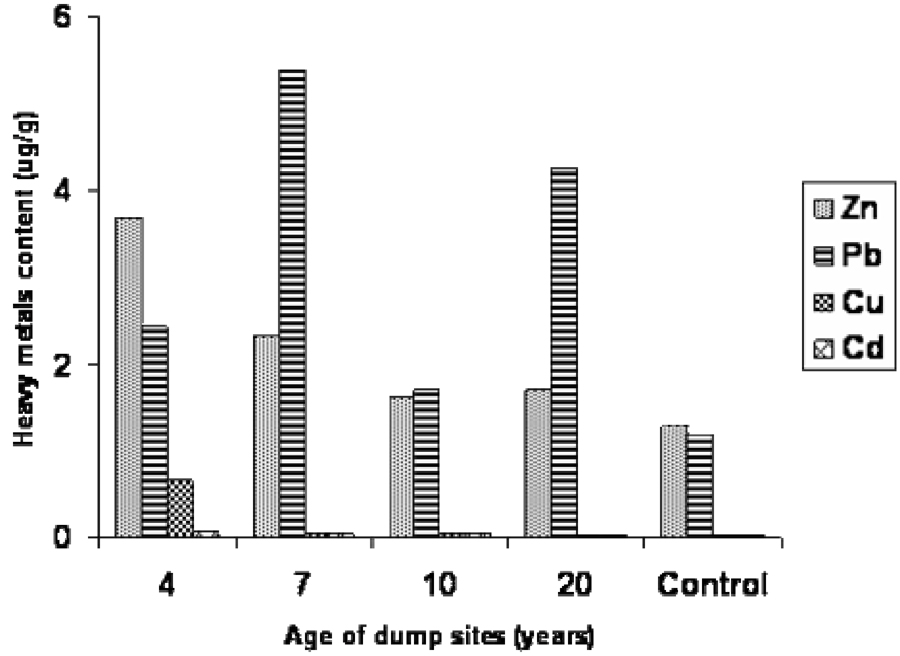

Figure 6. Influence of the age of dump site on the distribution of heavy metals (µg/g soil) in the subsoil (30-50 cm) in the dry season.

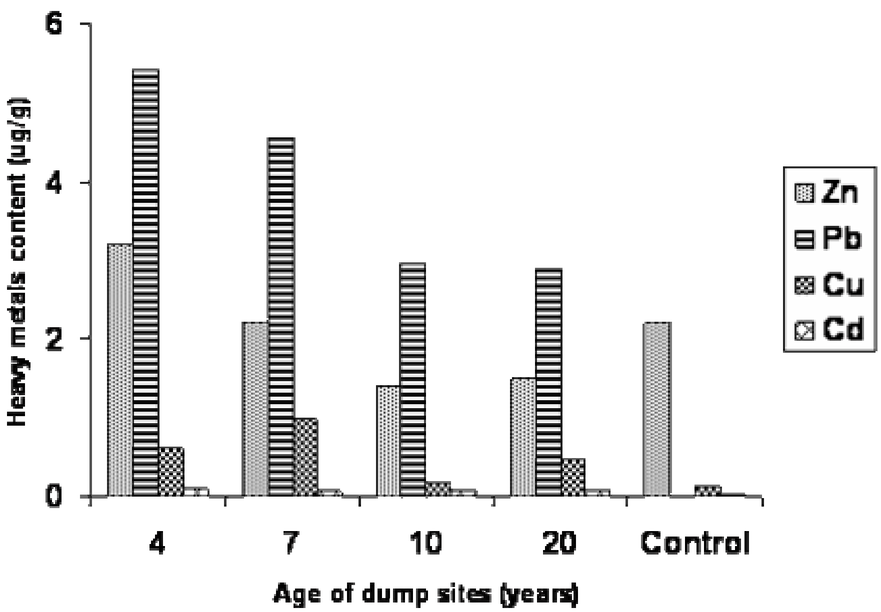

Figure 7. Influence of the age of dump site on the distribution of heavy metals (µg/g soil) in the subsoil (30-50 cm) in the wet season.

the heavy metals in these dumps sites to be transferred into the food chain through the consumption of edible plants on the sites by either animals or man.

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