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Assessment of lead, copper and zinc contamination of soil from University of Cape Coast School of Agricultural farmland, Ghana

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ABSTRACT

The extent of heavy metal contamination viz. lead (Pb), copper (Cu) and zinc (Zn) in the soil of the University of Cape Coast School of Agricultural farmland, Ghana, were assessed. Thirty soil samples were taken from six demarcated areas in the farm. The mean metal concentrations (mean ± cv) and ranges of the metals were (5.37 ± 45.44) 1.93- 11.88 for (Pb); (2.52 ± 118.9) 0.04-24.63 for (Cu); (475.87 ± 26.54), 135.6-887.01 and for Al, (393.83 ± 33.38) 138.32-1051.56. The results showed that the metal concentrations in the soil at six sites decreased in the order: Zn > Pb >Cu. The variation in the distribution of the metals in the soil was found to be in the order Cu > Pb > Zn. The enrichment factor indicated that the soil was enriched with the metals, and the extent of enrichment was in the order, Zn > Pb > Cu. The geoaccumation index and the mean enrichment quotient indicated that the soil was polluted. This contaminated soil sediments could act as a source of pollutant for crops grown in the farm.

Keywords: Heavy metal pollution, enrichment, soil.

INTRODUCTION

The accumulation of heavy metals in agricultural soils and crops raise concerns because they contribute toxic elements into the human food chain. Heavy metal contamination of soil results from anthropogenic source such as agriculture (Vaagalmaa and Conley, 2008; Srivastava et al., 2005; Igwe et al., 2005). Heavy metal pollution of soil enhances plant uptake causing accumulation in plant tissues and eventually phytotoxicity and change of plant community (Ernst 1996; Zayed et al., 1998; Gimmler et al., 2002). According to Alloway et al. (1990), leafy vegetables generally tend to accumulate higher metal concentrations than root, grain or fruit crops. Vegetables contamination with heavy metals derives from factors such as the application of fertilizers, sewage sludge or irrigation with wastewater (Devkota and Schmidt, 2000; Mangwayana, 1995).

Furthermore, the uptake and bioaccumulation of heavy metals in vegetables are influenced by a number of factors such as climate, atmospheric

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depositions, the concentrations of heavy metals in soil, the nature of soil on which the vegetables are grown and the degree of maturity of the plants at the time of harvest (Lake et al., 1984; Scott et al., 1996; Voutsa et al., 1996). Certain trace elements are essential in plant nutrition, but crops, which are raised on the metal-contaminated soils, can accumulate metals in quantities that are excessive enough to cause clinical problems to both animals and human beings who consume these metal-riched plants (Tiller, 1986; Kabata-Pendias and Pendias, 1984; Alloway, 1990). Previous studies have shown that heavy metals are potentially toxic to crops, animals and humans when contaminated soils are used for crop production (Xian, 1989). Heavy metals may enter the human body through inhalation of dust, consumption of contaminated drinking water, direct ingestion of soil and consumption of food plants grown in metal-contaminated soil (Cambra et al., 1999; Dudka and Miller, 1999).

When the soils of farmland are polluted with zinc, animals will absorb concentrations that are damaging to their health. Water-soluble zinc that is located in soils can contaminate groundwater. Zinc cannot only be a threat to animals, but also to plant species. Due to the accumulation of zinc in soils, plants often have a zinc uptake that their systems cannot handle. Too much zinc can be harmful to health. According to VanMouwerik et al. (1998) and Lenntech (1998), too much zinc may cause poisoning in humans. Zinc is a component of tyres, which is released as they wear (Doss et al., 1995). Plant studies have shown that although Zn is an essential element for higher plants, it is considered phytotoxic in elevated concentrations, directly affecting crop yields and soil fertility. Soil concentrations ranging from 70-400 mg/kg total Zn is classified as critical, above which toxicity is considered likely (Alloway, 1990).

Lead (Pb) levels in plants are to a large extent governed by air-borne Pb contamination which makes leaves and leafy vegetables most vulnerable to this airborne deposition (CCFAC, 1995). Shahi et al. (1997) identified exhausts from petrol-engine motor vehicles that use petrol lead as one of the major sources of Pb in soils. Lead from the atmosphere that lands on soils has low mobility and tends to stay in the top inch of soil. Pb in soil is poorly taken up by roots and is not transported away to the rest of the plant. Therefore, shallow-rooted plants, such as grasses and common vegetables, are particularly vulnerable to picking up lead contamination that originated in the atmosphere. About 7% of the lead in soil is taken up by plants; excessive lead will kill off the plants (Subhuti Dharmananda, 1997). In soils with pH of > or = 5 and with at least 5% organic matter, atmospheric lead is retained in the upper 2-5 cm of undisturbed soil (EPA, 1986).

Lead exposure is strongly associated with learning disorders and behavioural problems of children and the problems persist into adulthood (Mushak et al., 1989; Needleman et al., 1996, 2000). Women exposed to Pb during childhood subsequently pass the Pb onto the foetus during pregnancy and to the neonate during nursing (Gulson et al., 1998, 2002). In this way, Pb exposure is passed from generation to another and the problems become intergenerational legacy of the community (Mielke et al., 2004). Widespread Pb poisoning corresponds to IQ deficits, violent crimes and unwed pregnancies, all of which have implications to an array of social and psychological outcomes (Nevin, 2000). It may also lead to higher risks of heart attacks and strokes in adults.

When copper ends up in soil, it strongly attaches to organic matter and minerals. As a result, it does not travel very far after release and it hardly ever enters groundwater. The effect of copper toxicity is largely on root growth and morphology. Copper tends to accumulate in the root tissue with little translocated to the shoots. Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Usually water-soluble copper compounds occur in the environment after release through application in agriculture (Lenntech, 1995, 1998). Heavy metals exert toxic effects on soil microorganism (Pawlowska & Charvat, 2004) hence results in the change of the diversity, population size and overall activity of the soil microbial communities (Smejkalova et al., 2003; Gupta, 1992; Hattori, 1996; Kelly et al., 2003).

Previous studies have shown that the soil in the University of Cape Coast School of Agriculture Farms have high levels of Cu. This could be translocated to the crops grown on the land and render the crops hazardous for human consumption and also adversely affect cattle and sheep that feed on the land. Other metals, apart from Cu may be present due to the application of pesticides. The present study therefore was aimed at evaluating the pollution levels of Cu, Zn and Pb in soil from the University of Cape Coast School of Agricultural farmland contaminated with heavy metals.

MATERIALS AND METHODS

Sampling

The selected site is a farm located at the northern section of the University of Cape Coast. The sites were chosen because previous studies revealed that the soil was enriched with cu; and the proximity of some sections of the farm to the road and potential for food crops to be polluted with heavy metals.

Soil and plant samples were collected from pre-selected sites A, B, C, D, E and F. Each sample site was divided into five areas before sampling. Ten samples of soils were collected at random at a depth of 0-20 cm, from each of the demarcated areas using a garden trowel into a plastic container, mixed to obtain a homogenous sample and then placed into labeled plastic polyethylene bags for laboratory analysis. Five sets of samples were obtained from each of the six pre-selected sites.

Sample treatment

The soil was digested using the method described by MAFF (1981). Soil samples were air-dried and passed through 2 mm mesh. 1 g of each of the homogenized samples of soils was put into a 100 ml beaker and 10 ml of concentrated HNO_3 added. The mixture was heated until it almost dried. Further 10 ml of HNO_3 and 3 ml of $HClO_4$ were added and the solution heated and then allowed to evaporate to about 1-2 ml. 4 ml of hot concentrated HCl was placed into a labeled plastic polyethylene bags for laboratory analysis added and then reflux for 10 minutes. Finally, the wall of the beaker was wash down with double distilled water, filtered in to a 50 ml volumetric flask, and diluted to the 50 ml mark. All the digests and the blank solutions were analyzed for Pb, Cu, Zn and Al with an atomic absorption spectrometer (Spectr AA 220Fs, Varian). All experiments were carried out in duplicate.

In order to validate the precision of the analysis, reproducibility and recovery studies were carried out by analyzing double distilled water containing 1.0 ppm of Pb, Zn, Cu and Al and samples spiked with 5.0 ppm standards respectively.

The statistically analysis of the data was done using Microsoft Excel 2007 and SPSS software (version 16.0 for Windows) Shapiro-Wilk test of normality was used to explore the data at 0,05 significance level; Spearman Rho method of regression and correlation was used to identify the relationship among metals.

RESULTS AND DISCUSSION

The results of precision and accuracy analysis are shown in Table 1. The percentage recovery of the metals Pb, Cu, Zn and Al, from the spiked samples were respectively 98.6 5%, 97.65%, 97.1 % and 99.5%. The results for the analysis of heavy metals in the soil from UCC School of Agricultural farmland are shown in Table 2 and Figure 1. The distribution of heavy metals at all the six sites follow a general trend, Zn > Pb > Cu. There were variation trends in the levels of the metals at all the individual sites. The relative standard deviation (Table 2) showed that the variation in the distribution of the metals in the soil from the farmland was in the order Cu > Pb > Zn. The two sites E and F close to the road had the highest amounts of Zn, with mean and ranges, in mg/kg, being respectively 588.39 ± 150.54 (413.46-809.17) and 550.18 ± 202.26 (394.68- 887.01), but had the lowest amounts of both Pb and Cu. The levels of Pb and Cu at site E were respectively 3.62 ± 0.62 (2.31-3.91); and 0.20 ± 0.68 (0.23-1.71), and at site F the levels were respectively 3.83± 0.24 (3.69-4.27) and 2.28 ± 0.23 (1.24 -3.75. The overall mean concentrations (mean ± cv) and ranges of the metals in mg/kg for all the sites were Pb, 5.37 ± 45.44 (1.93- 11.88); Cu, 2.52 ± 118.9 (0.04-24.63); Zn, 475.87 ± 26.54 (135.6-887.01) and Al, 393.83 ± 33.38 (138.32-1051.56). The Cu levels are comparable to previous findings.

The mean concentration of Pb, 5.37 ± 0.45 mg/kg, was within the acceptable limits of Pb = 1-500 mg/kg (average = 50 mg/kg) recommended by the Interdepartmental Committee on Reclamation of Contaminated Land (ICRCL, 1987) for heavy metals in soil used for agriculture, but much lower than the maximum tolerable levels proposed for agricultural soil (90-300 mg/kg DW) by Kabata-Pendias and Pendias (1984). None of the samples had lead level greater than the recommended average. The mean concentration of Zn (475.87 ± 0.27) was greater than the level recommended by Alloway (1990). Soil concentrations ranging from 70-400 mg/kg total Zn is classified as critical, above which toxicity is considered likely (Alloway, 1990). 73 % of the samples had levels above the recommended limit, and 27 % had levels within the limits set by Alloway. Copper levels were within the normal range of 2-250 mg/kg recommended by Kabata Pendias and Pendias (1984) and also below 300 mg/kg recommended by EC (1986) and MAFF (1992). Generally the zinc levels were found to be above the normal range of 10-30 mg/kg observed by Logan (2000) and the 100 mg/kg given by EC (1986) and MAFF (1992). Regression and correlation analysis (Table 3) indicated that there were no significant relationships among the three metals at 0.05 and 0.01 confidence levels.

To evaluate the extent of contamination, the enrichment factor was calculated using the relation, $EF = [C_n / C_{ref}] / [B_n / B_{ref}]$ where C_n is content of the examined element in the examined environment, C_{ref} is content of the examined element in the reference environment, B_n is content of the reference element in the examined environment and B_{ref} is content of the reference element in the reference environment. Al was used as the reference element for normalization. Five contamination categories are recognized on the basis of the enrichment factors; EF < 2 –

depletion to minimal enrichment; EF = 2 – 5 – moderate enrichment; EF = 5 – 20 – significant enrichment; EF = 20 – 40 - very high enrichment; EF > 40 – extremely high enrichment (Huu et al., 2010). EF values increase with increase contributions of the anthropogenic origins (Sutherland 2000). The enrichment factors (Table 4) showed that the soil is extremely enriched with Pb and Zn and significantly enriched with Cu. The extent of enrichment was in the order Cu < Pb < Zn. All the 30 samples indicated extremely high enrichment of Zn; 22 samples showed extremely high enrichment of Pb and 8- very high enrichment. For Cu, 3 samples showed depletion to minimal enrichment of Cu; 7- moderate enrichment; 17- significant enrichment; 2 - very high enrichment and 1– extremely high enrichment. A mean enrichment quotient (MEQ) for the three metals**,** which is determined by summing EFs for Cu, Pb, and Zn and dividing by three, was used to estimate the magnitude of human-induced change in the soil on the farmland. The MEQ also indicated that the soil was contaminated. This observation is most likely due to the prolong application of fertilizers and other agricultural chemicals, particularly Koside 101 and topson. This observation is not strange as the application of agricultural chemicals on farms eventually enrich the soils with heavy metals.

Geo accumulation index (Igeo) was calculated using the formula Igeo = $\log_2 C_n/1.5 \text{ x } B_n$ where C_n is the measured concentration of the element in soil or sediment and B_n is the geochemical background value and 1.5 is a constant (Mediola et al., 2008). The extent of pollution was classified as follows ; Igeo value of < 0, Practically unpolluted; 0 – 1, Unpolluted to moderately polluted; 1 – 2, Moderately polluted; 2 – 3, Moderately to strongly polluted ; 3-4 strongly polluted and > 5 Very strongly polluted (Huu et al., 2010). The results indicated that the soil was not polluted with Pb and Cu but was moderately polluted with Zn. Also none of the individual samples was found to be polluted with Cu or Pb.

Pollution load index (PLI) for the entire sampling site was determined as the nth root of the product of the n contamination factors (CF). $PLI = (CF_1 \times CF_2 \times CF_3 \times \cdots \times CFn)^{1/n}$. This empirical index which provides a simple, comparative means for assessing the level of heavy metal pollution according to Usero et al. (2000), revealed that polluted soil has a value of PLI >> 1.

Table1: Recovery of metal from 1.0 ppm standard.

Variable	**Metal (ppm)**			
	Pb	**Cu**	**Zn**	**Al**
Mean	0.996	0.986	0.981	0.996
sd	0.017	0.03	0.011	0.017
CV	1.706	3.043	1.121	1.706
Std. Error	0.005	0.009	0.003	0.005

Table 2: Concentration of Pb, Cu, Zn and Al is Soil.

Sample	Pb	Cu	Zn	Al
A1	11.25	2.04	341.04	374.12
A2	6.71	1.78	250.45	337.57
A3	11.88	12.13	513.32	1051.56
A4	10.88	24.63	541.75	569.11
A5	8.12	1.67	492.95	569.71
B1	9.77	1.18	135.36	188.32
B2	1.93	2.1	158.6	138.32
B3	4.42	1.17	341.81	416.79
B4	3.53	0.84	265.85	301.51
B5	3.6	2.37	379.91	352.69
C1	5.58	0.94	414.71	444.2
C2	11.77	5.61	454.62	318.9
C3	7.93	0.01	518.49	330.25
C4	3.84	0.81	350.23	182.14
C5	3.83	0.81	530.82	272.52
D1	4.94	0.86	600.17	286.17
D2	3.66	1.97	442.74	172.65
D3	5.38	0.79	670.24	359.2
D4	3.57	1.33	667.79	288.99
D5	2.91	0.04	512.47	160.44
E1	3.31	0.8	413.46	417.71
E2	3.36	1.57	595.25	611.59
E3	3.17	0.23	491.76	273.3
E4	3.71	1.69	809.17	505.7
E5	3.91	1.71	632.29	501.47
F1	3.76	2.44	472.08	328.75
F2	3.74	2.03	394.68	445.22
F3	3.71	1.24	413.21	305.8
F4	3.69	3.75	583.92	634.19
F5	4.27	1.93	887.01	676.33

Table 3: Correlation matrix for elements in the soils of study area.

		Pb	Cu	Zn
Pb	Correlation Coefficient	1		
	P-value	.		
Cu	Correlation Coefficient	0.262	1	
	P-value	0.162	.	
Zn	Correlation Coefficient	0.017	-0.042	1
	P-value	0.927	0.827	.
	N	30	30	30

P= 0.05

Table 4: Summary of mean Igeo, and mean EF.

Metal	mean EF	mean Igeo
Pb	63.32	-2.66
Cu	11.12	-5.74
Zn	908.6	1.63

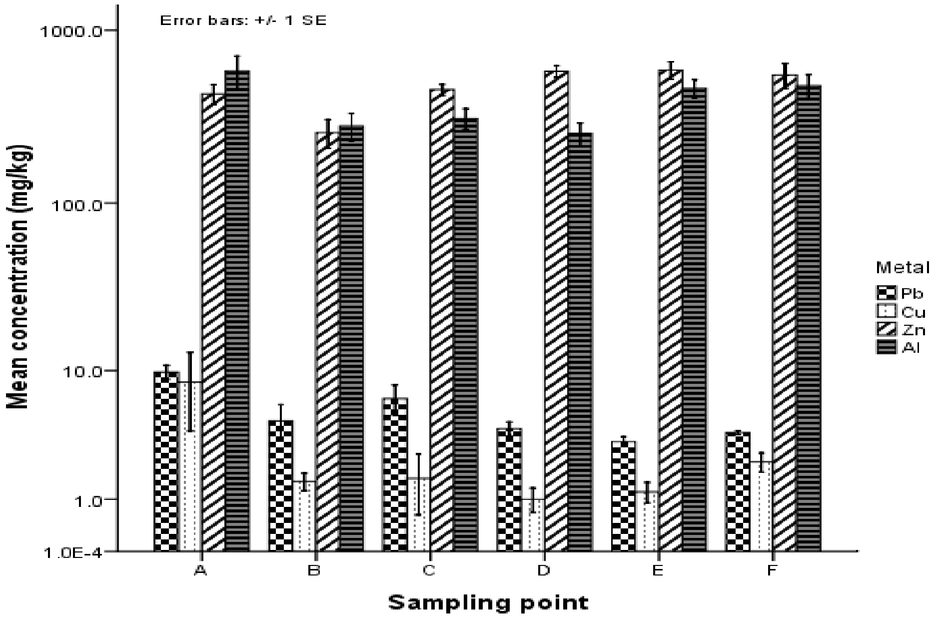

Figure 1: Mean concentrations of metals at the sampling sites.

Conclusion

In conclusion, Zn levels in the soil of the University of Cape Coast, School of Agricultural farm is remarkably high, but varied within the farmland. Our results suggest that special attention must be given to the need to control the use of agricultural chemicals, because a large portion of metals in the soil sediments are likely to be translocated into food crops grown on the soil.

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