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Toxicological Assessment of Crops Grown in Soils Amended with Municipal Solid Waste Ash

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Authors' contributions

This study was carried out in collaboration among all authors. Author GDI designed the study, wrote the protocol, performed the statistical analysis, managed data storage and wrote the first draft of the manuscript. Author EON co-designed the study, managed the data processing, supervised the study, managed the literature searches and reviewed drafts. Author GOA co-designed the study, co-supervised the study and read manuscripts. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed heavy metals (As, Cd, Cr, Cu, Pb, Ni, Fe and Zn) in sites and food crops (beans and groundnuts) harvested from farmland amended with municipal solid waste (MSW) ash. Farmlands with no amendments and crops grown on such soils served as control. Soils and crops samples were collected at full maturity to determine soil levels (mgkg^{-1}), translocation in crops and accumulation index of metals. The crops were separated into roots, leaves and grains before analysis and heavy metals were determined using VGB 210 Atomic Absorption Spectrometer. Mean concentrations (mgkg^{-1}) of studied metals were 0.053±0.03, 0.053±0.01, 648.55±1.07, 168.699±1.05, 36.514±4.66, 339.53±0.12, 232.331±0.69 and 363.482±0.00 in test soils and

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0.010±0.10, 0.050±0.01, 83.333±1.00, 38.618±1.03, 2.913±0.00, 163.248±0.22, 41.579±3.01and 82.798±0.28 in control soils for As, Cd, Cr, Cu, Ni, Pb, Fe and Zn respectively. Observed levels for test soils were significant (p≤0.05) in comparison to those of the control and were highest for Cr, Cu, Ni, Fe and Zn. Metals concentrations in the tissues of beans and groundnut grown on both sites were found to be decreasing in the order roots > leaves > grains. Levels of As, Cr, Cu, Ni and Fe fell below the WHO standard while Cd, Pb and Zn exceeded those set limits. Translocation factors for beans and groundnut cultivated on test site indicated effective translocation of arsenic from soils to the roots. Observed pattern has health implication for raised fodder for animal husbandry in such areas. Similarly, the geo-accumulation index of both test and control sites revealed they were polluted with Zn, Cr, Ni, Cu, Ni, Cu and Fe.

Keywords: Heavy metals; municipal solid waste; soil amendments; geo-accumulation index; translocation factor.

1. INTRODUCTION

Global environmental and soil quality have been degraded due to increase in the concentration of anthropogenic heavy metals resulting from urbanization, economic/industrial development and waste management problems [1,2]. These consequently increase the risk of human exposure to heavy metals toxicity [3]. Heavy metals are metallic elements that are toxic irrespective their densities, atomic numbers and relative atomic mass [4]. Some heavy metals like chromium compound especially chromium (III), copper, iron and zinc are important in human metabolism at trace quantity but at elevated concentrations, they pose great consequences to human health [5]. Others like Arsenic, lead, cadmium and nickel are non-essential and associated with various health implications. Arsenic exposure for instance is associated with cancer, kidney and respiratory disorders at an elevated concentration [6,7]. Critical ingestions of lead induce liver/kidney damages, nervous system disruption, reproductive and biological system impairment [8]. Cadmium on the other hand is highly toxic and carcinogenic. Excessive exposure can lead to early menopause, low sperm count, cardiovascular diseases and kidney impairment [9]. While nickel can cause skin allergies/inflammations, lung cancer, high dose may lead infertility and biological system malfunction [10]. In addition, food contamination through soil to food transfer is eminent in recent years due to the growing interest in the use of waste-ash derived soils as farm amendments especially in low-income countries [8,2]. The waste ash derived soils are used as amendment on farmland without regard to its constituent element e.g. heavy metals [11]. Safety evaluation is therefore required in order to safeguard the health of consumers. Several studies documented heavy metals in food crops however in places like Potiskum, limited or no data available on heavy metals in food crops. [12] carried out a study on the concentration of As, Cd, Co, Cu, Fe, Ni, Pb and Zn in farm soils adjacent to a dumpsite and a control farmland in Lafiya, Nasarawa state, Nigeria. Roselle, groundnut, maize, spinach and okra were grown on both farms. The study showed concentration in the edible parts of these crops below the WHO safety limits, the study also revealed higher concentration of metals in crops grown on farmland close to the dumpsite when compared with the control. This indicated dumpsites as a potential source of food contamination especially when used as an amendment on farmland. The occurrence of soils heavy metals in the farm around the dumpsite followed the pattern Ni < Zn < Pb < Co < Fe < As < Cd < Cu while for the control farm was Zn < Ni < Pb < As < Co < Fe < Cu < Cd. Similarly, [13] investigated metal composition in maize and tomatoes grown on a contaminated site in Osun, Nigeria, the finding revealed spatial differences in the levels of As, Cd, Co, Cr, Cu, Ni, Pb and Zn between test and control sites with test site recording the highest values ranging from 0.6-2.04, 0.8-5.2, 0.8-3.04 $mgkg^{-1}$ in tomatoes for As, Cd and Pb respectively. The concentration of As, Cd and Pb found in maize was between 0.60 - 2.00, 1.50 - 4.60 and 0.90 - 2.50 $mgkg^{-1}$ which both exceeded the safety limits in $mgkg^{-1}$ of 0.15, 0.02 and 2.0 for As, Cd and Pb respectively set by world health organization [14].

Translocation factor is a measure of the movement of heavy metals from soil via the roots to the shoots of crops cultivated on a contaminated land [15]. It explains the transport behavior of pollutant which is categorized into; soil-root, root-stem/leaves and stem/leaves-grains. [16] investigated geo-accumulation index in an old landfill and a control site in Cameroon. The finding revealed variations in index of geo-accumulation between the landfill site and the control site with landfill site recording higher indices. Similarly, research on metals uptake in plants grown on a dumpsite and a control in Ekiti state, Nigeria, the result indicated higher transfer factors for Cd, Co, Cu, Zn, Pb and Fe in plants grown on the test site than the ones on the control site. The soil geo-accumulation index from the dumpsite was found to be higher than the soil geo-accumulation index in the control [17]. Therefore, the aim of this study is to evaluate the concentrations and geo-accumulation index of heavy metals in the soils and crops cultivated with municipal solid waste ash amendments and a control site to ensure that they are below the permissible standards.

2. MATERIALS AND METHODS

2.1 Study Area

Potiskum is a local government area in Yobe state, north-eastern Nigeria. It is bounded on latitude 11°43′N and longitude 11°04′E, having an estimated land area of about 559 square kilometers with a population of about 205,876 based on 2016 national population census. It is the largest local government area in Yobe state. It has one of the largest cattle markets in West Africa [10]. Farming and livestock rearing are the mainstay of Potiskum residents [18]. Most cultivated crops are pearl millet, sorghum, beans, groundnut, sesame, water melon, onions, tomatoes and okra. The dry season starts from early November to late May and the hottest months are March, April, and May with temperatures ranging between 39°C and 42°C. The period of the rainy season in the area varies but generally lasts for about four to five months from June to early October with annual average rainfall between 500 mm to 1000 mm in total [8].

2.2 Study Site Description

The site chosen for this study consists of two sites of dimension 17m × 17m namely test site (amended with municipal solid waste ash-derived soil) and a control site (free of any amendment). The test site is located on latitude 11°53’21.6’’N and longitude 10°59’38.7’’E while the control site is located on latitude 11°54’21.9N and latitude 10°60’41’’E with a distance of about one kilometer between the two sites as shown in Fig. 1.

2.3 Site Preparation

The selected sites (test and control) were subjected to clearing and the test site was amended with composite municipal solid waste ash-derived soil collected randomly from some selected dumpsites in Potiskum. The sites were ridged and the planting operation was conducted after beans and groundnut seeds that was obtained from local farmers were carefully screened for viability. The planting operation was carried out at a depth between 0.01 – 0.03 m with an inter-planting space of about 0.05 – 0.01 m between stations. Thinning and weeding were conducted on both sites in order to remove excess plants and grasses respectively.

2.4 Soil Sampling and Analysis

Grid soil sampling technique was deployed to obtain soil samples before amendment and after growth in replicates of three with soil auger at a depth of 10 - 30 cm from each of the sites to form a bulk sample, placed in a polyethylene bag, labelled and transported to the laboratory. The samples were pretreated, pH and electrical conductivity was determined using standard methods. Aliquot of about 0.2 g sample was dissolved in 50 ml digestion tube with 6 ml of concentrated nitric acid (HNO_3) added to the samples and 2 ml of concentrated hydrochloric acid (HCl) thereafter and allowed to react for 10 minutes. Then 2 ml of hydrofluoric acid (HF) was finally added to the mixture and allowed to react for further 10 minutes. The prepared mixture was digested using SINEO MASTER 40 microwave digesters at a temperature of 120°C for 15 minutes, 160°C for 10 minutes, 180°C for 20 minutes and lastly 200°C for 30 minutes. The digest was transferred into 50 ml beaker and distilled water was added to the solution to make up 50 ml before analysis.

2.5 Plants Sampling and Analysis

Cultivated crops samples (i.e. beans and groundnut) were randomly selected at full maturity from both test and control sites, separated into roots, leaves and grains, bagged in a polyethylene bag, labelled and transported to the laboratory for pretreatment. The samples were thoroughly washed with tap water, rinsed with distilled water and air dried at room temperature for two weeks. The average temperature of the drying vicinity was 34 – 41^{o}C, the leafy parts of the crops dried earlier followed by stems and roots which were pulverized into powder for analysis. Aliquot of about 0.5 g powdered sample of pulverized roots, leaves and grains was transferred into 70 ml digestion vessels, 8 ml of nitric acid (HNO_3) was added to the samples, 1 ml of hydrogen peroxide (H_2O_2)

was added to the mixture and allowed to react for some time and 0.5 ml of hydrofluoric acid (HF) was finally added to the solution. The mixture was digested at a temperature of 130°C for 15 minutes, 150°C for 10 minutes and 180°C for 20 minutes in a microwave digester. The digest was filtered through 2 mm Whatman's filter paper and the filtered solution was transferred into 50 ml beaker where distilled water was added to the solution to make up 50 ml solution. The concentration of the heavy metals; As, Fe, Cd, Cr, Cu, Ni, Pb and Zn in the resulting solutions from soil and plants materials were analyzed with Buck Scientific 210VGB Atomic Absorption Spectrometer (AAS).

2.6 Quantification of Pollution Level

The translocation factor is mathematically represented as:

$$Translocation\ factor_{roots} = \frac{Roots\ Concentration}{Soils\ Concentration} \quad (2.1)$$

$$Translocationfactor_{stem} = \frac{Stems\ Concentration}{Roots\ Concentration} \quad (2.2)$$

$$Translocation\ factor_{leave} = \frac{Leave\ Concentration}{Roots\ Concentration} \quad (2.3)$$

$$Translocation\ factor_{grains} = \frac{Grains\ Concentration}{Roots\ Concentration} \quad (2.4)$$

The extent of heavy metals contamination in soil was determined using the index of geo-accumulation which indicates soil level of contamination and is categorized into seven classes varying from uncontaminated to extremely contaminated [13,11]. The index of geo-accumulation is given as:

$$Index\ of\ geo-accumulation = \log_2\left[\frac{C_n}{1.5\ B_n}\right] \quad (2.5)$$

Where Cn is the concentration of the metal determined in the soil, Bn is the geo-chemical background concentration and 1.5 is an associated matrix correction factor [2,19].

2.7 Statistical Analysis

Statistical Package for Social Sciences (SPSS) version 20 was used to determine the mean and standard errors of the mean in triplicates determinations. DMRT was deployed for test of significance at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Soil Physicochemical Parameters

The mean initial soil pH for this study was 6.750±0.09 and 8.477±0.03 with electrical conductivities of 87.667±0.33 and 51.000±0.00 respectively for test and control sites. The soil pH in the test site is within the range ideal for crops cultivation however the slight acidity observed and high electrical conductivity may be responsible for increase in soil metals concentration as acidic soil aid metals mobility and availability [20]. The alkalinity and low electrical conductivity observed in the control site could be responsible for observed decrease in soil metals concentrations as reported by [20].

3.2 Metal Concentrations in Soils

The soil's metal concentrations in mgkg^{-1} for test site is presented in Table 1, the concentration followed a sequence Cr (648.550±1.07) > Pb (339.530±4.66) > Fe (363.482±0.69) > Zn (232.331±0.00) > Cu (168.699±1.05) > Ni (36.514±0.12) > As (0.053±0.03)> Cd (0.053±0.01) while those observed in the control site was in the sequence Pb (163.248±0.00) > Cr (83.333±1.00) > Fe (82.798±3.01) > Cu (38.618±1.03) > Zn (41.579±0.28) > Ni (2.913±0.22) > Cd (0.050±0.01) > As (0.010±0.10). In general, the metals concentrations in test site were found to be significant ($P < 0.05$) than those in the control. This difference may have resulted from waste ash amendment. The result also showed that the concentrations of As, Cd and Fe in the test site were below the WHO permissible limits in mgkg^{-1} of 40, 0.8 and 7000 respectively (Table 1). While the concentration of Cr, Ni, Cu, Pb and Zn were above the limits of 100, 85, 100, 35 and 300 mgkg^{-1} for soils set by world health organization (Table 1). In contrast, observed metals concentration in the control site showed As, Cd, Cr, Cu, Fe and Zn below the WHO set limits in mgkg^{-1} of 40, 0.8, 100, 100 and 35 respectively while Ni exceeded the safety limits of 85 mgkg^{-1} (Table 1). The result also indicated concerns for Cr, Ni, Cu, Pb and Zn toxicity among farmers in the test site and Ni toxicity in the control site as the concentrations exceeded the maximum permissible limits in soils.

3.3 Metals Concentrations in Tissues of Cultivation Crops

Tables 2 and 3 presents metals concentrations in the tissues of beans and groundnut grown on test and control site. The concentrations in both sites were found to be decreasing in the sequence roots > leaves > grains with concentrations. As, Cr, Cu, Ni, Pb and Fe in edible parts of beans grown on both test and control sites below the limits in $mgkg^{-1}$ of 30, 10, 10, 10, 2.0 and 20 set by [19]. Cadmium in the edible parts of beans grown on both test and control site exceed the permissible limits in $mgkg^{-1}$ of 0.02 while Zn in the test exceeded but below 0.6 $mgkg^{-1}$ in the control (Table 2). Observed As, Cr, Cu, Ni, Pb and Fe concentrations in the edible parts of groundnut grown on both test and control were below the limits in $mgkg^{-1}$ of 30, 0.02, 10, 10, 2.0 and 20 respectively. While Zn concentration in groundnut grown on the test site was above the set limits of 0.6 $mgkg^{-1}$. Cadmium exposures was reported to have carcinogenic effect and is associated with early menopause, low sperm count, cardiovascular diseases and kidney impairment [17]. Therefore, careful safety evaluation of cadmium is necessary as the concentration in cultivated beans and groundnut was found to exceed the maximum permissible limits set by world health organization.

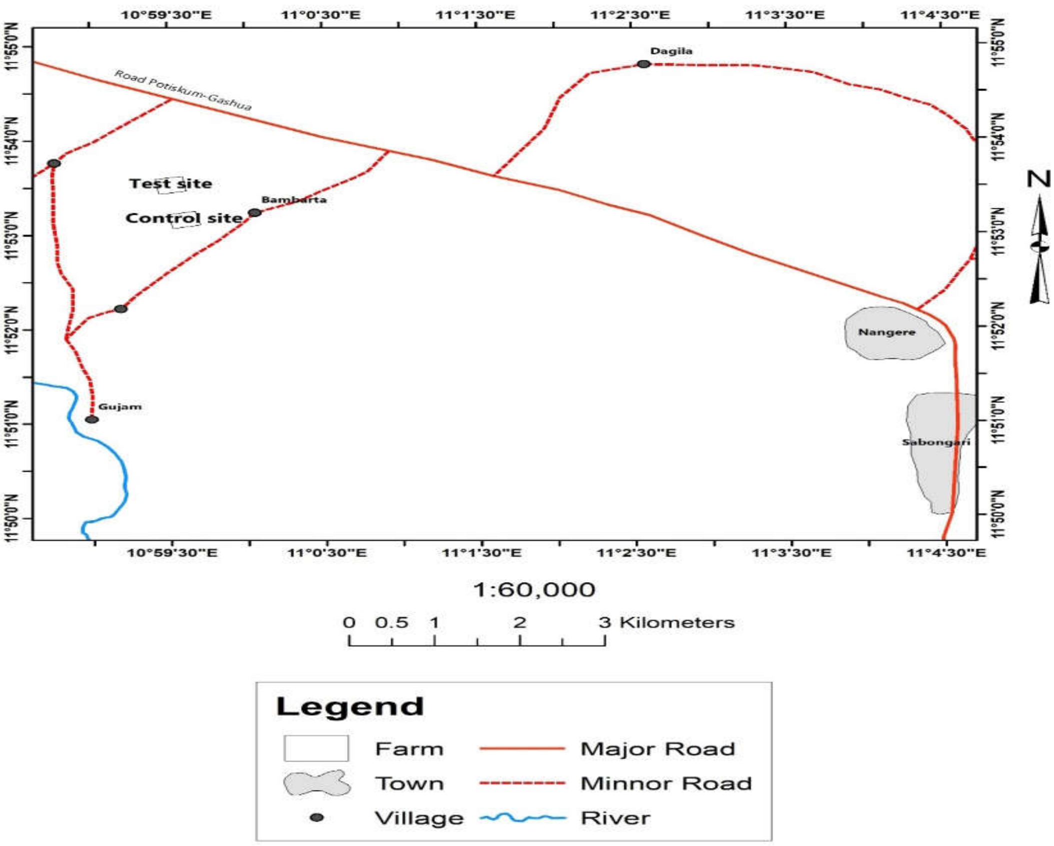

Fig. 1. Map of Potiskum showing test and control sites

Table 1. Mean heavy metals levels ($mgkg^{-1}$), standards, average shale values and the corresponding geo-accumulation indices for studied soils

Metals	Test site	Control site	WHO limits ($mgkg^{-1}$)	Average shale conc.	Igeo (Test)	Igeo (Control)
As	0.053±0.03	0.010±0.10	40	11	-0.410	-1.135
Cd	0.053±0.01	0.050±0.01	0.8	0.1	-2.452	-2.478
Cr	648.55±1.07	83.333±1.00	100	61	4.421	3.530
Cu	168.699±1.05	38.618±1.03	100	23	3.413	2.772
Pb	36.514±4.66	2.913±0.00	35	26	2.801	1.703
Ni	339.53±0.12	163.248±0.22	85	27	3.786	3.468
Fe	232.331±0.69	41.579±3.01	7000	2.94	2.658	1.911
Zn	363.482±0.00	82.798±0.28	300	74	4.253	3.611

Table 2. Heavy metals concentrations in beans tissue grown on test and control site

Beans tissues	As ($mgkg^{-1}$)	Cd ($mgkg^{-1}$)	Cr ($mgkg^{-1}$)	Cu ($mgkg^{-1}$)	Ni ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)	Fe ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)
Roots (Test)	1.420±0.21	0.3226±0.02	3.725±0.10	8.204±0.02	7.633±0.12	3.203±0.24	4.593±0.15	3.333±0.00
Leaves (Test)	0.373±0.00	0.230±0.03	0.6863±0.09	4.765±0.02	2.966±0.21	2.458±0.03	3.111±0.01	1.333±0.00
Grains (Test)	0.3524±0.04	0.0922±0.04	0.3922±0.10	1.322±0.00	0.020±0.07	1.117±0.40	1.037±0.15	1.111±2.22
Roots (Contl)	1.617±0.00	0.369±0.03	2.745±0.55	6.442±0.12	4.643±0.25	2.719±0.04	2.396±0.10	6.711±3.81
Leaves (Contl)	0.373±0.00	0.276±0.01	2.451±0.09	1.276±0.00	2.005±0.31	2.246±0.10	1.290±0.01	2.222±0.44
Grains (Contl)	0.352±0.02	0.0612±0.02	0.324±0.00	0.152±0.00	0.281±0.00	0.194±0.00	0.889±0.00	0.467±0.20
WHO-Limits	30	0.02	10	10	10	2.0	20	0.6

Test = test site, Contl = controls site, WHO Limits = maximum tolerable limit set by World Health Organization for safety

Table 3. Mean±SE of heavy metals in crops tissues of groundnut grown on test and control site

Beans tissues	As ($mgkg^{-1}$)	Cd ($mgkg^{-1}$)	Cr ($mgkg^{-1}$)	Cu ($mgkg^{-1}$)	Ni ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)	Fe ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)
Roots (Test)	1.420±0.21	0.3226±0.02	3.725±0.10	8.204±0.02	7.633±0.12	3.203±0.24	4.593±0.15	3.333±0.00
Leaves (Test)	0.373±0.00	0.230±0.03	0.6863±0.09	4.765±0.02	2.966±0.21	2.458±0.03	3.111±0.01	1.333±0.00
Grains (Test)	0.3524±0.04	0.0922±0.04	0.3922±0.10	1.322±0.00	0.020±0.07	1.117±0.40	1.037±0.15	1.111±2.20
Roots (Contl)	1.617±0.00	0.369±0.03	2.745±0.55	6.442±0.12	4.643±0.25	2.719±0.04	2.396±0.10	6.711±3.81
Leaves (Contl)	0.373±0.00	0.276±0.01	2.451±0.09	1.276±0.00	2.005±0.31	2.246±0.10	1.290±0.01	2.222±0.44
Grains (Contl)	0.352±0.02	0.0612±0.02	0.324±0.00	0.152±0.00	0.281±0.00	0.194±0.00	0.889±0.00	0.467±0.20
WHO-Limits	30	0.02	10	10	10	2.0	20	0.6

Test = test site, Contl = controls site, WHO Limits = maximum tolerable limit set by World Health Organization for safety

3.4 Metals Translocation in Plant

Tables 4 and 5 presents the translocation factors for beans and groundnut grown on both test and control sites respectively. Translocation factors are used to explain heavy metals mobility or phytoremediation capability of plants in metals contaminated environment [21]. Translocation factor < 1 indicate ineffective movement of metals from soil to plants or roots to shoots while translocation factor ≥ 1 indicate effective movement of metals from soil to plants [22]. The sequence of translocation for As and Cd observed in beans was found to be similar to the translocation trend reported for Zn and Fe in beans cultivated with sludge amendment [20]. Observed translocation trend in groundnut grown on test site were roots > leaves > grains for As and Cd, grains > leaves > roots for Cr, leaves > roots > grains and leaves > grains > roots for Cu, Pb, Fe and Zn. The translocation trend also indicated how different plants respond to heavy metals at different concentrations. Except Ni that showed translocation leaves > roots > grains, similar trend was observed for As, Cd, Pb, Fe and Zn for beans and ground. The translocation trend observed for Cd, Cr, Cu, Fe, Zn and Pb in beans and groundnut were found to be leaves > root > grains with a trend root > leaves > grains for Ni and As (Table 4). The overall sequence of metals translocation observed for all cultivated crops in both sites shows different translocation and responses to heavy metals stress as reported by [14,5]. Contrary to finding in [23] the values obtained for the edible parts of the cultivated crops were within the limit set for safe consumption. Nevertheless, there is need to constantly monitor heavy metals concentration in farm soil and the crops cultivated as the metals possess great health concerns (Table 1).

3.5 Soil Geo-accumulation index

The contamination load of the sites for this study was assessed using geo-accumulation index equations 2.5. Assessment for soils from the test site revealed the trend Cr > Zn > Ni >Cu > Pb > Fe > Cd > AS and were ranged from strongly polluted to extremely polluted with Zn and Cr, strongly polluted with Ni and Cu, moderately polluted to strongly polluted with Ni, Cu, Fe and not contaminated with As and Cd (Table 1). Assessment of contamination observed in the control site showed the trend Zn > Cr > Ni > Cu > Fe > Pb > Cd > with As showing moderately polluted to strongly polluted with Cu, strongly polluted with Zn, Ni, Cr, moderately polluted with Fe, Pb and not contaminated with As and Cd (Table 1). In general, the average index of geo-accumulation indicated high pollution level in test site than the control which could be attributed to the municipal solid waste ash-derived soil applied as amendment. The findings validate the report by [16,1] even though the research was conducted on crops grown on landfill and dumpsite as they both contain some as residues.

Table 4. Heavy metals translocation factors for beans grown on test and control sites

Beans samples	Heavy metals							
	As	Cd	Cr	Cu	Ni	Pb	Fe	Zn
Roots (Test)	3.295	0.905	0.006	0.200	0.269	0.042	0.017	0.239
Leaves (Test)	0.780	0.526	0.667	0.777	0.770	0.711	0.857	0.760
Grains (Test)	0.238	0.175	0.589	0.553	0.041	0.163	0.786	0.480
Roots (Control)	0.718	0.480	0.045	0.212	2.620	0.019	0.055	0.080
Leaves (Control)	0.263	0.713	0.184	0.581	0.389	0.767	0.677	0.400
Seeds (Control)	0.248	0.286	0.105	0.161	0.003	0.349	0.226	0.140

Table 5. Heavy metals translocation factors for groundnut grown on test and control sites

Groundnut samples	Heavy metals							
	As	Cd	Cr	Cu	Ni	Pb	Fe	Zn
Roots (Test)	3.751	0.581	0.006	0.070	0.130	0.018	0.017	0.202
Leaves (Test)	0.395	0.361	0.667	0.866	0.490	0.511	0.667	0.536
Seeds (Test)	0.092	0.115	0.926	0.655	0.077	0.284	0.351	0.441
Roots (Control)	1.021	0.549	0.033	0.167	1.594	0.017	0.029	0.161
Leaves (Control)	0.231	0.748	0.893	0.198	0.432	0.826	0.538	0.331
Seeds (Control)	0.228	0.166	0.118	0.024	0.061	0.071	0.371	0.166

Key: Translocation Factor Value > 1: indicated effective translocation, translocation factor value < 1: indicated ineffective translocation from the combustion of the waste. They reported significant metals accumulation index in the landfill and dumpsite when compared to the control.

4. CONCLUSIONS

This study analyzed the degree of As, Cd, Cr, Cu, Ni, Pb, Fe and Zn contaminations in both site (test and control) and the crops cultivated in ash amended soil revealed heavy metal contaminations than those reported for the control. The study further identified high translocation factor for arsenic and cadmium in the root and leaves of studied plants. This could consequently lead to food poisoning via biomagnification. Observed translocation potential in cultivated crops on both test and control site were found to be least effective in the grains but higher in roots and leaves. The pollution level in both test and control sites soil is a cause for concerns as the site is contaminated with varying levels of Zn, Cr, Ni, Cu, Ni, Cu and Fe. Evaluation of municipal solid waste ash is therefore necessary before use as amendment on farmland especially for cultivation of food crops. Cultivated crops and leafy parts should also be monitored for the safe consumption of human and animals as the leafy parts are used as fodders.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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