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Accumulation of Heavy Metals in Soil and Maize Plant (*Zea mays*) in the Vicinity of Two Government Approved Dumpsites in Benin City, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author NAO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BA and OA managed the analyses of the study. Author BA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil contamination by heavy metals is of great concern with respect to human health risks, groundwater contamination, phytotoxicity to plants, adverse effects on microbial activity and diversity, long-term effects on soil fertility and depreciation of land. Soil samples were obtained with the aid of soil Augar within a depth of 0 – 20 cm from the vicinity of the two selected dumpsites in Benin City, Edo State Nigeria. The soil samples were assessed for some physico-chemical properties using standard methods. Maize plants found growing in the dumpsite and control areas were also sampled, partitioned into leaves, stems, and roots prior to analysis in the laboratory for heavy metals determination using atomic absorption spectrophotometer (AAS). The soil sample showed Zn, Cu, Cd, Pb and Cr levels ranging from 42.66-243.81, 2.16-21.41, 0.35-2.59, 1.11-7.76 and 2.99-10.99 mg/kg respectively. Pollution indices such as contamination factor, contamination degree and pollution load index of the heavy metals analyzed were calculated and their values varied among the heavy metals and between the dumpsites. Concentrations of the metals in the

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dumpsite soil and plant were found to be higher compared to those of the control sites. Significant differences of heavy metals accumulations were observed per plant parts, roots having the highest concentrations. The translocation factor, biological concentration factor and biological accumulation coefficient values of the plant species varied for all the metals. These results imply that the dumpsites have associated human health and ecological risks.

Keywords: Dumpsites; heavy metals; translocation factor; soil maize (Zea mays).

1. INTRODUCTION

Dumpsites exist throughout developing countries. Most of these dumping sites are uncontrolled and years old, having grown over time from small dumps to large, unmanaged waste sites [1]. This constitutes serious health and environmental concerns because of the effects on the host soils, crops, animal and human health. Many cities in Nigeria have developed without proper planning and it has led to the presence of open dumps within built-up areas inhabited by millions of people [2]. Consequently, such waste dumps become point source for soil pollution as they serve as host for leachate from dumpsites. Composition of solid wastes in major cities in Nigeria comprises domestic garbage, wood, agricultural waste, industrial waste, hospital waste, polythene bags, plastics, broken glasses, abandoned automobiles, demolition waste, ash, dust, human and animal waste [3]. The proper wastes disposal has been a serious problem in Benin City and most cities in Nigeria. Solid and fluid wastes generation and their poor disposal mechanism in the urban areas of most developing countries have become a threat to the environment [4]. The contamination of soil with heavy metals is an environmental concern because accumulated metals may have adverse effects on soil ecology, agricultural production, animal and human health as well as groundwater quality [5]. While many heavy metals are essential elements at low levels of concentration, they can exert toxic effects at concentrations higher than permitted in the environment [6,7]. They may be volatilized to the atmosphere, especially during dry seasons [8]. In Benin City metropolis, most of the dumpsites are used as fertile soils for the cultivation of some fruits, food crops and vegetables due to the high cost of fertilizer. Some farmers collect the decomposed parts of the dumpsites and apply to their farms as manure. These cultivated plants take up these heavy metals either as mobile ion in the soil solution through their roots or through their leaves thereby making it unfit for human consumption [9]. Recent studies have also reviewed that waste dumpsite can transfer significant levels of these toxic and persistent metals into the soil environment. Eventually these metals are taken up by plant part and transfer same into the food chain [10]. Consequently, higher soil heavy metals concentration can result in higher levels of uptake by plants. Although, the rate of metal uptake by crop plants could be influenced by factors such as metal species, plants species, plant age, plant part soil composition, geographic and atmospheric conditions [11]. Transfer of heavy metal from soils to plants has been proved as an efficient way for removal of these heavy metals through harvestable plant parts such as roots, stems and leaves [12]. However, the metal availability and toxicity to plant can be determined by the soluble and exchangeable fraction of metals in particular [13]. Intake of heavy metals via the crop-soil system has been regarded as the predominant pathway of human exposure to toxic metals [14], and is normally chronic. This is because these metals are non-biodegradable and can undergo global ecological circles [15]. Thus, it become necessary to assess the uptake of heavy metals by maize plant (*zea mays*) in two government approved dumpsites in Benin City, Nigeria in order to determine their potential hazards to human beings and animals. The objective of this study was to determine and compare the content of heavy metals in various parts of the maize plant, namely the leaves, stems and roots compared to the levels in the soil around Oluku and Ikhueniro dumpsite zones.

2. MATERIALS AND METHODS

2.1 Study Area

Ikhueniro dumpsite is the largest and the major open dumpsite site in Benin metropolis. It has been in operation as a disposal facility; permitted to receive commercial and municipal solid waste. However, the absence of waste management and sorting systems lead to the dumping of industrial waste into the dumpsite [16]. Ikhueniro and Oluku dumpsites comprise household materials, hospitals disposables, metals scraps, polyethylene bags and papers, plants materials and debris among other substances. They also consist of scavengers that are involved in sorting some of these materials for re-use.

2.2 Collection of Soil Samples

Soil and plant samples were collected from two government approved dumpsites and their control sites within Benin City, namely Oluku dumpsites (A), Oluku control site (B), Ikhueniro dumpsites (C) and Ikhueniro control site (D). In this research, Soil samples at 0- 20 cm depth from rhizosphere of the maize plant were taken from each site from where plant sample was rooted. At each site, three different points were chosen using cluster random sampling technique to collect the sample. The soil samples were obtained by the use of soil auger, and then blended (mixed) to obtain a representative sample. The samples were air dried and ground to pass through a 2 mm sieve and used for both physico-chemical analysis [17]. Prior to the analysis of plant material, leaf, stem and roots of plants were separated and carefully washed with tap and deionized water in order to remove soil or dust deposits. Then the plant samples were oven-dried at 70°C to constant weight, pulverized, passed through 2 mm steel sieve and weighed in order to determine the heavy metals concentrations by atomic absorption spectrometry [18]. The control soil and plant samples were taken at about 1500 m away from each of the dumpsites.

2.3 Analysis of the Soil and Plant Samples

The pH and the CEC were determined as described by [17]. The hydrometer method described by [19] were used in evaluating the particle size. The method described by [20] were used to determine the organic carbon content, while the total heavy metals determination was carried out using the Tessier's method described by [21]. According to the method, 5 ml of aqua regia (BDH, England) and 1 ml of perchloric acid (BDH, England) were added to 1 g of soil sample in a 150 ml digestion tube and digested on a heating digester until white fumes of perchloric acid appeared. The tube was cooled and the sides rinsed with distilled water and then filtered through a Whatman 1 filter paper into a 100 ml volumetric flask. The volume was made up with distilled water All glasswares used were soaked and washed with chromic acid and rinsed with distilled water. Bulk scientific standard solution was used to calibrate the Atomic Absorption Spectrometer (Pg A500 model, USA). Procedural blank samples were subjected to similar extraction method using the same amount of reagents.

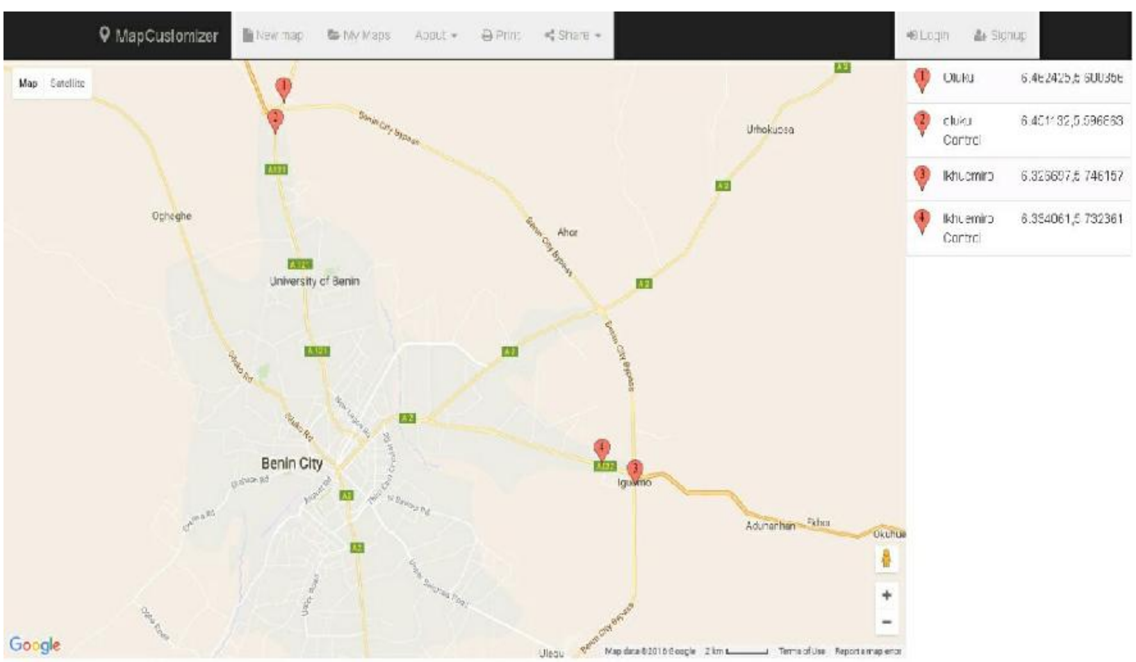

Fig. 1. Map of Benin City showing the sampled sites

3. RESULTS AND DISCUSSION

The physico-chemical properties of the soil samples at various sites are shown in Table 1.

Soil pH plays a major function in the sorption of heavy metals as it directly controls the solubility and hydrolysis of metal hydroxides, carbonates and phosphates [22]. The pH of the studied areas ranged from neutral to moderately alkaline. Most mineral and nutrients are more soluble or available in acidic soils than in neutral or slightly alkaline soils. Soils tend to become acidic as a result of rain water leaching away basic ions (Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) [23].

The CEC parameter particularly measures the ability of soils to allow for easy exchange of cations between its surface and solution. The soil samples from the two dumpsites and their controls shows a low CEC which indicates that they are more likely to develop deficiencies in potassium (K^{+}), magnesium (Mg^{2+}) and other cations, while high CEC soils are less susceptible to leaching of these cations [24]. The low values of the CEC were attributed to high sandy nature of the soil samples. Textural analysis showed the preponderance of sand fraction, followed by clay then silt, thus classifying the parent soil as loamy sand. Sandy soils are known to have a poor retention capacity for both water and metals [25]. Low organic matter (2.12 – 3.28 %) was observed in all the soil samples. The low organic matter content of the dumpsite and the control soil samples is an indication that these soils will have low adsorption strength and an increased metal mobility and bioavailability [26].

The soil samples showed the presence of Zn, Cu, Cd, Pb and Cr in all the sites analysed This could be attributed to the availability of wastes containing those metals at the dumpsites which are eventually leached into the underlying soils. The concentrations of heavy metals are higher in each of the dumpsites than their respective control sites. [14], observed that heavy metal concentration in soils is usually high near the sources, and decline with both distance and depth due to physical dilution and increasing limits in mobility. In overall terms, the results of the present study suggested that the five metals decline in the following order: Zn>Cu>Cr>Pb>Cd for each of the two sites. The results of heavy metals obtained from the analysis also indicate that the concentrations of the heavy metals were found to be higher in Ikhueniro dumpsite when compared with Oluku dumpsite. The higher concentration could be as a result of waste carrying more concentrations of these metals in Ikhueniro dumpsite compared to that of Oluku dumpsite.

3.1 Assessment of Metal Contamination

3.1.1 Contamination factor (CF)

The level of contamination of soil by metal is expressed in terms of a contamination factor (CF) calculated as:

$$CF= \frac{\text{Cm Sample}}{\text{Cm Background}} \quad (1)$$

Cm Sample = metal concentration in Sample.

Cm Background = metal concentration in background or control Sample [27].

Where the contamination factor CF < 1 refers to low contamination; 1 ≤ CF < 3 means moderate contamination; 3 ≤ CF ≤ 6 indicates considerable contamination and CF > 6 indicates very high contamination.

From the results of the contamination factors, the soil samples may be classified as moderately contaminated with respect to Zn and Cr, considerably contaminated with respect to Cd and Pb, and very highly contaminated with respect to Cu in the vicinity of Oluku dumpsite. The soil in the vicinity of Ikhueniro dumpsite may be classified as considerably contaminated with respect to Zn, Cd and Cr, and very highly contaminated with respect to Cu and Pb. It was also observed that the contamination factor of each metal in the vicinity of Ikhueniro dumpsite is greater than the contamination factor of the same metal in Oluku dumpsite except for cadmium which proved otherwise. This is because contamination factor is directly proportional to the concentration of each metal in the sediment, and all the metals in the vicinity of Ikhueniro dumpsite except cadmium have higher sediment concentrations than their counterpart in Oluku dumpsite.

3.1.2 Degree of contamination

The sum of contamination factors for all elements examined represents the contamination degree (Cdeg) of the environment. Using the sum of contamination factors obtained in Table 2 for all elements in each dumpsite.

Table 1. Physico-chemical properties and total heavy metal concentration of the soil samples

Parameters	Units	Dumpsite soil (Oluku)	Control soil (Oluku)	Dumpsite soil (Ikhueniro)	Control soil (Ikhueniro)
pH		8.10±0.01	7.14±0.02	7.40±0.00	7.05±0.02
CEC	meq/100 g	12.82±1.22	5.22±0.15	11.21±0.30	5.20±0.22
TOC	%	1.90±0.26	1.56±0.14	1.74±0.15	1.23±0.30
OM	%	3.28±0.26	2.69 ±0.14	3.00±0.15	2.12±0.30
Clay	%	10.71±0.12	16.71±0.22	28.24±0.40	31.72±0.30
Silt	%	2.09±0.11	2.09±0.10	2.56±0.15	2.49±0.17
Sand	%	87.20 ±0.35	81.20±0.50	69.20±0.31	65.79±0.25
Zn	mg/kg	156.78±2.35	58.93±2.07	243.81±5.00	42.66±2.00
Cu	mg/kg	20.17±1.44	2.30±0.24	21.41±1.71	2.16±0.22
Cd	mg/kg	1.40±0.19	0.35±0.08	2.59±0.42	0.73±0.10
Pb	mg/kg	6.36±0.25	1.32±0.56	7.76±0.55	1.11±0.05
Cr	mg/kg	7.92±1.12	4.68±0.50	10.99±0.64	2.99±0.23

Table 2. Contamination factor of each metal in the two dumpsites

Metals	Oluku dumpsite	Oluku classes	Ikhueniro dumpsite	Ikhueniro classes
Zn	2.66	Moderate contamination	5.72	Considerable contamination
Cu	8.77	Very high contamination	9.91	Very high contamination
Cd	4.00	Considerable contamination	3.55	Considerable contamination
Pb	4.82	Considerable contamination	6.99	Very high contamination
Cr	1.69	Moderate contamination	3.68	Considerable contamination

The contamination degree (Cdeg) values were 21.94 and 29.84 for Oluku and Ikhueniro dumpsites respectively. Therefore, the soils in the vicinity of the two dumpsites where the plant samples were gotten can be classified as having considerable degree of contamination according to [28]. However, it is worthy of note that the degree of contamination of soil in the vicinity of Ikhueniro dumpsite is greater than that of Oluku dumpsite; this might be attributed to the higher concentration, and hence higher contamination factor of each metal at the vicinity of Ikhueniro dumpsite than that of Oluku dumpsite.

3.1.3 The pollution load index (PLI)

Generally, pollution load index (PLI) as reported by [29], is as follows:

$$PLI = \sqrt[n]{Cf1 \, x \, Cf2 \, x \, Cf3 \, x \, Cf4 \, \ldots\ldots\ldots\ldots\ldots Cfn} \quad (2)$$

Where, CF = contamination factor, n = number of metals.

The PLI value of > 1 is polluted, whereas < 1 indicates no pollution [29].

The PLI values as calculated for both sites were 3.77 and 5.53 for Oluku and Ikhueniro dumpsites respectively. This showed a strong sign of pollution deterioration by the five measured metals in both sites since their PLI values are greater than 1. The PLI value was higher in the vicinity of Ikhueniro dumpsite than that of Oluku dumpsite. Hence, the vicinity of Ikhueniro dumpsite may cause more pollution to the environment than Oluku dumpsite.

3.2 Uptake of Heavy Metals by Plants in the Vicinity of the Open Dumpsites in Benin City

Although certain trace elements are essential in plant physiology, plants growing in a polluted environment can bioaccumulate trace elements at very high concentration in their edible parts and can present public health concerns [30].

Among all plant parts, roots accumulated the highest metal contents in all the sites (Table 4). Highest uptake of metals in roots compared to other parts was also observed in similar studies [31]. This could be due to roots direct exposure to the contaminated soil. It was also found that plant parts from the dumpsites have higher metal concentrations than control sites. This might be attributed to higher concentrations of metals in the dumpsite than the control site [32,33]. The results also indicated that the levels of metals in plants are dependent upon their concentrations in their habitual soil environment [34,12].

Transferability of Metals:

Biological Accumulation Coefficient (BAC) = $\frac{[\text{Metals}]\ \text{shoot}}{[\text{Metals}]\text{soil}}$ (3) [33].

Biological Concentration Factor (BCF) = $\frac{[\text{Metals}]\ \text{root}}{[\text{Metals}]\text{soil}}$ (4) [35].

Translocation Factor (TF) = $\frac{[\text{Metals}]\ \text{shoot}}{[\text{Metals}]\text{root}}$ (5) [36].

For Oluku dumpsite, the biological accumulation coefficient (BAC) decreased in the following order Cr>Cd>Cu>Zn>Pb, the biological concentration factor (BCF) decreased as follows Cu>Cd> Zn>Cr>Pb while the translocation factor (TF) followed the order of Cr>Cd>Cu>Zn>Pb. For Oluku control site, the BAC decreased in the following order Cr>Cd>Zn>Cu>Pb, the BCF decreased as follows Cu > Zn >Cd >Pb>Cr while the TF followed the order of Cr>Cd>Zn>Cu>Pb. Pb was not detected in the various plant parts but occurred in low concentrations in the roots of the maize plant. The TF of the maize plant is greater than 1 with respect to chromium shows the special ability of the maize plant to absorb chromium from soils and transport and store it in its above-ground part [37]. BAC was categorised as: < 1 excluder, 1-10 accumulator and > 10 hyperaccumulator [38]. Hence, using the results obtained for BAC in table above, it could be suggested that the maize plant is an excluder with respect to all the heavy metals analysed in Oluku dumpsite and its control site because all the BAC values were less than 1. TF > 1 signifies that the plant effectively translocates heavy metals from roots to the shoots [39]. Hence it could be observed from Table 5 that the maize plant effectively translocate chromium from roots to the shoots since the TF of the maize with respect to chromium is greater than 1 both in Oluku dumpsite and its control site.

For Ikhueniro dumpsite, the biological accumulation coefficient (BAC) decreased in the following order Cd> Cr>Cu>Zn>Pb, the biological concentration factor (BCF) decreased as follows Cu> Cr>Cd= Zn> Pb while the translocation factor (TF) followed the order of Cd>Cr> Zn>Cu> Pb. For Ikhueniro control site, the BAC decreased in the following order Cd>Zn>Cu> Cr>Pb, the BCF decreased as follows Zn >Cd > Cr >Cu>Pb while the TF followed the order of Cd>Zn>Cu>Pb >Cr. Using the results obtained for BAC in Table 6, it could be suggested that the maize plant is an excluder with respect to all the heavy metals analysed in Ikhueniro dumpsite and its control site [38]. Also considering the TF values in Table 6, it could be observed that the maize plant effectively

Table 3. Uptake of Zn, Cu, Cd, Pb and Cr (mg/kg) by different parts of the maize plants collected from Oluku dumpsite and its control

Metals	Roots	Stems	Leaves	Shoot
Zn	62.30(17.64)	25.14(7.36)	7.37(3.11)	32.51(10.47)
Cu	9.50(0.78)	3.21(0.36)	1.98(<0.05)	5.19(0.36)
Cd	0.62(0.10)	0.21(<0.05)	0.26(0.09)	0.47(0.09)
Pb	2.05(0.32)	0.62(<0.05)	0.35(<0.05)	0.97(0.00)
Cr	3.08(0.90)	2.15(0.72)	1.07(0.54)	3.22(1.26)

Table 4. Uptake of Zn, Cu, Cd, Pb and Cr (mg/kg) by different parts of the maize plants collected from Ikhueniro dumpsite and its control

Metals	Roots	Stems	Leaves	Shoot
Zn	89.55(13.83)	40.94(5.79)	22.87(3.88)	63.81(9.67)
Cu	10.30(0.44)	4.98(0.26)	1.08(<0.05)	6.06(0.26)
Cd	0.96(0.19)	0.54(0.09)	0.60(0.15)	1.14(0.24)
Pb	2.62(0.21)	1.05(0.10)	0.26(<0.05)	1.31(0.10)
Cr	5.07(0.72)	2.02(0.29)	1.77(<0.05)	3.79(0.29)

Key: Shoot = Stem + Leaf; Note: The values in bracket are for control

Table 5. BAC, BCF and TF for Zn, Cu, Cd, Pb and Cr in the maize plant at Oluku dumpsite and its control

Metals	Biological Accumulation Coefficient (BAC)	Biological Concentration Factor (BCF)	Translocation Factor (TF)
Zn	0.21(0.18)	0.40(0.30)	0.52(0.59)
Cu	0.26(0.16)	0.47(0.34)	0.55(0.46)
Cd	0.34(0.26)	0.44(0.29)	0.76(0.90)
Pb	0.15(0.00)	0.32(0.24)	0.47(0.00)
Cr	0.41(0.27)	0.39(0.19)	1.05(1.40)

Note: The values in bracket are for control

Table 6. BAC, BCF and TF for Zn, Cu, Cd, Pb and Cr in the maize plant at Ikhueniro dumpsite and its control

Metals	Biological Accumulation Coefficient (BAC)	Biological Concentration Factor (BCF)	Translocation Factor (TF)
Zn	0.26(0.23)	0.37(0.32)	0.71(0.70)
Cu	0.28(0.12)	0.48(0.20)	0.59(0.59)
Cd	0.44(0.33)	0.37(0.26)	1.19(1.26)
Pb	0.17(0.09)	0.34(0.19)	0.50(0.48)
Cr	0.34(0.10)	0.46(0.24)	0.75(0.40)

Note: The values in bracket are for control

translocate cadmium from roots to the shoots since the TF of the maize with respect to cadmium is greater than 1 [39]. High accumulation of heavy metals in roots and low translocation in shoots may indicate appropriateness of a plant species for phytostabilisation [40,12]. Phyto-stabilization process depends on roots' ability to limit the heavy metals' mobility and bioavailability in the soils and these occurs through sorption, precipitation, complexation or metal valance reduction [41]. High root to shoot translocation of metals indicate that the plants have vital characteristics to be used in phytoextraction of the metals [12].

4. CONCLUSION

The two dumpsites studied in Benin City had revealed that indiscriminate disposal of wastes such as municipal wastes, industrial wastes, agricultural wastes, etc are major sources of soil contamination and pollution by heavy metals. A knowledge of the total concentration of these heavy metals through soil analysis (as indicator) could be considered as a starting point for evaluating the degree of pollution as investigated in this study. All of the heavy metals studied were found to accumulate mainly in the roots of the maize plant. It can be concluded that Ikhueniro dumpsite area is more polluted than Oluku dumpsite area and that the indiscriminate disposal of wastes on these land had contributed to the increment in concentrations of these metals in the land. All of the heavy metals studied were found to accumulate mainly in the roots of the maize plant. Linearity dependence was found between the total heavy metal content in the soil and in the plant for all the elements studied. This may suggest that, plant absorption is controlled by the content of heavy metals in the soil solution and also by the content that is bioavailable in the soil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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