# Effects of Lead (Pb) Mining on Pb and Cd Concentration in Cassava and Soils of Ebonyi State, Southeastern Nigeria.

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**Abstract**
Mining of lead (Pb) exposes the environment to Pb and other heavy metals that present a risk for human health because they are non-degradable pollutants. The study investigated the effects of lead mining on Pb and Cd concentration in cassava and soils of Ebonyi State, southeastern Nigeria. Using transect method, triplicate auger soil samples (0-30cm depth) were collected from eleven equal distances (0,10,20,30,.......,90 and 100m) and 2.5km away from two mining sites located in Amegu and Enyigba. Also, triplicate cassava roots were harvested from each corresponding distances starting from 10m away from the mining sites. A total of 288 soil samples and 264 cassava samples were used for the study. Analysis of variance (ANOVA) was used to establish variation of soil and cassava data while simple correlation and multiple regressions were used to study the relationship among the soil properties Pb and Cd in both soil and cassava. Coefficient of variation was conducted to ascertain the pattern of variable distribution across the distances. Principal component analysis (PCA) was conducted to pick out the most significant properties that substantially increased across the distances. It was showed that mining activities caused significant ($p<0.05$) reduction in soil physico-chemical properties; moisture content (33.6 - 10.5 %), total porosity(62.6 -29.02%), soil pH (5.82-4.8), organic matter(28.45 -13.29 $gkg^{-1}$), total nitrogen(1.75-0.92 $gkg^{-1}$), available phosphorus(11.88 -4.88 $mgkg^{-1}$), Mg(4.03-1.5$cmolkg^{-1}$), K(1.16-0.38 $cmolkg^{-1}$) and Na(2.16-1.27 $cmolkg^{-1}$) but however, the mining activities increased CEC (12.81-20.12 $cmolkg^{-1}$), concentrations of Pb in soil (28.1- 321.4 $mgkg^{-1}$) and cassava(0.22- 4.78$mgkg^{-1}$), Cd in soil (0.15- 42.05$mgkg^{-1}$) and cassava(0.003- 1.77$mgkg^{-1}$) as well as metal transfer (MTF) of Pb(0.0056-0.15) and Cd(0.03-0.32) and pollution load index (PLI) of Pb(5.18-12.09) and Cd(2.0-160). Distribution pattern of soil properties with distance was uniform to moderate, moderate to irregular and irregular for physical, chemical properties and heavy metals respectively. Moisture content, soil bulk density and pH($H_20$) showed significant influence on metal concentration and accumulation attributes. Efforts should be made to locate cassava farmlands at a very far distance from the mining site due to the higher concentrations of these metals at closer distances.

**Keywords:** cadmium, heavy metals, lead, mining, metal transfer.

## Introduction

Vegetables as well as foodstuffs like cassava play important roles in our daily diet as economic crops. However, various human activities such as mining, industrial processing (smelting), automobile exhausts, and applications of organic manure/fertilizers are causing elevated heavy metal concentrations in environmental media and absorption by food crops (Akoto *et al*., 2014; Smedley *et al*., 2002). Vegetables/foodstuffs take up heavy metals and/or metalloids by absorbing them from contaminated soils, as well as from deposits on parts of the crop exposed to air from polluted environments (Wang *et al*., 2005). The main pathway by which plants accumulate heavy metals is through root uptake from soils (Uzu *et al*., 2009). Some heavy metals present in the soil solution are adsorbed onto the roots, and then become bound to carboxyl groups of mucilage uronic acid, or directly to the polysaccharides of the rhizoderm cell surface (Seregin and Ivanov, 2001). Once adsorbed onto the rhizoderm roots surface, they may enter the roots passively and follow translocating water streams.

The accumulation of heavy metals in soils especially in mining environments is of increasing concern to researchers in the agricultural industry. This is because the metals are biomagnified by plants. In addition to being non-biodegradable, heavy metals have long biological half-lives as well as the potential to accumulate in different body organs, leading to unwanted side effects. Due to their cumulative behaviour and toxicity, they have a potentially hazardous effect not only on crops but also on human health (slagle *et al*., 2004). Consumption of vegetables and fruits containing heavy metals is one of the main ways in which these elements enter the human body. Once in the body, heavy metals are deposited in bone and fat tissues, overlapping noble minerals and cause an array of diseases (Egbenda *et al*., 2015). Cassava (*Manihot esculenta*) is a perennial crop native to tropical America (Allen, 1994; Olsen and Schaal, 2001). The plant is characterized by palmate lobed leaves; inconspicuous flowers and a large, starchy, tuberous root with a tough papery brown bark and white to yellow flesh, (New World Encyclopedia, 2008). This is one of the major crops consumed by many people in Ebonyi State.

The contamination of cassava crop with heavy metals as a result of the contamination of the soil and atmosphere creates a threat to the quality and safety of the crop, hence the need for determining their concentrations. According to Murray *et al*, (1999), migration of metals in the soil is influenced by physical and chemical characteristics of each specific metal and by several environmental factors; the most significant appear to be: soil type, total organic content, redox potential, and pH. Evidence of heavy metal contamination pollution of agricultural soils and uptake of the heavy metals in vegetables and fruits in Romania and Brazil were reported by Lacatusu (2008) and Guerra *et al*. (2012). In addition, studies on heavy metals in leaf and tuber crops as a consequence of soil and atmospheric contamination by mining and related activities showed concentrations of cadmium, zinc and lead were detected in the: leaves of cassava growing near base metal deposit in Ebonyi State, Nigeria (Chukwuma, 1995; Ajiwe *et al*., 2018); tubers of cassava in the environs of the Arufu base metal deposit in Nigeria (Nganje *et al*., 2010); as well as in the tubers of cassava, sweet potato and yam in other districts in the same country (Onyedika and Nwosu,2008). Concentrations of arsenic and zinc in cassava tubers were also investigated in areas where gold was mined in Obuasi, Ghana (Amonoo-Neizer *et al*., 1996) and Dunkwa-on-Offin, Ghana (Golow and Adzei, 2002). Cassava crops cultivated in areas affected by mining were found to contain higher concentrations of heavy metals/metalloids when compared with those grown in uncontaminated areas (Kríbek *et al*., 2014).

The toxic and detrimental impacts of heavy metals become apparent only when long-term consumption of contaminated cassava occurs. Thus, regular monitoring of heavy metals in cassava and other food items should be performed in order to prevent excessive build up of these heavy metals in the human food chain (Khanna and Khanna, 2011). Therefore this study aimed at determining the levels of two heavy metal (lead and cadmium) in the soil and cassava samples obtained from two mining sites in Ebonyi State, Nigeria.

## Materials and methods

### Description of the study area

The studies were conducted at Enyigba and Amegu in Abakaliki local government area of Ebonyi State, lying on latitudes $06^0$ 11' 24" N, longitude $08^0$ 8' 26" E and on latitudes $06^0$ 11' 6" N, longitude $08^0$8' 30" E respectively. The sites are underlain by shale and some mudstones. These areas are marked by undulating range of shale outcrops, that host for Pb-Zn mineral ore bodies. The soils are over 1m deep and belong to the order ultisols, with shale as the parent material and usually acidic in nature (FDALR, 1985). Alluvium from Coastal Plain Sands (Benin formation), (Ofomata, 1975). The topography is flat, with few hills interspersed in the area. The drainage system of the area is dendritic in pattern, due to the lithology. The area is majorly drained by Ebonyi River. The highest elevation in the area is 60m and 30m as its lowest elevation above sea level. The area falls within the tropical rainforest belt of South East Nigeria, and characterized by an average rainfall of 1750- 2000 mm per annum (Obi and Salako, 1995). The rainy season and dry season are the two major seasons in the area with mean annual atmospheric temperature of $27^0$C - $31^0$C (Monanu, 1975). While relative humidity during dry season and wet seasons is between 60-80% respectively (Ofomata, 1975). The vegetation is derived from savanna zone of the southeast agro-ecology. Common vegetation within the study area includes orange trees, oil palm, mangoes trees and coconut trees with abundance of grasses, shrubs and other trees. Economic activities common among the inhabitants of the area include small scale farming (Yam, cassava and rice etc), commercial exploration and exploitation of minerals such as zinc and lead.

### Field Study

Field Reconnaissance visit was conducted, a census of the existing lead mine site and area coverage was estimated and triple auger soil samples (0-30cm depth) collected from eleven equal distances (0,10,20,30,.......,90 and 100m) and 2.5km away from the mining site. Core samples were collected in each of sampling point for bulk density determination. Soil samples collected were air-dried and sieved using a 2-mm sieve before laboratory analysis. Triple cassava roots were also harvested from each corresponding distances starting from 10m where soil samples were collected. A total of hundred and forty four (144) soil samples and hundred and thirty two (132) cassava samples were used for the study.

### Laboratory Analysis

Particle size distribution was determined by hydrometer method according to the procedure of Gee and Or, (2002). Bulk density was determined by core method (Grossman and Reinsch, 2002). Gravimetric moisture content was determined by oven-drying saturated soil samples for 24 hours (Obi, 1990) and amount of moisture calculated in percent. Soil pH was determined in 1:2.5 soil-liquid ratio using a pH meter (Thomas, 1996). Total nitrogen was determined by kjeldahl digestion method (Bremner, 1996). Organic carbon was determined by wet digestion method (Nelson and Summers, 1982). Available phosphorus was determined using Bray II method as described by Olson and Sommers (1982). Exchangeable acidity was determined by leaching the soil with 1N KCl and titrating with 0.05N NaOH (Mclean, 1982). Exchangeable base was extracted with 1N $NH_4O_{AC}$ solution, with exchangeable calcium and magnesium obtained by EDTA complexometric titration. Exchangeable potassium and sodium will be estimated by flame photometry (Jackson, 1962). Cation exchange capacity (CEC) was determined by aluminum acetate leaching at pH 7 (Blackemore *et al*., 1987). Percentage base saturation (%BS) was calculated by dividing total exchangeable bases by ECEC and multiplied by 100. Heavy metals extraction from soil samples and cassava roots was determined by wet digestion method according to Benton (2001).

**Determination of metal transfer factor (MTF)**

The metal transfer factor, also referred to as 'bio-accumulation factor', an index of the ability of a vegetable to accumulate a particular metal as a function of its concentration in the soil (Ghosh and Singh, 2005) was calculated from the following equation:

$$MTF = \frac{C_{plant}}{C_{soil}}$$

where $C_{plan}$and $C_{soil}$ were the heavy metal concentrations in edible portions of vegetables and in soils, respectively, on a dry weight basis.

**Determination of pollution load index (PLI)**

The level of soil pollution for each metal was measured using pollution load index (PLI) technique. The following equation was used to assess the PLI levels in soils.

PLI= Csoil sample/Creference (Liu *et al*., 2005).

Where Csoil = the mean value of heavy metal concentration in soils from the mining areas and Creference = heavy metal concentration in soil from control areas (2.5km away).

**Data Statistical Analysis**

Data was subjected to analysis of variance (ANOVA) to establish variation in properties while simple and multiple regressions and correlation was used to study the relationship among the soil properties and heavy metals. Coefficient of variation was conducted to ascertain the pattern of variable distribution across the distances (Wilding *et al*., 1994). These analyses were done using Genstat Statistical Package Version 18. Also, SPSS Version 21 was used to conduct principal component analysis (PCA) in order to reduce the set of soil variables as well as pick out the most significant soil properties that substantially increased across the compass directions.

## 3.0 Results and discussion

**Effects of lead mining on soil physical properties studied**

In Table 1 it was shown that all the physical properties across the studied locations were not distinctly different ($p<0.05$). There was regular pattern of the particles sizes (CV≤15%) (Wielding *et al*., 1994). Sand, silt and clay particles varied between 699.5 and 710.5 (mean=705), 204.2 and 212.2 (mean=208.2) and 86.9 and 90.4 $gkg^{-1}$(mean=88.65) decreasing as

**Table: 1 Effects of lead mining on physical properties of soils of the mining sites**

| Location | Sand | Silt($gkg^{-1}$) | Clay | TC | SCR | MC (%) | BD ($gcm^{-3}$) | TP (%) |
|---|---|---|---|---|---|---|---|---|
| Amegu | 710.5 | 204.2 | 86.9 | LS | 2.36 | 20.34 | 1.445 | 44.99 |
| Enyigba | 699.5 | 212.2 | 90.4 | LS | 2.39 | 20.49 | 1.441 | 45.18 |
| **LSD Fa** | **12.64** | **11.04** | **4.19** | | **0.166** | **1.916** | **0.062** | **2.36** |
| **Distance (m)** | | | | | | | | |
| 0 | 710.8 | 199.2 | 90 | LS | 2.3 | 10.5 | 1.9 | 29 |
| 10 | 704.5 | 203 | 92.5 | LS | 2.2 | 12.3 | 1.7 | 34.6 |
| 20 | 719.5 | 190.5 | 90 | LS | 2.1 | 14.8 | 1.7 | 34.8 |
| 30 | 713.2 | 200.5 | 86.2 | LS | 2.3 | 16.1 | 1.7 | 37 |
| 40 | 729.5 | 188 | 82.5 | LS | 2.3 | 16.2 | 1.5 | 41.4 |
| 50 | 718.2 | 198 | 83.8 | LS | 2.4 | 18.6 | 1.5 | 43.3 |
| 60 | 709.5 | 210.5 | 90 | LS | 2.4 | 19.1 | 1.4 | 45.6 |
| 70 | 702 | 210.5 | 87.5 | LS | 2.4 | 23.8 | 1.4 | 47.8 |
| 80 | 679.5 | 228 | 92.5 | LS | 2.5 | 25.1 | 1.2 | 53.7 |
| 90 | 702 | 220.5 | 90 | LS | 2.5 | 25.8 | 1.2 | 53.2 |
| 100 | 682 | 228.2 | 89.8 | LS | 2.6 | 29 | 1.1 | 57.9 |
| 2500 | 689.5 | 221.8 | 88.8 | LS | 2.5 | 33.6 | 1 | 62.6 |
| **CV** | **0.96** | **3.66** | **4.09** | | **5.86** | **35.09** | **21.32** | **24.29** |
| **LSD Fb** | **30.96** | **27.04** | **10.27** | | **0.4** | **4.7** | **0.2** | **5.8** |
| **LSD Fa X Fb** | * | * | * | | * | * | * | * |

SCR=silt clay ratio, MC=moisture content, BD=bulk density, TP=total porosity.

sand>silt >clay. This is consistent with the report of Igwe and Stahr (2004). Averaged over distances, significantly ($p<0.05$) highest (729.5 $gkg^{-1}$) and lowest (679.5 $gkg^{-1}$) were recorded at 40m and 80 m away from the lead mining site. While significantly ($p<0.05$) highest (228.2 $gkg^{-1}$) and lowest (188$gkg^{-1}$) silt fraction were recorded at 100m and 40m away from the site, clay was insignificantly ($p<0.05$) highest (92.5 $gkg^{-1}$) in both 10 and 80m whereas it was least (82.5$gkg^{-1}$) at 40m away from the site. The high sand and silt contents of the mine soils imply that the substrates have low aggregates and nutrient binding capacity (Brady and Weil 1996), and their capacity to retain water is low. However, finer soils/sediments that have more clay or silt have high retention ability than coarse soils/sediments (Witheetrirong *et al*., 2011). The soil texture were generally loamy sand. The textural composition of soils clearly showed they were derived from similar parent material with similar environmental conditions (Eni *et al.,* 2011; Abua *et al.,* 2010). Soil texture affects other soil properties, which in turn determine microbial growth and activity, and hence reported as key determinants of microbial ecology. The textural composition and particle size distribution influences different hydrological regimes including bulk density, water holding capacity and moisture content (Pasayat and Patel, 2015). According to Ebrahim *et al.* (2016), the greater adsorption and persistence of metals like lead and cadmium occurs in fine textured soils. Across the sampling distances, silt clay ratio (SCR) ranged from 2.1-2.6 and was regular in its distribution (CV=5.86%). The values of the silt – clay ratio of the soils were 2.39 in Enyigba and in 2.36 Amegu locations an indication that the soils are not old soils derived from old parent materials and is of intense degree of weathering; as old soils usually have silt – clay ratio less than 0.15, with low degree of weathering (Eze, 2014).

Moisture content (MC) was shown to increase progressively with increasing distances away from the mining site and was irregular (CV>35%) in its distribution. It was highest (33.6 %) and lowest(10.5%) at 2500m and 0m respectively. Higher MC in distance far away from the mining activities as compared to closer distance to the Pb mine overburden spoil may be attributed to dense vegetation cover and gradual supplements of organic matter (Singh *et al.,* 2004), increased aggregation and total pore space (Vengadaramana and Jashothan, 2012). Slightly higher (20.49%) was found in Enyigba compared to Amegu. Moisture is one of the most important properties of soil. Absorption of the nutrient by soil is largely depends on moisture content of the soil, moisture of soil also shows its effect on the texture of soil (Kekane *et al*., 2015). Averaged over location, bulk density of Amegu (1.45$gcm^{-3}$) mining site was insignificantly highest compared to Enyigba(1.44$gcm^{-3}$).

Unlike MC, soil bulk density (BD) appeared to decrease with increasing distance away from the mining site. Significantly ($p<0.05$) highest (1.9$gcm^{-3}$) Bd was recorded at 0m of the mining sites compared to the least(1.0 $gcm^{-3}$) BD that occurred at 2500m away from the mining site. Importance of bulk density lies with the fact that it regulates the space, air and water availability to soil microbes (Foissner, 1992). The decline in bulk density with distance from mine site can be interpreted as a reduction in soil compactness because of the development of soil micropore space (Ohta and Effendi, 1992) and higher bulk density in this closer area may be due to the removal of vegetation arising from the mining activities (Ezeaku and Ikemefuna, 2012). Bulk density of productive natural soils generally ranges from 1.1 to 1.5 $gcm^{-3}$. High bulk density limits rooting depth in mine soils. Values of BD at the areas within the mining site is similar to values of BD at seven year old overburden dumps where the bulk density was found to be as high as 1.91 $gcm^{-3}$ (Maiti and Ghose, 2005). Total porosity(TP) generally varied inversely with BD with highest .

Along the distance, TP increased with increasing distance with the highest (62.6%) and lowest(29%) recorded at 2500m and 0m respectively. Within the locations, highest(45.18 %) TP occurred in Enyigba than Amegu(45%). According to Gülser and Candemir (2014), increases in sand and silt content in soil texture as observed in distances close to the mine site could cause increases in ratio of macro porosity in total porosity. However, Fetter (1998), and Riue and Sposito (1991) recommended that soils having porosity of 45-50 percent of volume are good agricultural soils. Based on this, soils from 60-2500m away from the sites could be regarded as good agricultural soils

**Effects of lead mining on soil chemical properties studied**

Soil pH in both water and salt was generally acidic (Table 2.). In water and salt, soil pH varied significantly ($p<0.05$) from 4.55- 5.46 (mean=5.00) and 3.51 -3.44 (mean=3.47) respectively. Soil pH($H_20$) was generally higher than pH(KCl). The pH values of soil obtained from the different sources in the mining community of Ameka mining area of Ezza South, Ebonyi State also varied and was observed by Aloh *et al.* (2016) to be slightly acidic. Near neutral pH values (4.45- 7.54 ) was obtained by Ogbonna *et al*., (2013) in lead-zinc mining in the Ishiagu mining area in Ivo Local Government Area of Ebonyi State. Soil pH has been widely reported as

**Table 2:Effects of lead mining on chemical properties of soils of the mining sites**

| Location | pH (H20) | pH (KCl) | OM | TN g/kg | AvP (mg/kg) | Ca | Mg | K (cmolkg$^{-1}$) | Na | TEA | CEC | BS (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amegu | 5.46 | 3.44 | 17.46 | 1.07 | 4.06 | 5.22 | 1.54 | 0.64 | 1.68 | 2.46 | 11.88 | 78.65 |
| Enyigba | 4.55 | 3.51 | 27.28 | 1.49 | 10.71 | 11.77 | 2.96 | 0.75 | 1.77 | 1.68 | 19.39 | 90.67 |
| **LSD Fa** | **0.07** | **0.07** | **1.45** | **0.1** | **0.67** | **0.54** | **0.23** | **0.08** | **0.11** | **0.22** | **0.87** | **1.65** |
| **Distance(m)** | | | | | | | | | | | | |
| 0 | 4.9 | 3.44 | 13.29 | 0.98 | 6 | 9.25 | 1.5 | 0.69 | 1.23 | 2.42 | 20.12 | 83.96 |
| 10 | 4.84 | 3.41 | 22.96 | 1.27 | 6.5 | 8.59 | 1.83 | 0.9 | 1.3 | 2.15 | 15.46 | 84.83 |
| 20 | 4.88 | 3.45 | 22.04 | 1.21 | 7.62 | 7.81 | 2.86 | 0.91 | 1.78 | 2.67 | 16.06 | 82.61 |
| 30 | 4.9 | 3.56 | 21.52 | 1.22 | 8.75 | 7.46 | 2.11 | 0.86 | 2.09 | 2.94 | 16.96 | 79.93 |
| 40 | 4.98 | 3.42 | 21.1 | 1.23 | 9.62 | 8.71 | 2.04 | 0.41 | 1.96 | 1.74 | 14.41 | 87.8 |
| 50 | 4.99 | 3.32 | 26.8 | 1.42 | 6.12 | 9.8 | 1.78 | 0.39 | 1.39 | 1.68 | 14.84 | 87.58 |
| 60 | 5.01 | 3.34 | 24.14 | 1.19 | 4.88 | 8.73 | 2.13 | 0.38 | 1.75 | 1.65 | 13.57 | 87.89 |
| 70 | 4.94 | 3.37 | 18.91 | 0.92 | 5.12 | 8.36 | 1.94 | 0.8 | 1.8 | 1.83 | 15.07 | 85.48 |
| 80 | 4.91 | 3.4 | 27.9 | 1.6 | 8.75 | 7.91 | 2.34 | 0.78 | 1.86 | 1.91 | 13.85 | 84.89 |
| 90 | 4.95 | 3.39 | 21.95 | 1.37 | 5.88 | 7.07 | 2.11 | 0.54 | 1.88 | 2.44 | 14.61 | 79.84 |
| 100 | 4.94 | 3.31 | 19.4 | 1.2 | 7.5 | 7.4 | 2.31 | 0.49 | 1.48 | 1.75 | 12.81 | 84.66 |
| 2500 | 5.82 | 4.29 | 28.45 | 1.75 | 11.88 | 10.81 | 4.03 | 1.16 | 2.16 | 1.68 | 19.88 | 86.46 |
| **CV** | **11.85** | **15.51** | **27.18** | **26.50** | **33.67** | **18.04** | **51.50** | **56.83** | **23.73** | **16.78** | **19.83** | **2.96** |
| **LSD Fb** | **0.17** | **0.18** | **3.56** | **0.24** | **1.63** | **1.31** | **0.57** | **0.21** | **0.27** | **0.54** | **2.13** | **4.04** |
| **LSD Fa X Fb** | * | * | * | * | * | * | * | * | * | * | * | * |

OM=organic matter, TN=total nitrogen, AvP=available phosphorus, TEA=total exchangeable acidity, ECEC=effective cation exchange capacity, %BS=base saturation

exerting a controlling influence on the availability of micro-nutrients to plants and a pH range of 6.5 to 7.5 is reported to be optimal for plant nutrient availability (Arias *et al*., 2005). Across the distances, distribution of soil pH($H_20$) was low while it was moderate (CV≥15<35%) for that in KCl. In water (5.82) and KCl (4.29), soil pH was better at 2500m away from the mining site, indicating that mining activities reduced soil pH. In a similar study in Nigeria, Osakwe and Okolie (2015) found that in all samples, pH in water was higher than pH in KCl. According to WHO (2010), if the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. In acidic soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity.

Organic matter (OM) content of the soils differed significantly ($p<0.05$) in terms of the effects of various locations and the interaction of location and distance. Overall, OM was moderately distributed with the highest (27.28 gkg$^{-1}$) occurring in Enyigba compared to the least (17.46gkg$^{-1}$) recorded in Amegu. Highest (28.45gkg$^{-1}$) and lowest (13.29gkg$^{-1}$) OM was equally recorded at 2500m and 0m. These results are in line with a range of 8.10-51 gkg$^{-1}$ and 14.7-23.3 gkg$^{-1}$ OM recorded by Ogbonna *et al*., (2013) and Aloh *et al*. (2016) in soils of lead-zinc mining area of Ishiagu Ezza south, Ebonyi State, Nigeria respectively. Increase in OM with distance away from the mining area may be due to vegetation and topsoil removal around the mining area and the immediate surrounding (Agboola, 1982; Salami *et al.* 2002). Additionally, promotion of organic also has been reported to lower soil acidification (Sahani and Behera, 2001). Moreover, organic matter is an important soil component that can significantly affect the environmental behavior of heavy metals. For example, the bioavailability of heavy metals could be decreased through adsorption or through the formation of stable complexes with humic substances (Zeng *et al*., 2011). In addition, OM can supply organic chemicals such as humic acid and fulvic acid to the soil solution. These organic chemicals serve as chelates of metals and increase the bioavailability of metals in plants (Zeng *et al*., 2011).

Nitrogen is the most critical element obtained by plants from the soil and is a bottleneck in plant growth (Gorde, 2013). In Table 2, total nitrogen (TN) of the soils almost followed similar trend with OM in its distribution. It was significantly ($p<0.05$) higher (1.49 gkg$^{-1}$) in Enyigba than Amegu (1.07gkg$^{-1}$). Highest mean value of 1.75 gkg$^{-1}$ was recorded at 2500m whereas it was lowest (0.92 gkg$^{-1}$) at 0m distance away from the lead mining site. Lower values of TN within the mining site could perhaps be attributed to the fact that the total N content of a soil is directly associated with its OC content (Mengel and Kirkby, 1987; Tisdale *et al*., 1995). Following the rating of total N of > 1% as very high, 0.5 to 1% high, 0.2 to 0.5% medium, 0.1 to 0.2% low and < 0.1% as very low N status as indicated by Landon (1991), TN of the soils in the various locations are rated low.

Available phosphorus (Avp) content of the soil like TN also followed slightly similar pattern with OM. Overall, Avp varied significantly ($p<0.05$) between 4.06 mgkg$^{-1}$ at Amegu and 10.71 mgkg$^{-1}$ at Enyigba. Available P were observed to increase slightly with distance with highest and lowest recorded at 60m(4.88 mgkg$^{-1}$) and 2500m (11.88 mgkg$^{-1}$) away from the mining sites respectively. The results of available P content in the study of Ramahlo (2013) in three mining sites in phalaborwa, Limpopo Province also showed a decrease further away from the pollution source. The low available P content in the soil samples (below 15mgkg) (FPDD, 1990) may be attributed to inherent soil characteristics such as high calcium content across the study areas which could potentially render P unavailable through fixation (Wild, 1995; Dutta and Agrawal, 2002).

The interaction of location and sampling distance had significant ($p<0.05$) effect on basic cations (Ca, Mg, K and Na) studied. Calcium, Mg, K and Na concentrations of the soils varied from 5.22- 11.77 (mean= 8.5), 1.54- 2.96 cmolkg$^{-1}$ (mean=2.25), 0.64- 0.75 cmolkg$^{-1}$ (mean=0.69) and 1.76- 1.68 cmolkg$^{-1}$ (mean=1.72) respectively with distribution pattern of Ca and Na being moderate (CV≥15<35%) and Mg and K being (CV>35%). This showed that the basic cation was dominated by Ca followed by Mg, Na and K. It has been reported that Ca usually dominates the exchange sites of most soils with Mg, K, $NH_3$ and Na having lower concentrations (Enloe *et al*., 2006). Reason for this would be the possibility that monovalent cations (K and Na) might have leached from the system substantially while the divalent cations (Ca and Mg) are strongly adsorbed to soil particles at increasing soil moisture content (Chileshe *et al*., 2020). Moreover, the addition of lime into the effluent by the mining company would attribute to high content of Ca in mine waste substrates (Chileshe *et al*., 2020) with resultant higher soil concentrations (10-20 cmolkg$^{-1}$) (FAO, 2004) especially in Enyigba. The exchangeable magnesium of all soils were within the medium (0.4–2.5 cmolkg$^{-1}$) to high (>2.5 cmolkg$^{-1}$) categories of exchangeable magnesium for crop production (Horneck *et al*., 2011). It was observed that on average basis, Na content at 2500m away from the mining site was very high (above 2 cmolkg$^{-1}$) (FAO, 2004) apart. High levels of exchangeable sodium as recorded in distance far away from the site could affect soil structure, soil permeability and may be toxic to sensitive plants (Horneck *et al*., 2011).

Total exchangeable acidity (TEA) like other chemical properties was significantly ($p<0.05$) affected by the combined effect of location and distance. Averaged over location, it varied between 1.68- 2.46 (mean=2.25 cmolkg$^{-1}$). Total acidity decreased relatively with increasing distance. Accordingly, highest (2.94cmolkg$^{-1}$) and lowest (1.65cmolkg$^{-1}$) TEA was recorded at 30m and 60m distances respectively. Acidity of a soil increases the rate in which nutrients and also metals are taken up from soil to plants. According to the ratings of Holland *et al*. (1989), exchangeable acidity values were low (>2.1) to medium range of 2.1 to 4 cmol kg$^{-1}$ and according to Kabata-Pendias (2004), low soil acidity as recorded in far distance from the mining site is a stabilizing factor for toxic metals in soil and increases metal solubility in soil. Moreover, the acidification of mine spoil may be due to different minerals deposition (Jha and Singh, 1991; Suzuki *et al.,* 1999; Dutta and Agrawal, 2002) or due to oxidation of residual elements such as iron and sulphur (Hazarika *et al.,* 2006) that hinder the release of available essential plant nutrients (Rai *et al.,* 2011).

Cation exchange capacity (CEC) measures the ability of soils to allow for easy exchange of cations between its surface and solutions (Garba *et al*., 2012b). Cation exchange capacity of the studied soils also varied significantly ($p<0.05$) across the locations and sampling distance with distribution pattern being moderate (CV=19.83). Cation exchange capacity was better (19.39 cmolkg$^{-1}$) in Enyigba compared to Amegu (11.88 cmolkg$^{-1}$). Along the distances, it was also better (20.12 cmolkg$^{-1}$) compared to the least (12.81cmolkg$^{-1}$) mean value recorded at 100m distance away. High CEC values were found in soils with high organic matter content and clay particles. This shows that CEC in the present study is mainly dependent on soil clay minerals (Manrique *et al*., 1991; Harada and Inoko, 2012) which were relatively higher at distances within the mining sites. Although, cation exchange capacity of these soils were generally high (>12 cmolkg$^{-1}$) according to rating of Esu (1991), these values were far lower than range of 40.55- 79.37 cmolkg$^{-1}$ recorded by Aloh *et al*. (2016) in Ameka lead-zinc mining area of Ezza south, Ebonyi State. As also observed by Aloh *et al*. (2016), the higher value of CEC obtained for the soils around mine sites compared to far distance away from the mining site showed that mining could affect the properties of soils in close proximity to them.

Equally, percentage base saturation (%BS) differed significantly ($p<0.05$) in terms of the effects of the locations, distances and distances and their combinations. On average, %BS varied between 78.65 % at Amegu and 90.67% in Enyigba (mean=84.66%) with the distribution pattern being uniform (CV≤15%). Across the sampling points, %BS was observed to be relatively increased with increasing distance with the best (87.89%) and least (79.84%) mean value recorded at 60m and 90m sampling distance respectively. The soils that have high base saturation were observed to have low aluminium saturation and high Ca values and vice versa. This is in agreement with the findings of Streck *et al*. (2008), who reported that low saturation of bases could be traced to high Al saturation and low pH in Oxisols and Alfisol.

**Effects of mining on Pb and Cd concentrations**

Results of Table 3 displayed the effects of mining activities on Pb and Cd in soils and cassava. It was shown that Pb concentration was relatively higher than Cd concentration irrespective of locations and distances. Lead content of the soil varied significantly ($p<0.05$) from 198.9-206.4 and 321.4-28.1 mgkg$^{-1}$ within the location and along the distances respectively with the distribution pattern being erratic (CV>35%), suggesting that Pb was more concentrated at Amegu and 0m distance. With the exception of Pb concentrations at 0-30m distance, values of soil Pb recorded in the study were within the USEPA **(**2010**)** allowed limits of 30-300mgkg$^{-1}$ for agricultural lands. Similarly high value of Pb (90.96-338.94mgkg$^{-1}$) was recorded by Udiba *et al*. (2019) in farmland close to lead mining site in Dareta Village, Zamfara, Nigeria. Lower values (16.22-95.35mgkg$^{-1}$) were previously recorded by Nnabo (2015) in Enyigba Pb & Zn mines site. In a Pb-Zn mine in Hunan Province, China, average contents of Pb in soils was recorded as 384.8 mgkg$^{-1}$ which is 4.27 times those of the reference (Liao *et al*. 2008). The findings of this study is in line with that of Elom (2018) who observed that Pb concentrations were more in the samples collected within the mining premises than samples collected 500m away from the sites. The high level of Pb at the distances within the mining sites could be due to lower acidic pH at these areas (Osuocha *et al*., 2015) as this has been shown to increase retention capacity and stabilization of trace metals in soils (Ogbonna *et al*., 2013). It has been reported (Osher *et al*., 2006; Xiangdong and Thornton, 1993) also that Pb is immobile in soil and accumulates over time which may result in elevated concentration. Obviously, such scenarios could be a potential threat to human health and the environment. Lead is also considered as a probable human carcinogen by the USEPA (USEPA, 1996a) and concentrations of 500– 1,000 mg kg$^{-1}$ in soil can affect children's health (Xintaras, 1992). In addition, elevated Pb in soils may decrease soil productivity and if in very low concentrations, Pb may also inhibit some important plant processes i.e. photosynthesis, mitosis, water absorption and vegetative growth Bhattacharyya *et al*. (2008).

Plants are known to take up and accumulate trace metals from contaminated soil (Abdul Kasheem and Singh, 1999), hence detection in plant crop samples was not surprising. In cassava, Pb had mean values of 19.11 and 24.22mgkg$^{-1}$ at Amegu and Enyigba respectively. Like its soil counterparts, cassava Pb concentration diminished with increasing distance away from mining site with pattern of distribution also being erratic (CV= 45.49). It was highest (42.05 mgkg$^{-1}$) and lowest(0.15 mgkg$^{-1}$) at 0m and 2500m distance away from the mining site respectively. Values of Pb in cassava in this study was far higher

**Table 3 Effects of lead mining on Lead and Cadmium concentrations of soils of the mining sites (mg/kg)**

| Location | S Pb | S Cd | Cas Pb | Cas Cd |
|---|---|---|---|---|
| Amegu | 206.4 | 3.18 | 19.11 | 0.81 |
| Enyigba | 198.9 | 0.76 | 24.22 | 0.09 |
| **LSD Fa** | **13.87** | **0.3** | **3.52** | **0.11** |
| **Distance(m)** | | | | |
| 0 | 321.4 | 4.78 | | |
| 10 | 313.9 | 4.56 | 42.05 | 1.77 |
| 20 | 320.5 | 4.15 | 41.41 | 1.23 |
| 30 | 253 | 3.16 | 32.41 | 0.95 |
| 40 | 218.5 | 1.93 | 21.4 | 0.63 |
| 50 | 187.6 | 1.15 | 27.95 | 0.32 |
| 60 | 162.7 | 1.03 | 15.66 | 0.18 |
| 70 | 163 | 1.03 | 16.75 | 0.16 |
| 80 | 168.6 | 0.83 | 16.14 | 0.08 |
| 90 | 155 | 0.55 | 12.94 | 0.05 |
| 100 | 139.2 | 0.28 | 11.49 | 0.03 |
| 2500 | 28.1 | 0.22 | 0.15 | 0.003 |
| **CV** | **46.15** | **58.29** | **45.49** | **58.48** |
| **LSD Fb** | **33.98** | **0.74** | **8.62** | **0.26** |
| **LSD Fa X Fb** | * | * | * | * |

S=soil, Cas=cassava

than 0.03-2.59mg/kg and 0.45-0.74mg/kg recorded by Udiba *et al*. (2019) and Harrison *et al*. (2018) in cassava plant grown in Dareta village, Zamfara, Nigeria close to lead mining site and crude oil contaminated soil at Ikot Ada Udo, Nigeria respectively. Hayford *et al*. (2008) on the other hand reported that concentrations of Pb in cassava and plantain were higher than 0.20 $mgkg^{-1}$ proposed by the FAO/WHO (2001) in mining communities around the Tarkwa–Prestea area. Lead has been ranked the second most hazardous substance in the USA by the Agency for Toxic Substances and Disease Registry (ATSDR) and the US Environmental Protection Agency (USEPA) (ATSDR, 2005). Therefore, consumption of cassava tubers from distances within the mining site thus poses significant risk of lead toxicity.

Soil cadmium was also significantly ($p<0.05$) impacted by location and distance and the interaction of these factors. Overall, soil Cd concentration varied from 0.76-0.01 $mgkg^{-1}$ (mean= 1.97 $mgkg^{-1}$) with distribution being irregular (CV= 58.29%). Along the sampling distance, it decreased progressively with the highest (4.78 $mgkg^{-1}$) and lowest (0.22 $mgkg^{-1}$) concentrations occurring at 0m and 2500m respectively. On average, Cd concentration in Amegu location as well as 0-30m distance of the mining sites was above the critical permissible limit of 3.0$mgkg^{-1}$ for agricultural soils (USEPA, 2010). These localized high concentrations of Cd in the Amegu area may be related to the vicinity of the highly oxidized ore zones (Bolucek, 2007). The apparent increase of heavy metals concentration in mine site compared to the far distance away almost certainly confirms reports from various studies have implicated metal accumulation in vegetative plant part declining with distance from possible contamination sites (Little, 1995). Elevated level of metals in soil may render the soil unsuitable for plant growth and destroy biodiversity (Obute *et al*., 2010), leading to low productivity of ecosystem (Matthews *et al*., 2012).

Similar to soil Cd, Cd in cassava was relatively decreased with increasing distance away from the mining site. Accordingly, significantly ($p<0.05$) highest (0.81 $mgkg^{-1}$) and lowest (0.09 $mgkg^{-1}$) mean Cd occurred in cassava planted in Amegu and Enyigba. This also agrees with the findings of Ayari *et al*. (2010) that concentration of metals in plant is dependent on their concentration in soil. Values of Cd in cassava in was within the range of 0.03-0.43mg/kg recorded by Ajiwe *et al*. (2018) in cassava grown in soils from a Galena Mining Area in Ishiagu, Ivo L.G.A of Ebonyi State. In general, the values for each of the locations were less than 1 $mgkg^{-1}$ threshold level recommended by FAO/WHO (1976) for foods and vegetation. Equally, Cd in cassava decreased progressively with increasing distance with distribution also being irregular (CV= 58.48). Highest (0.92$mgkg^{-1}$) and lowest(0.07$mgkg^{-1}$) mean concentrations occurred 10m and 2500m respectively. It can be from the results that growing of cassava within 0-30m distance of the mine site can pose a serious health challenge to consumers since these areas had Cd ≥ 1 $mgkg^{-1}$. Acute doses (10-30 mg/kg per day) of Cd can cause severe gastrointestinal irritation, vomiting, diarrhoea and excessive salivation, and doses of 25 $mgI_2$ /kg body weight can cause death (ATSDR, 1999a; Amfo-Out, 2007). Moreover, Chronic lower level intakes of toxic elements have damaging effects on human beings and other animals (Ikeda *et al*., 2000), since there is no efficient mechanism for their elimination, and the detrimental impact becomes apparent only after several years of exposure (Bahemuka and Mubofu, 1999).

**Effects of mining on metal transfer factor and pollution load index of Pb and Cd**

As shown in Table 4, metal transfer factor (MTF) of Cd was relatively higher than MTF of Pb irrespective of location and distance. As reported by other workers (Ahmadipour *et al*. 2014; Baran *et al*. 2014), Lead seems to be more stable than cadmium in soil because it is bound stronger to the crystalline structures of the mineral and soil organic matter higher than cadmium. Cadmium is a highly mobile element and can easily be transported through the shoots of plants and uniformly distributed throughout the affected plant (Baker *et al.*, 2000; Sekara *et al.*, 2005). Metal transfer factor of Pb varied significantly ($p<0.05$) from 0.08- 0.104 and 0.0056-0.006 within the locations and distances respectively. Concentrations were higher in Enyigba and 50m distance respectively with distribution being erratic (CV=39.55%) and decreasing slightly with increasing distance. Indicating that mining activities relatively increased the MTF of Pb. Similar lower range of 0.009-0.115 was recorded by Udiba *et al*. (2019) for MTF of Pb in cassava planted in soils close to lead mining site in Dareta Village, Zamfara. Equally, metal transfer factor of cadmium also differed significantly ($p<0.05$) with locations, directions and their combination. It was highest (0.247) in Amegu compared to mean value of 0.114 recorded for Enyigba. Like Pb, MTF of Cd decreased with distance away from the mine site with distribution also being erratic (CV= 35.66%). It was highest (0.32) at 10m compared to the least (0.03) recorded at 2500m distance away from the mine site. A slightly lower range of 0.09-0.11 was recorded by Harrison *et al*. (2018) in cassava plant grown in crude oil contaminated soil at Ikot Ada Udo, Nigeria. Soil to plant transfer is one of the major pathways by which heavy metals and other contaminants in soils enter the food chain (Sparg *et al*., 2004). Food crops such as vegetables, tuber crops and cereals grown in heavy metal impacted soil take up toxic metal from the soil (Harmanescu *et al*., 2011). If the TF values are ≥ 1.0 it shows a higher uptake of metal from soil by the plant, while lower values mean less absorption of the metal from the soil, and the plant can be used for consumption (Rangnekar *et al*., 2013). Therefore, the high level of transfer factors (TF) of Cd compared to Pb is an indication of a possible and faster transfer of Cd accumulated in the mining site into human system via consumption of products derived from the cassava plant obtained from this soil. Higher values of MTF of Cd also suggest poor retention of this metal in soil and/or more translocation in plants

Similar to Pb in soil, lead pollution load index (PLI) was relatively decreased with increasing distance away from the mining site. Specifically, significantly ($p<0.05$) highest(12.1) and lowest(5.18) Pb PLI occurred at 10m and 100m distance respectively. Across the locations, mean Pb PLI was highest(8.31) and lowest(8.07) Amegu and respectively. Values of PLI of Pb recorded in most of the soils studied were greater than PLI of Pb of 6.88 and 2.07 recorded by Chileshe *et al*. (2020) in tailings dam and overburden soils of copper mine wastes in Zambia respectively and were accordingly rated as Very high and moderate. Therefore, values of PLI of Pb of this study were extremely high.

**Table 4 Metal transfer factor and pollution load index of lead and cadmium of the soils studied**

| Location | MTF Pb | MTF Cd | PLI Pb | PLI Cd |
|---|---|---|---|---|
| Amegu | 0.08 | 0.25 | 8.07 | 115 |
| Enyigba | 0.1 | 0.11 | 8.31 | 11 |
| **LSD Fa** | **0.01** | **0.03** | **0.98** | **54.3** |
| **Distance(m)** | | | | |
| 0 | | | 12.09 | 147 |
| 10 | 0.13 | 0.32 | 11.74 | 160 |
| 20 | 0.13 | 0.27 | 11.92 | 133 |
| 30 | 0.13 | 0.28 | 9.48 | 102 |
| 40 | 0.1 | 0.28 | 8.29 | 56 |
| 50 | 0.15 | 0.25 | 7.16 | 24 |
| 60 | 0.1 | 0.2 | 6.11 | 21 |
| 70 | 0.1 | 0.18 | 6.1 | 20 |
| 80 | 0.08 | 0.16 | 6.23 | 16 |
| 90 | 0.08 | 0.12 | 5.79 | 9 |
| 100 | 0.08 | 0.09 | 5.18 | 2 |
| 2500 | 0.006 | 0.03 | | |
| **CV** | **39.55** | **35.66** | **71.59** | **36.26** |
| **LSD Fb** | **0.03** | **0.07** | **2.3** | **127.3** |
| **LSD Fa X Fb** | * | * | * | * |

MTF=metal transfer factor, PLI=pollution load index.

Variation in pollution load index (PLI) of cadmium was also significantly ($p<0.05$) with location, distance and the interaction of these factors. It varied from 11 – 115 (63.0). Amegu had significantly ($p<0.05$) highest(115) mean value compared to 11recorded Enyigba. Like Pb, PLI of Cd was observed reduce gradually with increasing distance away from the mining site with highest(160.0) and least (2.0) recorded at 20m and 100m distance away from the mining site respectively. Values of PLI of Cd recorded in the present study was far greater than PLI of Cd of 0.77 and 0.32 recorded by Chileshe *et al*. (2020) in tailings dam and overburden soils respectively and was rated as low. Therefore, PLI of Cd in the present study can regarded as being very high. Pollution load index (PLI) greater than 1 for a given heavy metal shows a significant contamination of the soil of interest with the particular metal (Zango *et al*., 2013). Very high levels of PLI might be attributed the pollution from blasting instruments such as car batteries and explosives used for the illegal artisan mining in the study area (Obasi *et al*., 2017). According to Ikenaka *et al*. (2010), heavy metal pollution in either soils or sediments is strongly associated with geological differences.

**Relationship between heavy metals and soil physico-chemical properties studied**

According to Okereke *et al*., (2016) the physicochemical properties of soil and plants could influence the transfer or mobility of metals from soil to plant. As displayed in Table 5, very few strong associations were recorded. Lead in soil had strong positive relationship with Pb in cassava ($r=0.46$) soil Cd($r=0.51$), PLI of Pb($r=0.87$) and soil bulk density($r=0.78$), implying that increase in these parameters will cause significant increase in soil Pb concentration whereas

**Table 5 Relationship between heavy metals and soil physico-chemical properties**

| Soil properties | Soil Pb | Cas Pb | Soil Cd | Cas Cd | MTFpb | PLI Pb | MTF Cd | PLI Cd |
|---|---|---|---|---|---|---|---|---|
| **Cas Pb** | 0.46* | | | | | | | |
| **Soil Cd** | 0.51* | 0.13 | | | | | | |
| **Cas Cd** | 0.42 | 0.36 | 0.71** | | | | | |
| **MTFpb** | -0.06 | 0.81** | -0.13 | 0.14 | | | | |
| **PLI Pb** | 0.87** | 0.40 | 0.36 | 0.31 | -0.04 | | | |
| **MTF Cd** | 0.20 | 0.36 | 0.20 | 0.61* | 0.25 | 0.20 | | |
| **PLI Cd** | 0.33 | 0.18 | 0.61* | 0.50* | 0.00 | 0.20 | 0.19 | |
| **Sand** | 0.23 | 0.23 | 0.23 | 0.23 | 0.17 | 0.22 | 0.21 | 0.16 |
| **Silt** | -0.38 | -0.33 | -0.26 | -0.26 | -0.20 | -0.36 | -0.23 | -0.16 |
| **Clay** | 0.18 | 0.07 | -0.13 | -0.10 | -0.06 | 0.18 | -0.20 | -0.15 |
| **SCR** | -0.41 | -0.30 | -0.15 | -0.17 | -0.12 | -0.39 | -0.08 | -0.05 |
| **MC** | -0.69* | -0.32 | -0.45* | -0.34 | 0.00 | -0.62* | -0.19 | -0.30 |
| **BD** | 0.78** | 0.33 | 0.47* | 0.35 | -0.01 | 0.69* | 0.20 | 0.27 |
| **pH($H_20$)** | -0.01 | -0.19 | 0.38 | 0.39 | -0.23 | -0.11 | 0.49* | 0.31 |
| **OM** | -0.26 | 0.30 | -0.36 | -0.35 | 0.47* | -0.19 | -0.17 | -0.29 |
| **TN** | -0.18 | 0.09 | -0.35 | -0.35 | 0.19 | -0.18 | -0.20 | -0.23 |
| **AvP** | -0.08 | 0.21 | -0.26 | -0.22 | 0.28 | -0.09 | -0.33 | -0.19 |
| **Ca** | 0.01 | 0.19 | -0.26 | -0.34 | 0.23 | 0.09 | -0.46* | -0.18 |
| **Mg** | -0.08 | 0.21 | -0.13 | -0.19 | 0.26 | 0.01 | -0.23 | -0.11 |
| **K** | 0.35 | 0.28 | 0.51* | 0.41 | 0.09 | 0.31 | 0.05 | 0.26 |
| **Na** | -0.21 | 0.05 | -0.07 | -0.06 | 0.16 | -0.19 | 0.04 | -0.16 |
| **TEA** | 0.30 | 0.12 | 0.45* | 0.40 | -0.07 | 0.13 | 0.17 | 0.24 |
| **CEC** | 0.26 | 0.13 | -0.01 | -0.18 | 0.05 | 0.23 | -0.50* | 0.06 |
| **%BS** | -0.12 | 0.06 | -0.33 | -0.36 | 0.17 | 0.02 | -0.30 | -0.20 |

SCR=silt clay ratio, MC=moisture content, BD=bulk density, TP=total porosity, OM=organic matter, TN=total nitrogen, AvP=available phosphorus, TEA=total exchangeable acidity, ECEC=effective cation exchange capacity, %BS=base saturation, Cas=cassava, MTF=metal transfer factor, PLI=pollution load index.

negative significant relationship that it had with moisture content (MC) (r=-0.69) implied that increase in MC will cause obvious decrease in soil Pb concentration. Distinct positive association existed between Lead in cassava and MTFpb (r=0.81) whereas relationship existed between MTFpb and OM (r=0.47). Concentration of soil Cd showed positive serious association with Cd in cassava(r=0.71), PLI of Cd(r=0.61), bulk density(r=0.47), K(r=0.51) and TEA(r=0.45) while it had strong negative association with MC(r=-0.45). Concentration of Cd in cassava only had positive interaction with its MTF(r=0.61) and PLI(r=0.50), suggesting that increase in this indices will result in its significant increase. Lead PLI only exhibited negative and positive significant association with MC(r=-0.62) and BD(r=0.69), indicating that while soil compaction increases PLI of Pb, moisture content reduces it. Equally, MTF of Cd significantly correlated positively with pH($H_20$) (r=0.49) while it had negative correlation with Ca(r=-0.46) and CEC(r=-0.50). Earlier, Kabata-pendias (2004) and Obasi *et al*. (2013) stated that apart from organic matter, soil pH, the concentration of trace elements are associated with several factors such as biological and biogeochemical cycling, parent materials and mineralogy, soil age, redox concentration and microbial activities. This study is in disagreement with other study (Dayton *et al*., 2006) which indicated that pH had no significant effect on the accumulation of metals (Pb) from soil to vegetables. In addition, no strong association was recorded in the interaction of PLI of Cd with parameters measured.

**Multiple regression among some selected soil properties, metal concentrations and accumulation indices**

Results of predicting equations expressing the contributions of selected soil properties (clay, MC, Bd, pH, OM and CEC) are displayed in Table 6. As shown, the combined efforts of these properties yielded significant influence on all the metal concentrations and accumulation indices estimated apart from. The efforts accounted for about 73% and 42% soil lead and Cd concentrations respectively while it produced about 35% and 31% cassava Pb and Cd concentrations. Furthermore, these combined contributions produced about 32%, 44%, 53% and

30% MTFPb, MTF Cd, PLI Pb and PLI Cd respectively. As observed in the Table below, stronger efforts were contributed by soil bulk density and pH compared to other parameters measured. Towers and Paterson (1997) as well as Wieczorek and Baran (2013) also indicated that the soil pH is the key factor controlling the metal-binding capacity of the soil. According to Tangahu *et al*. (2011), absorption and accumulation of heavy metals in plant tissues depend upon temperature, moisture, organic matter, pH, and nutrient availability.

**Rotated principal component analysis**

Principal component analysis (PCA), one of several multivariate methods, simplifies the complexity in high-dimensional variables by geometrically projecting them onto lower dimensions called principal components (PCs), in order to find the best summary of the data using a limited number of PCs (Borcard *et al*., 2018; Zhang *et al*., 2019). Principal component analysis (PCA) was performed for 27 parameters by grouping the soil and cassava data. Principal loadings and the variances (Eigenvalues) for the parameters were computed. Based on the approach of various rotation as well as the Kaiser rule of selecting components with eigenvalue >1 (Gaur and Gaur, 2006). Seven components were selected (Table 7). The extracted components contributed a total variance of 78.27% in the data set. On $PC_1$, 7 soil parameters with positive values loaded significantly. These parameters include soil Ca (0.90), pH($H_20$) (0.89), AvP (0.82), CEC (0.80), %BS (0.77), Mg (0.64) and OM (0.64). The positive loading implies that these parameters increase as the distance from the mining site increases. This component ($PC_1$) was regarded as measuring the soil chemical properties and this first principal axis accounted for 20% of the total variance.

On the $PC_2$, 3 parameters with positive values [BD(0.93), Soil Pb(0.86) and PLI Pb(0.78)] and 2 parameters with negative [TP (-0.92) and MC (-0.82)] loaded strongly. This suggested that while these parameters positive values increases with mining activities, the parameters negative values decreases. This component contributed 17% of the total variance. This component together with $PC_4$ can be regarded as measuring the soil physical properties. Principal component 3($PC_3$) strongly loaded 5 parameters positively namely Soil Cd (0.78), PLI Cd (0.74), Cassava Cd (0.66), K (0.65) and pH(KCl) (0.63). This component contributed 11% of the total variance. This component together with $PC_5$ can be assumed to measure soil metals and indices, indicating their increase with mining. According to Ofomata (2003), mining operations are being recognized as important source of heavy metals in the environment and are considered an environmental

**Table 6 Multiple regression among selected soil properties and indices studied**

| Predicting equation | R | $R^2$ | Sig. |
|---|---|---|---|
| **S Pb=** 37.14+ 1.06clay -2.89MC+ 167.84Bd -14.28pH ($H_20$) -1.85OM+ 0.06CEC | 0.86 | 0.73 | 0.00 |
| **S Cd=**-0.01 clay -0.07MC+ 3.13Bd +1.39pH ($H_20$) -0.05OM+ 0.03CEC-6.12 | 0.64 | 0.42 | 0.00 |
| **Cas Pb=** 4.97 + 0.01 clay -0.28 MC+ 22.07 Bd -3.39 pH ($H_20$) +0.71 OM-0.68 CEC | 0.60 | 0.35 | 0.00 |
| **Cas Cd=**-0.002clay -0.02MC+0.85 Bd+0.43pH ($H_20$) -0.01OM-0.01CEC-1.99 | 0.56 | 0.31 | 0.00 |
| **MTF Pb=**0.22-0.00clay -0.00MC+ 0.05Bd -0.03pH ($H_20$) +0.00OM-0.00 CEC | 0.57 | 0.32 | 0.00 |
| **MTF Cd=**-0.00 clay -0.00MC+ 0.20Bd +0.07pH ($H_20$) +0.00OM-0.01 CEC-0.17 | 0.67 | 0.44 | 0.00 |
| **PLI pb=**3.24+ 0.05clay -0.15MC+5.83 Bd -0.85pH ($H_20$) -0.06OM-0.01 CEC | 0.73 | 0.53 | 0.00 |
| **PLI Cd=**-0.82 clay -3.84MC+ 33.64Bd +175.20pH ($H_20$) -0.09OM+16.54 CEC-954.60 | 0.55 | 0.30 | 0.00 |

Key: S=soil, Cas=cassava**,** MTF=metal transfer factor, PLI=pollution load index.

**Table 4.11 Rotated principal component analysis**

| | Principal Components | | | | | | |
|---|---|---|---|---|---|---|---|
| **Soil properties** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| Ca | 0.90 | 0.10 | -0.12 | -0.09 | -0.03 | 0.04 | -0.15 |
| pH($H_20$) | -0.89 | -0.12 | 0.22 | -0.12 | -0.02 | -0.14 | -0.04 |
| AvP | 0.82 | -0.03 | -0.07 | 0.08 | 0.12 | -0.07 | 0.19 |
| CEC | 0.80 | 0.29 | 0.12 | -0.07 | -0.24 | 0.06 | 0.05 |
| %BS | 0.77 | -0.10 | -0.15 | -0.06 | 0.06 | 0.05 | -0.51 |
| Mg | 0.64 | -0.13 | 0.07 | 0.04 | 0.21 | -0.02 | -0.02 |
| OM | 0.64 | -0.21 | -0.25 | 0.23 | 0.44 | -0.03 | -0.05 |
| TN | 0.48 | -0.25 | -0.21 | 0.13 | 0.24 | 0.00 | -0.22 |
| BD | -0.01 | 0.93 | 0.12 | -0.14 | 0.02 | 0.00 | 0.02 |
| TP | 0.02 | -0.92 | -0.11 | 0.14 | -0.02 | 0.00 | -0.03 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Soil Pb | -0.03 | 0.86 | 0.25 | -0.10 | 0.09 | 0.23 | -0.03 |
| MC | -0.01 | -0.82 | -0.17 | 0.15 | -0.04 | 0.18 | 0.01 |
| PLI Pb | 0.03 | 0.78 | 0.17 | -0.12 | 0.10 | 0.24 | -0.11 |
| Soil Cd | -0.22 | 0.38 | 0.78 | -0.06 | -0.03 | -0.03 | 0.04 |
| PLI Cd | -0.15 | 0.18 | 0.74 | -0.04 | 0.03 | -0.12 | -0.19 |
| Cassava Cd | -0.37 | 0.28 | 0.66 | -0.06 | 0.36 | 0.00 | 0.00 |
| K | 0.15 | 0.15 | 0.65 | 0.03 | 0.08 | 0.31 | 0.33 |
| pH(KCl) | -0.02 | 0.04 | 0.63 | -0.10 | -0.08 | -0.13 | 0.16 |
| Silt | 0.06 | -0.27 | -0.10 | 0.93 | -0.13 | -0.02 | -0.01 |
| Sand | -0.08 | 0.17 | 0.10 | -0.91 | 0.09 | -0.25 | 0.02 |
| SCR | 0.03 | -0.24 | -0.02 | 0.74 | -0.08 | -0.60 | 0.00 |
| MTF pb | 0.26 | -0.06 | -0.03 | -0.15 | 0.84 | -0.04 | 0.12 |
| Cassava Pb | 0.18 | 0.35 | 0.11 | -0.14 | 0.82 | 0.12 | 0.10 |
| MTF Cd | -0.54 | 0.15 | 0.14 | -0.07 | 0.61 | -0.14 | -0.09 |
| Clay | 0.07 | 0.08 | -0.13 | 0.10 | -0.04 | 0.93 | -0.03 |
| Na | 0.09 | -0.28 | -0.01 | -0.03 | 0.17 | 0.00 | 0.73 |
| TEA | -0.42 | 0.29 | 0.28 | -0.02 | -0.05 | -0.07 | 0.71 |
| **Eigenvalues** | 5.38 | 4.72 | 2.91 | 2.50 | 2.37 | 1.63 | 1.62 |
| **% variance** | 19.92 | 17.49 | 10.79 | 9.27 | 8.76 | 6.02 | 6.01 |
| **Cumulative %** | 19.92 | 37.42 | 48.20 | 57.47 | 66.24 | 72.26 | 78.27 |

degrading venture. On $PC_5$, three variables loaded strongly and positively [silt (0.84) and sand (0.82)] while one parameter [SCR (0.61)] loaded negatively. This component contributed 9% of the total variance.

Equally, 3 variables [MTF Pb (0.84), cassava Pb(0.82) and MTF Cd (0.61)] loaded heavily on $PC_5$. This component contributed 9% variance of the linear variables. Only one positive variable Clay (0.93) were strongly loaded on $PC_6$. This component accounted for 6% variation. Table 7 also showed that two positive parameter was recorded on $PC_7$ [Na (0.67)] and TEA (0.95)] with corresponding 6% variance in the linear combination of soil properties. Their positive values imply that they increase with increasing mining activities.

**Conclusions**

It was shown by the findings that none of the soil physical properties varied significantly with location. Amongst them, moisture content and total porosity were mostly reduced by mining activities. Distribution pattern of soil physical properties with distance was uniform to moderate while that of chemical properties apart from %BS was moderate to irregular. All the chemical properties apart from Na differed significantly with location and sampling distance. Enyigba had higher soil pH, organic matter, total nitrogen available phosphorus, basic cations as well as CEC, %BS, Pb in cassava, MTF of Pb and PLI of Cd while total exchangeable acidity, Cd in soil and cassava as well as soil Pb were higher in Amegu. Equally, mining activities within close distances reduced contents of soil chemical properties including soil pH, organic matter, total nitrogen, available phosphorus and basic cations but however, increased soil CEC, concentrations of Pb and Cd in soil and cassava as well as their accumulation indices. Nevertheless, distribution pattern of heavy metals and accumulation index with distance was irregular. Amongst the soil parameter measured, moisture content, soil bulk density and pH($H_2$0) had stronger impact the concentrations and accumulation indices of Pb and Cd. Therefore, efforts should be made to locate cassava farmlands at a very far distance from the mining site to minimize health risks associated with heavy metals poisoning.

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