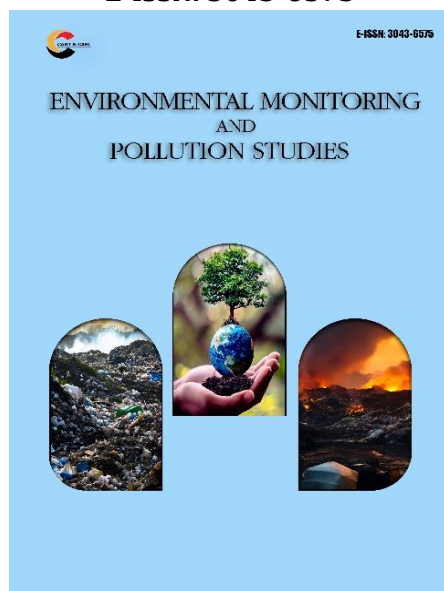




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## Authors

a\* Solomon, M. P.,<sup>abc</sup> Agbagwa, I. O.,<sup>abd</sup> Osuji, L. C.

<sup>a</sup> Institute of Natural Resources, Environment and Sustainable Development, University of Port Harcourt, PMB 5323, Choba, Port Harcourt, Nigeria

<sup>b</sup> World Bank Africa Centre of Excellence in Oilfield Chemicals Research (ACE-CEFOR), University of Port Harcourt

<sup>c</sup> Department of Plant Science and Biotechnology, Faculty of Biological Sciences, University of Port Harcourt, Port Harcourt, Nigeria

<sup>d</sup> Petroleum & Environmental Chemistry Research Group, Department of Pure and Industrial Chemistry, University of Port Harcourt, PMB 5323, Port Harcourt, Nigeria

\*Corresponding Author  
Solomon, M. P.

([mmefreukut\\_solomon@uniport.edu.ng](mailto:mmefreukut_solomon@uniport.edu.ng))

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## Human Health Risk Assessment of Heavy Metal Contaminated Food Crop from Farmlands in Artisanal Refining Areas in Parts of Rivers State, Niger Delta

### Abstract

Farmlands near communities in the Niger Delta Region are experiencing increased damage from heavy metals due to various pollution sources, including gas flaring, artisanal refining, agricultural activities, and traffic, among others. The study was aimed at assessing heavy metal contamination in food crops and soil and the potential risk for residents in Rivers State. Soil and cassava samples from the areas near the artisanal refining areas were sampled and analysed. Plant and soil samples were digested following standard procedures and subjected to atomic absorption spectrophotometric (AAS) analysis. The results indicate that the anthropogenic artisanal refining activities have caused local agricultural soil contamination with Pb, Cd, Ni, Cu, Zn, Hg and Mn in the ranges of 4.49–5.87 mg/kg, 2.37–3.11 mg/kg, 5.10–6.02 mg/kg, 3.54 – 6.72 mg/kg, 6.87 – 13.37 mg/kg and 118.8–156.5 mg/kg, respectively. GIS-based mapping shows that soil heavy metal concentrations were higher in samples collected at the polluted areas than samples taken from non-polluted (Control) areas. The concentrations of Pb, Ni, Cu, Zn, Hg and Cd found in cassava tubers (*Manihot esculenta*) were in the ranges of 0–0.33 mg/kg, 0.13–0.33 mg/kg, 0.36 – 0.82 mg/kg, 1.55 – 2.58 mg/kg, 12.06 – 34.61 mg/kg and 14.53–65.08 mg/kg, respectively. Most of these concentrations exceeded their maximum permissible limits for contaminants in foods as stipulated by USEPA. Food consumption, soil ingestion and soil dermal exposure are the three routes that contribute to the average daily intake dose of heavy metals for local adults. Moreover, the total hazard indices of Cu, Pb and Cd are greater than the safety threshold of 1.

**Keywords:** Human Health Risk, Contaminated Food Crops, Farmlands, Artisanal Refining Areas, Niger Delta

### Introduction

Artisanal refining of crude oil has concurrently been the practice in the Niger Delta for many decades. This practice poses a major source of environmental pollution through flared gases, oil spillage, and discharge of highly toxic effluents. The consequences are long-term and can be observed in soil, water, and the food chain contamination with hydrocarbons and heavy metals. Reports have shown high levels of heavy metals in the soil of crude oil-impacted communities. This type of contamination has implications for the health of farmers and consumers of farm produce from these areas. The study carried out in Rivers State, Niger Delta, found that vegetables and soil had significant concentrations of heavy metals, which presented health hazards for adults and children who consumed these products above USEPA guidelines. Furthermore, studies have looked into the possibility that eating cassava crops grown in places where there has been an oil leak or illicit oil activity could cause cancer. (Orisakwe, 2021). While mercury, lead, arsenic, chromium, and cadmium are nonessential elements because they are toxic even at low

concentration levels, metals like zinc, iron, manganese, and copper are essential elements because they are vital to biological systems and only become harmful at high concentrations (Saad et. al., 2013). Heavy metal toxicity is typically caused by the ions' chemical reactivity with membrane systems, enzymes, and structural proteins in cells (Ghori et. al., 2019). Due to their cumulative nature and lack of biodegradability, metals are persistent pollutants (Olaniran et. al., 2013).

Kalagbor et. al (2014) study showed that crops harvested from oil prospecting regions have higher levels of most heavy metals when compared to those from areas of non-oil exploration in the Niger Delta. Dietary intake is the main route of exposure for most people, although inhalation can play an important role in highly contaminated sites (Tripathi et al., 1997). Serious systemic health problems can develop as a result of excessive dietary accumulation of heavy metals such as Cd and Pb in the human body (Jan et. al., 2015). Roba et al. (2016) reported that soil and vegetables polluted with Pb and Cd significantly contributed to decreased human life expectancy within the affected areas of Cospa Mica and Baia Mare in Romania, reducing average age at death by 9 – 10 years. When heavy metals are absorbed by plants, which may serve as food and medicine to man and as forage to animals, they find their way into the body system, causing cancer and even heart disease (Mahurpawar, 2015). The high concentration of heavy metals in the soil is reflected by higher concentrations of metals in plants and, consequently, in animals and human bodies. The impact of artisanal refining of crude oil on soil and water quality in parts of Okrika and Ogu-Bolo areas of Rivers State was assessed. Results showed elevated levels of heavy metals and other physicochemical parameters such as nitrate, which may be associated with spontaneous miscarriage, ectopic pregnancy, adult malignant lymphomas, soft tissue sarcomas, cancers and lesions (Nwankwoala et al., 2017). Risk assessment of human health from consumed food crops on artisanal refining impacted farmland involves hazard identification, characterisation, exposure assessment, and risk characterisation. A paradigm shift is required to deliver testing strategies that enable reliable, animal-free hazard and risk assessments, which are based on a mechanistic understanding of chemical toxicity and make use of exposure science and epidemiological data (Trosko et al., 2010). Health risk associated with chromium (Cr), manganese (Mn) and arsenic (As) through consumption of some food crops in selected industrialised areas located in the south eastern states of Nigeria using the estimated or chronic daily

intake (EDI), target hazard quotient (THQ) and incremental lifetime cancer risk (ILCR) was investigated. Available studies on food contamination due to artisanal refining in the Niger Delta are limited to a few places within the region, undermining the health and safety of farmers in those neglected areas. It is, therefore, important to carry out a comprehensive assessment of the safety of consumed staple food crops such as cassava, which is majorly produced and consumed in the region and even exported to other regions in Nigeria and abroad. Hence, the objective of this study was to assess the level of heavy metals (Pb, Cd, Cr, Mn, Ni and Cu) and associated health risks in agricultural soil as well as the food crop (*Manihot esculenta*) commonly consumed in these areas.

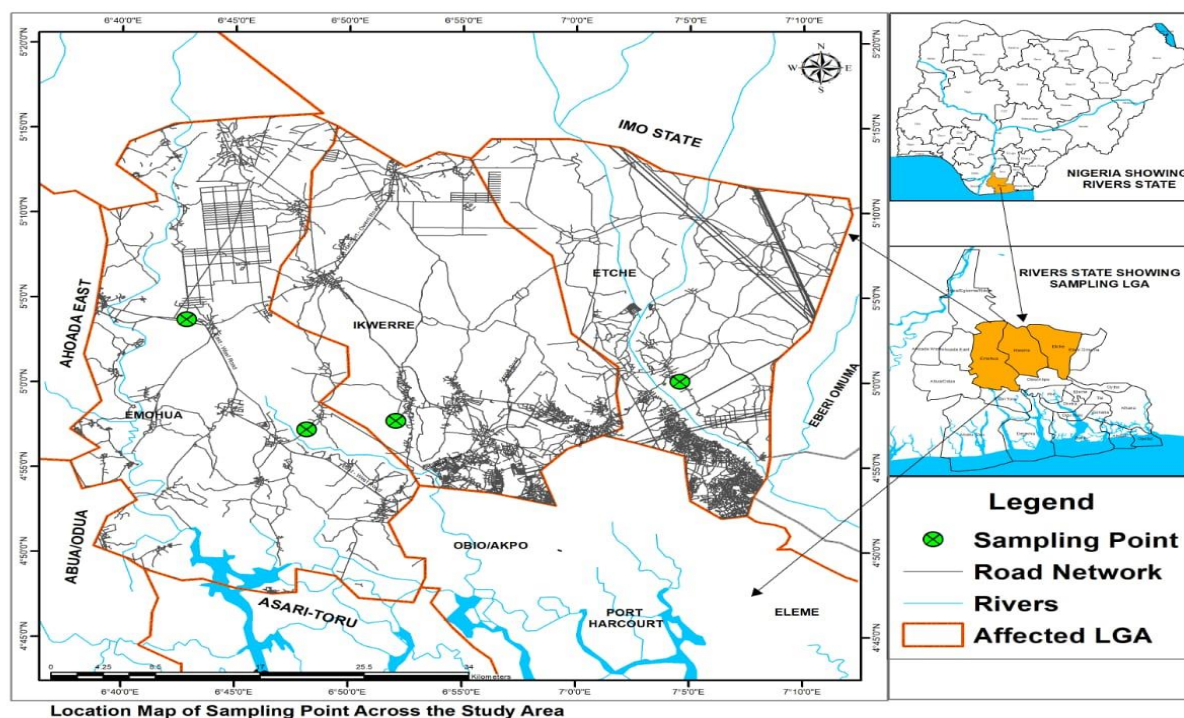
## Materials and Methods

### Study Area

Emuoha and Ikwerre are among the twenty-three (23) Local Government Areas of Rivers State. The study area is located between latitude 4°53'N - 4°54'N and longitude 6°52'30'E - 7°1'30'E in the South-South geographical zone of Nigeria (Figure 1). The topography is a flat terrain, average height of about 11m above sea level. The flat terrain encourages water stagnation after rain episodes, and there is no good drainage system to channel runoff to the river. The climate is a humid tropical/equatorial zone with a mean annual temperature of about 29°C. The temperature ranges from about 22°C - 35°C within the rainy and dry seasons, respectively. The highest rainfall occurs between July and September, and decreases as the dry season approaches between December and January, with a mean annual rainfall of 2500mm.

### Sample Collection

Soil samples were collected from farmlands located in artisanal crude oil refining areas in Emuoha and Ikwerre Local Government Areas of Rivers State. Farmlands located in Etche LGA served as the control. Fifty (50) soil samples were collected randomly at 2 depths (0-15 cm and 15- 30 cm) from farmland measuring 100m x 100m in Emuoha and Ikwerre LGA, respectively. A plant sample (cassava tuber) was collected along the same gradient as the soil samples. All the sample stations were properly geo-referenced, and a clear reproducible sampling map was produced (Figure 1). Samples collected were kept in polythene bags to avoid evaporation of important constituents and later dried and preserved for analysis at the laboratory, as adopted by Osuji and Nwoye (2007).



**Fig. 1:** Map of study area showing Ikwerre, Emohua and Etche, where samples were collected

### Pre-treatment and Analysis of Soil and Plant Samples

Soil samples were air-dried in the laboratory and sieved through a <2 mm mesh size sieve. Parts of the soils were ground in a porcelain mortar <100 mesh. They were stored in polyethene bags at 4 °C before analysis. The samples were washed in distilled water and subsequently rinsed again with high-purity deionised water. After being milled by a ceramic-coated grinder, the plant samples were kept in a freezer at 18 °C until chemical analysis. Soil pH (H<sub>2</sub>O) and electrical conductivity (EC) were determined in distilled water (1:2.5 w/v). Soil mechanical composition (sand, silt, clay) was determined by a hydrometer method (Bouyoucos, 1962). Total Pb, Cd, Cr, Cu, Hg, Ni and Zn in the soils and plant samples were measured. The amounts of soil and plant samples for analysis were 2 g and 5 g, respectively. The dry and ground samples were weighed into a 100 ml beaker. Two (2ml) of nitric acid and 6ml of hydrochloric acid (1:3 ratio mixture) were added and allowed to stand overnight or until the vigorous reaction phase is over. After the preliminary digestion, the beaker with the sample was placed on a hot plate at 105°C and heated to near dryness. After the digestion was complete, the beaker was allowed to cool. The sample was carefully filtered into a measuring cylinder, using filter paper and a funnel. The digestate was made up to a known volume with distilled water. Concentrations of the heavy metals (cadmium, lead, zinc, nickel and mercury) in the samples were determined by an atomic absorption

spectrophotometer (AAS). The limits of detection (LOD) for Pb, Cd, Cr and Hg were 11.9, 2.3, and 113.7, 2.0 and 20.0 ng L<sup>-1</sup> respectively, as described by Liu et al. (2013).

### Estimation of Transfer Factor (TF)

The transfer factor (TF) is a measure of the level of accumulation of toxic elements by the plants from the soil (Adamo et al., 2014). This was evaluated by dividing the concentration of heavy metals in the cassava tuber samples by the concentration of heavy metals in the soil samples. This is expressed mathematically as,

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

Where, C<sub>plant</sub> = Concentration of heavy metals in cassava tuber (mg/kg). C<sub>soil</sub> = Concentration of heavy metals in soil (mg/kg). The significance of the result is that if TF is greater than 1, it implies that the plants have accumulated elements. However, if TF is less than 1, it connotes that the plant resists the uptake of the elements. However, if TF is around 1, it simply shows that the plants are not affected by the element (Chojnacka et al., 2005)

### Risk Assessment Methods

The human health risk models, including carcinogenic and non-carcinogenic ones, raised by the US EPA, have proved successful and have been adopted worldwide. Currently, there is no agreed limit for acceptable maximum carcinogenic and non-carcinogenic risk levels



in Nigeria. We therefore employed the US EPA model and its threshold values to assess the potential human health risks posed by heavy metal pollution in this study. The health risk assessment was divided into four steps: (1) hazard identification, (2) dose–response assessment, (3) exposure assessment, and (4) risk characterisation (US EPA, 1992). The multiphase and multicomponent risk assessment model developed by the US EPA was used to evaluate the heavy metal pollution hazard in urban residential areas (US EPA, 2004). The intake doses of heavy metals were calculated through two sources (soil and air). Human beings can be exposed to heavy metals from soils and crops via the following 4 main pathways: (1) direct ingestion of soil particles, (2) dermal contact with soil particles, (3) ingestion of food crops through the food chain, (4) inhalation of soil particles from the air. The calculations for the daily exposure dose of contaminants via various exposure pathways and the detailed explanation for all the parameters are listed in Table 1 (US EPA, 2000, 2002, 2004; Wang et al., 2018). The risk effects consist of carcinogenic and non-carcinogenic risk assessments for all the metals through ingestion, inhalation, dermal and diet exposure pathways in the study area. Cancer risk can be evaluated from:

$$\text{Cancer Risk (CR)} = \text{CDI} \times \text{SF}$$

where cancer risk represents the probability of an individual's lifetime health risks from carcinogens; CDI is the chronic daily intake of carcinogens ( $\text{mg kg}^{-1} \text{d}^{-1}$ ); SF is the slope factor of hazardous substances ( $\text{mg kg}^{-1} \text{d}^{-1}$ ). The cumulative cancer risk can be calculated from:

$$\text{Total Cancer Risk} = \sum \text{CDI}_k \text{SF}_k$$

Where  $\text{CDI}_k$  is the chronic daily intake ( $\text{mg kg}^{-1} \text{d}^{-1}$ ) of substance  $k$ ,  $\text{SF}_k$  is the slope factor for substance  $k$  ( $\text{kg d}^{-1} \text{mg}^{-1}$ ). The acceptable or tolerable risk for regulatory purposes is within the range of  $10^{-6}$  –  $10^{-4}$  (US EPA, 2001). The non-carcinogenic risk from individual heavy metals can be expressed as the hazard quotient

$$\text{HQ} = \frac{\text{CDI}}{\text{RfD}}$$

where the non-cancer hazard quotient (HQ) is the ratio of exposure to hazardous substances, and RfD is the chronic reference dose of the toxicant ( $\text{mg kg}^{-1} \text{d}^{-1}$ ).

$$\text{Chronic Hazard Index} = \sum \frac{\text{CDI}_k}{\text{RfD}_k}$$

The  $\text{SF}_k$  values of Cr, Ni, As, Pb, and Cd were 0.5, 1.7, 1.5, 0.38, and 0.01  $\text{mg/kg/day}$ , respectively (Gebeyehu and Bayissa, 2020).

Where the chronic hazard index (HI) is the sum of more than one hazard quotient for multiple substances or

multiple exposure pathways,  $\text{CDI}_k$  is the daily intake of the heavy metal ( $k$ ), and  $\text{RfD}_k$  is the chronic reference dose for the heavy metal  $k$ . HI values  $> 1$  show that there is a chance that non-carcinogenic risk may occur, and when  $\text{HI} < 1$ , the reverse applies.

### Quality control and statistical analysis

The accuracy of data was ensured by including a standard reference in every batch of sample digestion and analysis as a part of the quality control protocol. Each sample was analysed in triplicate, and two standards were tested after every 10 samples. The calibration curves were linear within the concentration range, with the regression coefficients ( $R^2$ )  $> 0.989$ . Relative standard deviations (RSDs) of repeated measurements were  $> 11\%$ . These results showed that the elemental analysis method was both reliable and precise. Descriptive statistics were calculated using the SPSS software version. 23. Microsoft Excel (Windows 10 software) was employed for all the graph plotting. The data were displayed using the parameters of the minimum value, maximum value, mean value, the median, standard deviation and 95.

## Results and Discussion

### Characterisation of soil and crop samples

The physicochemical properties of 50 soil samples from the study area had a wide range of pH values (4.22–4.73; mean: 4.52), EC (66.67–100.9  $\mu\text{S/cm}$ ; mean: 88.02  $\mu\text{S/cm}$ ), and moisture content (7.21–10.35 %; mean: 8.49 %). The descriptive statistical analysis for the data of all the heavy metal concentrations in the cassava tuber and their corresponding soils is shown in Table 1 and Table 2.

### Heavy Metal Contamination

Potential toxic metals in test crop showed mean and ranges as  $0.113 \pm 0.168$  ( $<0.001$  – 0.330);  $0.247 \pm 0.168$  (0.130 – 0.330);  $0.607 \pm 0.207$  (0.360 – 0.820);  $2.145 \pm 0.397$  (1.55 – 2.58);  $22.62 \pm 9.58$  (12.06 – 34.61) and  $31.19 \pm 17.88$  (14.53 – 65.08) for Pb, Cd, Ni, Cu, Zn and Mn, respectively (Table 1 and 2, Figure 1). Metal concentrations in plants were within the WHO permissible limits (Pb: 2.0  $\text{mg/kg}$ , Cd: 0.02  $\text{mg/kg}$ , Ni: 10  $\text{mg/kg}$ , Cu: 10  $\text{mg/kg}$ , Zn: 0.6  $\text{mg/kg}$ ). Mercury (Hg) was present below the instrument detection limit. However, the concentrations of heavy metals in the test soil as well as the Control locations were within WHO maximum limit for Pb (50  $\text{mg/kg}$ ), Cd (0.8  $\text{mg/kg}$ ), Ni (35  $\text{mg/kg}$ ), Cu (36  $\text{mg/kg}$ ), Zn (140  $\text{mg/kg}$ ), Hg (0.5  $\text{mg/kg}$ ) (WHO, 2010). Lead (Pb) contamination in crops and soils can have detrimental effects on human health, the environment, and agricultural productivity, especially

when absorbed by plants from contaminated soils or water. Impact could lead to Pb poisoning when humans consume crops that have taken up Pb with resultant

health disorders, including neurological damage, developmental delays in children, reproductive issues, and kidney damage (Collin et al., 2022).

Table 1: Descriptive Statistical Analysis for Heavy Metals in the Indicator Plant (Cassava Tuber)

|        | Pb       | Cd       | Ni       | Cu       | Zn       | Hg | Mn       |
|--------|----------|----------|----------|----------|----------|----|----------|
| Mean   | 0.113    | 0.247    | 0.607    | 2.145    | 22.623   | ND | 31.192   |
| Sd     | 0.168    | 0.072    | 0.207    | 0.398    | 9.583    | ND | 17.875   |
| 10     | 0        | 0.175    | 0.360    | 1.745    | 15.005   | ND | 18.240   |
| 25     | 0.22     | 0        | 1.940    | 17.95    | 21.950   | ND | 0        |
| Median | 0.01     | 0.255    | 0.640    | 2.185    | 18.255   | ND | 26.885   |
| 75     | 0.25     | 0.290    | 0.775    | 2.430    | 30.598   | ND | 31.820   |
| 90     | 0.33     | 0.310    | 0.820    | 2.505    | 34.610   | ND | 48.450   |
| 95     | 0.33     | 0.320    | 0.820    | 2.543    | 34.610   | ND | 56.765   |
| F      | -        | 0.191    | -        | 0.326    | -        | ND | 0.167    |
| p      | P > 0.05 | P > 0.05 | P > 0.05 | P > 0.05 | P > 0.05 | ND | P > 0.05 |

10, 25, 75, 90, 95 are percentile values of heavy metal concentrations in crop plants

Table 2: Descriptive Statistical Analysis for Heavy Metals in the Corresponding Soil

|        | Pb       | Cd       | Ni       | Cu       | Zn       | Hg | Mn       |
|--------|----------|----------|----------|----------|----------|----|----------|
| Mean   | 5.225    | 2.648    | 5.635    | 4.220    | 10.188   | ND | 136.42   |
| Sd     | 0.536    | 0.301    | 0.359    | 1.242    | 2.208    | ND | 15.764   |
| 10     | 4.590    | 2.380    | 5.215    | 3.555    | 7.865    | ND | 121.33   |
| 25     | 2.400    | 0        | 3.595    | 9.213    | 124.10   | ND | 0        |
| Median | 5.335    | 2.585    | 5.715    | 3.685    | 10.320   | ND | 135.11   |
| 75     | 5.570    | 2.823    | 5.900    | 4.015    | 11.135   | ND | 148.14   |
| 90     | 5.750    | 2.980    | 5.975    | 5.420    | 12.380   | ND | 152.81   |
| 95     | 5.810    | 3.045    | 5.998    | 6.070    | 12.875   | ND | 154.66   |
| F      | 4.054    | 8.083    | 0.246    | 0.352    | 3.835    | ND | 0.159    |
| p      | P > 0.05 | P > 0.05 | P > 0.05 | P > 0.05 | P > 0.05 | ND | P > 0.05 |

10, 25, 75, 90, 95 are percentile values of heavy metal concentrations in soil

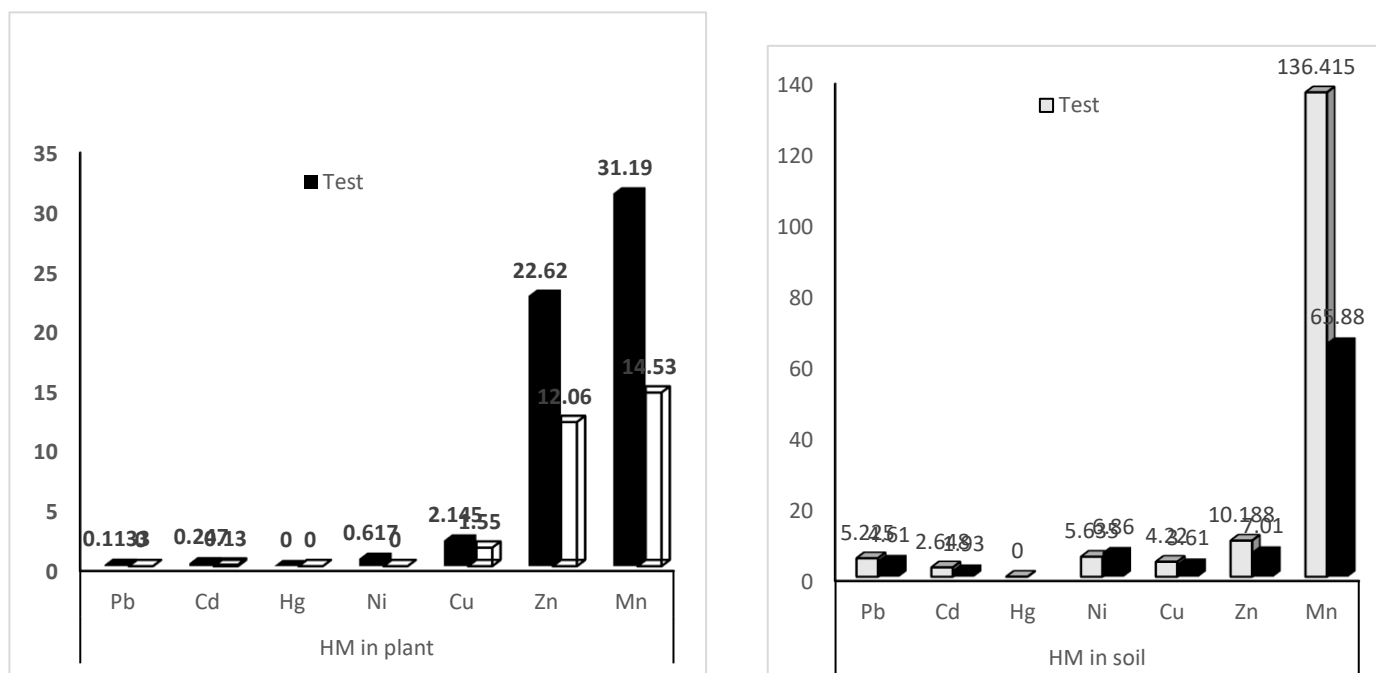


Figure1: Heavy Metal Concentrations in Test and Control Soils and Plants at the Study Area

Mean concentration of Pb in soil at the test sites was 5.23 mg/kg, which was significantly ( $p < 0.05$ ) higher than that of the control (4.61 mg/kg). Similar ranges of Pb in contaminated soils were reported by Amonoo-Neizer et al. (1996), who found levels ranging from 3.5 to 7.4 mg/kg in Ghana. Conversely, lower Pb levels were recorded by Okorie et al. (2012) in urban gardens in Nigeria, where the concentrations were between 1.2 and 3.5 mg/kg. Osuji et al. (2005) reported elevated Pb concentrations around an artisanal refining facility in the Niger Delta, ranging from 40 to 5000 mg/kg in soil samples, far higher than those obtained in this study. Similarly, Iwegbue et al. (2019) found alarming levels of Pb contamination in soil samples near artisanal refining sites, corroborating a significant influence of artisanal refining on Pb in soils and crops. Soil serves as a crucial component of ecosystems, supporting plant growth and microbial activity. However, excessive Pb contamination disrupts soil quality, leading to degradation and loss of biodiversity. Moreso, Pb can accumulate in plants, posing risks to agricultural productivity and food safety. Cadmium is a toxic heavy metal capable of accumulating in plants through uptake from contaminated soil and water; it bioaccumulates in the food chain, impacting wildlife and biodiversity. The mean Cd concentration in the test soils was 2.65 mg/kg, significantly higher than the control (1.93 mg/kg). This was in consonance with findings by Sharma et al. (2007) in India, where soil Cd levels ranged from 2.0 to 3.5 mg/kg in industrial areas. McLaughlin et al. (2000) reported lower ranges of Cd in Australian soils, showing levels between 0.1 and 0.5 mg/kg. Higher levels were observed by Toth et al. (2016) in European soils, where concentrations were up to 5 mg/kg. WHO/FAO and EU limits for Cd in soil are 3 mg/kg and 1.5 mg/kg, respectively, indicating that test site concentrations exceed the EU limits but are within WHO/FAO guidelines. An elevated level of Cd in soil could be attributed to the effect of artisanal refining in

The mean Zn concentrations in test soils were 10.188 mg/kg, while the control sites had lower values (7.01 mg/kg). Comparable ranges were noted by Alloway (1995) in UK soils, between 10 and 50 ppm. Lower ranges were reported by McBride et al. (1997) in US agricultural soils, where levels ranged from 1 to 5 mg/kg. Higher Zn concentrations were documented by Smolders and Six (2003) in Belgian soils, with levels up to 150 mg/kg. WHO/FAO, EU, and DPR limits for Zn are 300 mg/kg, 200 mg/kg and 50 mg/kg, respectively, indicating that the levels in this study are far below the safety thresholds. Otaiku (2019) found Zn values of 1.52-2.05 mg/kg, which were lower than those found in this study. The heavy metal (Zn) values determined by

the study areas. Artisanal refining, an illegal process, can result in the release of various heavy metals, including cadmium, into the environment. Nwilo and Badejo (2005) investigated heavy metal contamination in soils around artisanal oil refining sites in the Niger Delta and recorded elevated levels of Cd in the soil samples collected near the refining sites. Uwem and Sunday (2018) investigated the levels of heavy metals, including Cd, in soils around artisanal refining sites in the Niger Delta and discovered a higher level of the metal. Another study by Richard et al. (2022) around artisanal oil refining sites in the Niger Delta and the impact on agricultural productivity showed an alarming heavy metal impact, including Cd, with consequential impacts on soil fertility and crop growth, posing significant challenges to agricultural sustainability. Copper gave a mean value of 4.22 mg/kg at the test sites compared to 3.61 mg/kg at the control sites. These values are in line with those reported by Adriano and Adriano (2001) in the USA, with ranges between 2 and 20 mg/kg in agricultural soils. Lower ranges were documented by Kabata-Pendias (2001) in Polish soils, from 0.3 to 3 mg/kg. Higher Cu concentrations were found by Yruela (2005) in industrial areas of Spain, reaching up to 30 ppm. The WHO/FAO and EU limits for Cu in soil are 100 mg/kg and 140 mg/kg, respectively, indicating the observed levels are well within acceptable limits. Results revealed a considerable presence of heavy metals in the soil. This can be attributed copious use of chemicals with heavy metals in the course of petroleum production activities. Cu is an essential micronutrient for plants, playing a vital role in various physiological processes such as photosynthesis, respiration, and enzyme activation. However, excess copper in soil can have both beneficial and detrimental effects on plants and the environment. Values of Cu in this study were within stipulated ranges, hence no adverse impacts were expected.

Udoetok et al. (2011) at an oil spill site in Nigeria's Niger Delta region were 9.84 0.93 mg/kg, which was consistent with these studies. While examining oil-impacted soil at Akinima, Rivers State, Nigeria, Nwankwo et al. (2015) found higher levels of Zn above normal limits (50mg/kg) in the range of 33.2 to 235.98mg/kg values. While having too little or too much zinc might have negative effects, it can also be harmful. Normal starting points for harmful effects are 10 to 15 times higher than those needed for a healthy body. Large doses taken orally, even for a brief time, may cause nausea, vomiting, and cramps in the stomach. It can cause anaemia and diminish your levels of healthy cholesterol if taken for a long time. Although it is unknown if high zinc concentrations affect human

fertility, rats given significant zinc dosages were sterile (US DPHHS, 2005). Breathing significant amounts of zinc (as dusts or vapours) might result in a short-term sickness known as metal fume fever. Zinc is a contaminant in locations near petroleum processing plants.

The level of lead in test locations (soils) was lower than in the Control. The highest lead concentrations were found in Ibaa during the dry season and Elele Alimini during the wet season. The values at Ibaa in the dry season and Elele Alimini in the rainy season were statistically ( $p < 0.05$ ) different; however, both were within the WHO intervention limit (85mg/kg) for agricultural soil. These results surpass the lead's 5.00 mg/kg toxicity characteristic leachate limits (TCL) (Bowen, 1979). Lead contamination of soils is caused by waste products from the use of chemicals like pipe lax, lube 106, and other lubricants like diesel oil used in the production of petroleum. Several reasonably resistant plant species exist, even though Pb has been reported to be dangerous for many plant species. When lead is eaten, a disease called plumbism develops. The brain, central nervous system, kidney, liver, and reproductive system are all at risk from lead exposure. According to Nwankwaola et al. (2015) and Sobolev and Begonia (2008), lead has no biological purpose and may be harmful to microorganisms. Pearson Correlation for metal concentrations within the soil, metal concentrations within the plant and metal concentrations between the plant and the soil showed no statistical significance difference at  $p > 0.05$ .

### Soil – Metal Transfer

The soil-to-plant transfer quotient is the main source of human exposure and expresses the efficiency of cassava tuber in accumulating these metals from the soil. A convenient way for quantifying the relative differences of bioavailability of metals to plants is the transfer quotient, and it is important to assess the human Health Risk Index (HRI) transfer quotient (Gupta et al., 2021). The transfer quotient for the metals was in the order: Zn (2.23) > Cu (0.51) > Mn (0.23) > Ni (0.11) > Cd (0.10) > Pb (0.02). The bio-concentration factors (BCF) for heavy metals were calculated to determine the efficiency of cassava in accumulating these metals from the soil. The BCF for Cd was particularly high in the test sites, indicating significant bioaccumulation. This was similar to the findings of Nwaichi et al. (2014) at Ishiagu, who reported high soil-metal values for Cd in cassava. In a similar vein, Onyedikachi et al. (2011) in Isiagwu recorded high ratios for Cd in soil-cassava transfer. The higher transfer quotient of heavy metal indicates the stronger

accumulation of the respective metal by the cassava crop. A transfer quotient of 0.1 indicates that the plant is excluding the element from its tissues (Wang et al., 2006). The greater the transfer coefficient value of 0.50, the greater the chances of cassava crop for metal contamination by artisanal refining activities will be, and so the need for environmental monitoring of the area will be required for possible (Ebong et al., 2022).

### Health Risk Assessment

Health risk assessments were conducted based on the chronic daily intake (CDI) of heavy metals as presented in Table 3. Our study shows CDI of Pb values of 7.464E-06 for adults and 6.97E-05 for children, which are slightly higher than the findings of Aigberua et al. (2018) (6.8E-06 and 6.5E-05, respectively). The values for Cd are 3.783E-06 (adult) and 3.53E-05 (child), which are within the range reported by Ndubuisi and Kelechi (2021) (3.2E-06 and 3.1E-05). The CDI values for Ni are 8.05E-06 (adult) and 7.51E-05 (child) in our study, slightly higher than the findings of Makanjuola (2019) (7.0E-06 and 6.5E-05). The CDI values for Cu are 6.03E-06 (adult) and 5.63E-05 (child), slightly higher than report of Iniaghe and Osioma (2022) (5.5E-06 and 5.2E-05) while the CDI values for Zn and Mn in our study indicate low non-carcinogenic risks, consistent with previous studies in the region where these metals were also not found to be significant contributors to health risks. The THQ for Pb in our study is 1.42E-01 (adult) and 9.04E-01 (child), comparable to Aigberua et al. (2018) (1.37E-01 and 8.95E-01). The THQ for Cd is 5.78E-02 (adult) and 3.67E-01 (child), aligning closely with the previous findings (5.62E-02 and 3.45E-01) (Ndubuisi and Kelechi, 2021). Similarly, THQ for Ni is 3.05E-03 (adult) and 1.96E-02 (child), similar to Makanjuola (2019), who recorded 2.95E-03 and 1.87E-02, respectively. THQ for Cu is 1.14E-03 (adult) and 7.31E-03 (child), similar to the previous study (1.02E-03 and 6.98E-03) by Iniaghe and Osioma (2022). The ILTCR for Pb is 0.142 (adult) and 0.904 (child), which are slightly higher than the previous study, indicating a consistent significant risk. ILTCR values for Cd in our study are 0.0578 (adult) and 0.367 (child), slightly higher than Ndubuisi and Kelechi (2021), with 0.0512 and 0.318, respectively, reflecting a persistent risk. The ILTCR values for Ni are 0.00305 (adult) and 0.0196 (child), marginally higher than the previous study (0.0029 and 0.018), indicating a consistent risk for ingestion or dermal contact of soil around the study area. ILTCR for Cu, Zn and Mn were not determined in the previous studies, but our THQ values suggest low non-carcinogenic risks.

Table 3: Soil Ingestion and Dermal Contact due to Soil Sampled from the Study Area

| Element | Soil Ingestion |        |             |             | Dermal Contact |             | HQ         |            |
|---------|----------------|--------|-------------|-------------|----------------|-------------|------------|------------|
|         | RfD            | CSF    | CDI (adult) | CDI (child) | CDI (adult)    | CDI (child) | HQ (adult) | HQ (child) |
| Pb      | 0.0004         | 0.0085 | 7.464E-06   | 6.97E-05    | 4.92E-05       | 2.92E-04    | 1.42E-01   | 9.04E-01   |
| Cd      | 0.0005         | 0.38   | 3.783E-06   | 3.53E-05    | 2.51E-05       | 1.48E-04    | 5.78E-02   | 3.67E-01   |
| Ni      | 0.02           | 0.91   | 8.05E-06    | 7.51E-05    | 5.3E-05        | 3.16E-04    | 3.05E-03   | 1.96E-02   |
| Cu      | 0.04           | ND     | 6.03E-06    | 5.63E-05    | 3.97E-05       | 2.36E-04    | 1.14E-03   | 7.31E-03   |
| Zn      | 0.3            | ND     | 1.45E-05    | 1.35E-04    | 9.52E-05       | 5.67E-04    | 3.66E-04   | 2.34E-03   |
| Mn      | 0.14           | ND     | 1.95E-04    | 1.82E-03    | 1.23E-03       | 7.65E-04    | 1.02E-02   | 1.85E-02   |

## Conclusions and Recommendations

The study concludes that heavy metal contamination in soil and cassava crops in the test areas is significant and poses serious health risks. The high levels of Pb and Cd are primarily due to anthropogenic activities. The study underscores the importance of determining the health risks associated with Pb, Cd, and Ni from artisanal refining activities in the Niger Delta region are consistently significant. Children are particularly at risk for both non-carcinogenic and carcinogenic effects, with THQ values greater than 1 and ILTCR values indicating probable lifetime cancer risks. These findings emphasise the need for urgent intervention to mitigate the contamination and protect public health, especially for vulnerable populations.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Credit Authorship Contribution Statement

**Solomon, M.P.:** Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Agbagwa, I.O.,** and **Osuji, L.C.:** Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

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