Occurrence of Heavy Metals Concentration in Grown Food Crops (Manihot esculenta and Colocasia esculenta) around Disused Ogbete Coal Mine in Enugu Metropolis, South Eastern Nigeria

Ogbuene Emeka Bright[a*], Ezeanata G. Chinenye[b], Ogbuka C. Josiah[a], Achoru E. Fred[a], Alo G. Obianuju[b], Okolo J. Obiageli[a], Ozorme A. Vivian[a].

[a] *Centre for Environmental Management and Control (CEMAC), University of Nigeria, Nsukka, Nigeria.*

[b]*Enugu State University of Science and Technology (ESUT), Enugu, Nigeria.*

ogbuene.emeka@unn.edu.ng

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The major food crops frequently consumed by communities in southeastern Nigeria are Manihot esculenta (cassava) and Colocasia esculenta (cocoyam). The crops are sometimes grown in disused mining sites. The study was carried out in Ogbete disused coal mine area, GRA (government residential area) Enugu, in Enugu State, Nigeria. the study area is located between latitude 6° 27' N and 35.8704" N and longitude7° 32' E and 56.2164" E. This study was conducted to assess the occurrence and concentration of heavy metals in the soil and crop samples. The five heavy metals studied were (Cd, Cr, Zn, Ni and Pb). The samples included twenty-four crops of which eighteen were collected from three sampling locations. The study shows that food grown in the site could pose health risks. The study recommends the ongoing monitoring of heavy metal concentration in the study area.

Introduction

Presently, contamination of agricultural soil by heavy metals has become a critical environmental concern due to their potential adverse ecological effects. Coal is one of the world's greatest resources, especially during the industrial revolution in the 18th and 19th centuries, but it remains a serious environmental challenge [1]. During the mining processes of coal, some metals are left behind as tailings scattered in open and partially covered pits [2]. According to Dang *et al* [3], these tailings after the stripping process undergo a pedogenesis process by quick swelling (expansion)–contraction, wetting and drying, oxidation and reduction processes. During this process, chemically bound trace elements and heavy metals are released in soil solution and become available to the plants [4]. Unfortunately, the mining of mineral resources results in extensive soil damage; altering microbial communities and affecting vegetation leading to the destruction of vast amounts of land [5]. Years later, even long after the mining activities have ended, these released heavy metals persist in the soil. Food crops, however, become contaminated but the quantity and associated bioaccumulation needs to be examined. This is of particular concern in a country like Nigeria where effective quality management and control are lacking in the food production process.

Moreover, the insufficiency of land for agricultural activities, as a result of urban sprawl/ urban expansion in the Enugu metropolis has led some subsistence farmers to cultivate their food crops in disused coal mines areas in Ogbete Enugu coal mine. Cassava and cocoyam are well-known staple food crops in Eastern Nigeria with a high daily consumption rate. Constant and Prolonged consumption of contaminated foodstuff may lead to the unceasing accumulation of toxic metals in the liver, kidney and other parts of the human body resulting in the disturbance of biochemical processes and disorders [6].

Metals are classified into three based on health hazards: Firstly, are nutritionally essential metals (Cobalt, Chromium, Copper, Iron, Manganese, Molybdenum, Selenium and Zinc). Secondly, metals with possible benefits (Boron, Nickel, Silicon and Vanadium) and thirdly, metals with no known benefits (Aluminium, Antimony, Arsenic, Barium, Beryllium, Cadmium, Lead, Mercury, Silver and Strontium) [7]. Despite the health risk involved in the cultivation of food crops around coal-polluted areas, scanty information is available in the literature on the levels of heavy metals build up in the tissues of these food crops as some researchers underscore the issue. Thus, this study will examine the level of heavy metals in food crops (Cassava and Cocoyam) around the disused coal mine in Enugu metropolis, Nigeria. The driving force for this research is a risk assessment of the extent of exposure to toxicity associated with heavy metal contamination in selected crops grown in the study area.

Experimental part

Materials and methods. Enugu state is located approximately between latitude 6° 27' N 35.8704" N longitude7° 32' E 56.2164" E. The study area is characterized by coal deposits which contributed to the development of Enugu through coal mining activities.

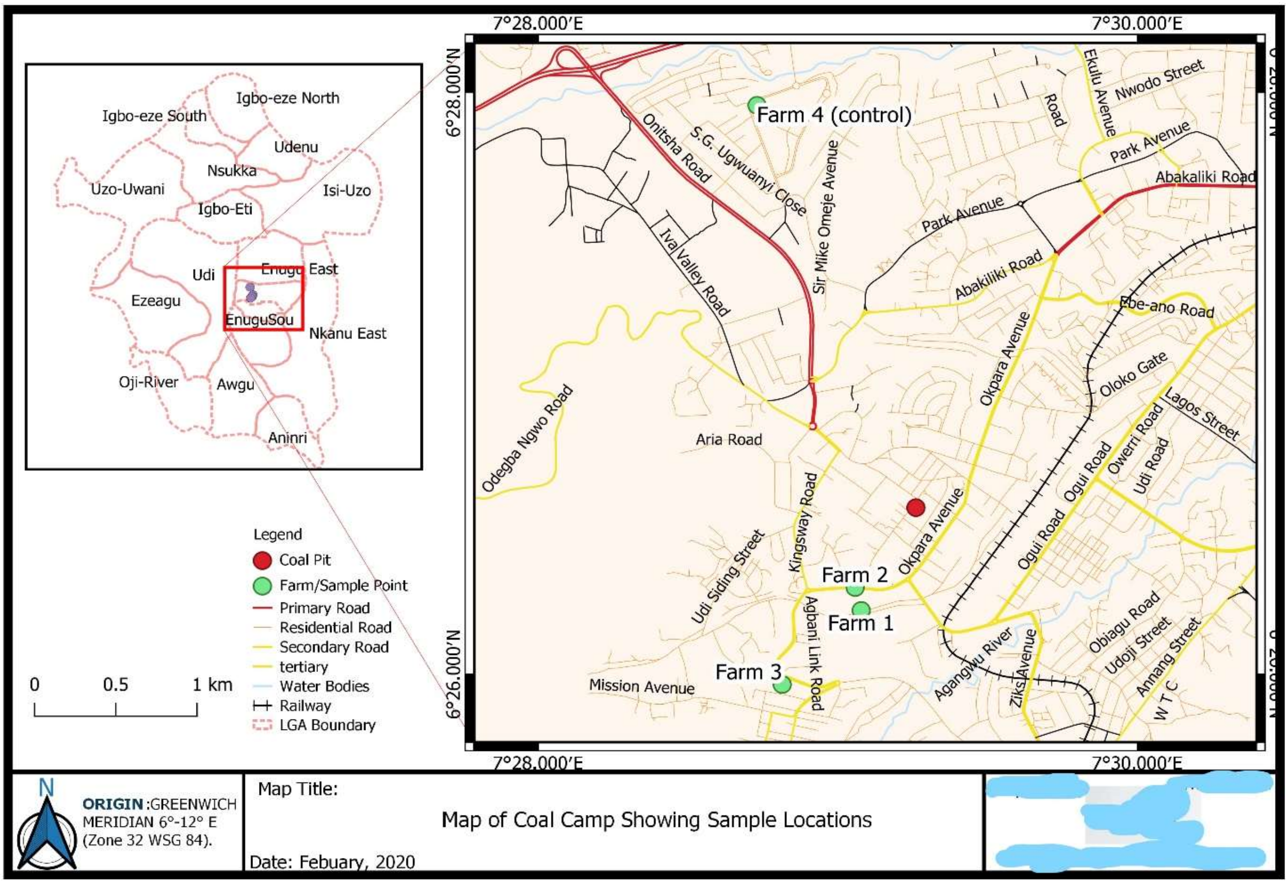

Figure 1. Map of Enugu State Showing the Study Area [8]

The map in **Figure 1** shows the Ogbete disused coal mine and GRA Enugu, in Enugu State (study area).

The sampling areas were located in farmlands around the Ogbete disused coal mine areas. The three points of sample collection included Latitude 6.4428719 Longitude 7.4876739, Latitude 6.4369684 Longitude 7.4846296, Latitude 6.4382951 Longitude 7.4842913, and Latitude 6.4327372 Longitude 7.4802324, while the control included Latitude 6.465927 Longitude 7.478832. These locations were chosen as sampling points because of their proximity to the disused coal pit as well as their strategic locations in the mining areas.

A total of Twenty-four (24) grown food crop samples were collected, comprising 18 experimental (nine samples each) of *Manihot esculenta* and *Colocasia esculenta* and 6 control samples, made up of three samples in each food crop samples harvested at three sampling locations (Farm 1, Farm 2 and Farm 3) in the experimental sites. The first location (Farm 1) was 80m away from the coal pit. The second (Farm 2) was 113m away from the coal pit while Farm 3 was 728m away from the coal pit, a point of disposal of waste from the processing plant. The control food crop samples were harvested in farmland around GRA Enugu (**Figure 1**).

Sample Preparation and Analysis. The samples were collected in different seasons. The collected vegetables and root tuber samples were washed thoroughly with deionized water to remove soil and air-borne debris. The edible parts of the samples were weighed and air-dried at 75^0C for twelve hours in a clean section of the laboratory for 4 days to reduce water content. Dried samples were then powdered using a pestle and mortar and sieved through a muslin cloth. The study also analyzed the concentration of heavy metals such as Cadmium, Nickel, lead, iron and Chromium in the food samples using an Agilent Atomic Absorption Spectrophotometer (AAS). Samples were analyzed in triplicates. Soil samples were also collected from each farmland, airdried at 25^0C for two hours and analyzed in the laboratory. For statistical analysis, ANOVA was utilized for comparing sample results and the Post HOC test accounts for mean ±standard deviation.

Results and discussion

The distribution of heavy metal concentration in the samples of soil, cocoyam and cassava are presented in **Table 1** and **2**. The set of data in Table 1 disclosed the Cadmium, Chromium, Lead**,** Nickel and zinc levels (mg/kg) in soil samples in the Ogbete disused coal mine in Enugu Metropolis, Eastern Nigeria. The results of heavy metals present in the soil samples occurred at varying concentrations ranging from 0.10 to 1.20, 0.20 to 1.00, 0.612 to 0.709, 0.298 to 0.516, and 0.10 to 1.00, for cadmium, chromium, zinc, nickel and lead respectively for all three farms studied. However, the soil sample in the coal pit recorded the highest concentration of heavy metal which is Nickel (with a value of 0.798).

The value recorded in the soil sample taken from the coal pit could be linked to an increase in the concentration of coal deposits within the coal pit which could post more risk to the value of heavy metal accumulation in the soil within the disused coal mining.

In addition, the occurrence of heavy metal concentrations in the root tubers (cassava and cocoyam) in the sampling site and control site were shown in Table 2. The details of the result can be summarized as follows:

For cadmium; In Farm 1, cassava recorded the values of 0.13, 0.023 and 0.076 while Farm 2, it records 0.028 and 0.07. For Cocoyam, cadmium was not recorded in Farm 1, 2 and 3 as well as the control samples.

For chromium; In Farm 1, cassava recorded values of 0.923, 0.851 and 0.755 while in Farm 2, recorded values are 0.495, 0.407 and 0.471 respectively. Farm 3 is 0.03 while the control samples are 0.01 and 0.03. The values of chromium for cocoyam in Farm 1, 2 and 3 are 0.00 in all the sampled points.

For Nickel; this particular heavy metal was present in both cassava and cocoyam samples in Farm 1, 2 and 3 respectively. Also, Nickel was present only in cocoyam within the control samples.

Table 1. Heavy metal concentration in soil sample in Ogbete disused Coal Mine.

HEAVY METALS Unit - (mg/kg)	FARM 1	FARM 2	FARM 3	CONTROL	COAL PIT SOIL
CADMIUM	1.20 0.97 0.73	0.97 0.01 0.43	0.20 0.10 0.20	0.02 0.01 0.10	0.10 0.20 0.03
CHROMIUM	0.98 0.95 1.00	0.50 0.20 0.60	0.065 0.075 0.061	0.80 0.30 0.52	0.276 0.276 0.276
ZINC	0.633 0.640 0.649	0.691 0.647 0.709	0.612 0.667 0.706	0.013 0.000 0.030	0.401 0.407 0.407
NICKEL	0.298 0.298 0.298	0.516 0.516 0.516	0.382 0.382 0.382	0.020 0.011 0.020	0.798 0.798 0.798
LEAD	0.74 0.10 0.30	1.00 0.40 0.27	0.10 0.48 0.20	0.20 0.50 0.10	0.40 0.34 0.12

Lead was not present in both cassava and cocoyam at both experimental and control samples except in one sample point in Farm 1. Zinc was not present in any sample of cocoyam in Farm 1 as shown in **Table 2**.

The heavy metal concentrations values in all the crop samples in both the experimental and control site were relatively similar to the WHO standard limit. The mean concentration of cadmium and nickel ranges from 0.033 to 0.067(mg/kg), and 0.843 to 0.032(mg/kg), respectively are relatively lower than the WHO standard limit. Zinc recorded an average value ranging from 0.137 to 0.164(mg/kg) in cassava and 0.103 to 0.236(mg/kg) in cocoyam. This result is not surprising because the coal mining area is not an active mining site, but it could pose risk farming in the disused mining site due to variations in the bioaccumulation of some species of plants. The study further computed the daily intake of heavy metals to establish the associated health risk of consuming crops grown in the disused coal mining site.

Table 2. Heavy metal concentrations in crop samples in the experimental Control and WHO Standard

HEAVY METALS Unit - (mg/kg)	**FARM 1**		**FARM 2**		**FARM 3**		**CONTROL**		**WHO Standard -1996**
	Cassava	**Cocoyam**	**Cassava**	**Cocoyam**	**Cassava**	**Cocoyam**	**Cassava**	**Cocoyam**	
CADMIUM	0.103 0.023 0.076	0 0 0	0.028 0 0.07	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0.02
CHROMIUM	0.923 0.851 0.755	0 0 0	0.495 0.407 0.471	0 0 0	0 0.03 0	0 0 0	0 0.01 0.03	0 0 0	1.3
ZINC	0.16 0.125 0.125	0 0 0	0.187 0.172 0.132	0.257 0.197 0.254	0.11 0.166 0.137	0.142 0.092 0.074	0 0.01 0.04	0.02 0.02 0.02	0.6
NICKEL	0.367 0.367 0.367	0.64 0.64 0.64	0.58 0.58 0.58	0.483 0.483 0.483	0.468 0.468 0.468	0.202 0.202 0.202	0 0 0	0.03 0 0.01	10
LEAD	0 0.015 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	0 0 0	2

Table 2: Source; Authors' Field work and [6]

Daily Intake Rate for adults (g person-1 day-1) of heavy metals through consumption of root tubers grown around Ogbete disused coal mine in Enugu metropolis, Nigeria

The Daily Intake Rate (DIR) of heavy metals for the adult population via consumption of cassava and cocoyam tubers is shown in **Table 3**. This was calculated with the use of the mean concentration of heavy metals in the two food crops studied.

The formula for the Daily Intake Rate is stated as:

$$\text{Daily Intake Rate} = \frac{C\ \text{metal} \times D\ \text{food Intake}}{B\ \text{average weight}}$$

Where: C - metal is heavy metal concentration in crop (μg/g)

D - food intake is daily food crop intake (kg/person)

B - average weight is average body weight

The Adult and child average body weight were considered to be 55.9kg and 32.7kg respectively. Studies have shown that the average daily intake of vegetables is considered 0.345 and 0.232kg for adults and children respectively (10; 11).

Table 3. Daily Intake Rate for Adults (g person-1 day-1) of heavy metals

	FARM 1		FARM 2		FARM 3		CONTROL	
HEAVY METALS **Unit - (mg/kg)**	Cassava	Cocoyam	Cassava	Cocoyam	Cassava	Cocoyam	Cassava	Cocoyam
Cadmium	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Chromium	0.005	0.000	0.003	0.000	0.000	0.000	0.001	0.000
Zinc	0.001	0.001	0.001	0.002	0.001	0.001	0.001	0.001
Nickel	0.002	0.004	0.004	0.003	0.003	0.001	0.000	0.002
Lead	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3: Source; Authors' Field work, (2022) and [6]

The trends of the estimated DIR of Chromium, Cadmium, Lead, Nickel and Zinc for *Manihot esculenta* and *Colocasia esculenta* were in the following order; Pb<Cd<Zn<Cr=Ni; Pb=*Cd=Cr<Zn<Ni* respectively. The highest DIR for Chromium (0.005) and Cadmium (0.001) was seen in *Manihot esculenta* while the highest DIR for Nickel (0.004) was seen in both *Colocasia esculenta* (farm 1) and *Manihot esculenta* (farm). Lead recorded 0.00 for both *M. esculenta* and *C. esculenta*.

Health risk index of heavy metals in food crops around the disused coal mine in Ogbete, Enugu metropolis

Data in **Table 4** shows the health risk index of heavy metals in food crops in the study area. The Health Risk Index is the ratio of the daily intake rate to the oral reference dose USEPA. It is calculated thus:

$$\text{Health risk index} = \frac{\text{Daily intake rate}}{\text{Oral reference dose}}$$

HRI > 1 for any metal in food crops means that the consumer population faces a health risk.

Note that Oral Reference dose is defined by as an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. (U.S. EPA,1987) The U.S. EPA oral reference dose for chromium, Nickel, cadmium, lead and zinc is 0.003, 0.02, 0.001, 0.004 and 0.3 respectively [6].

Table 4. Health risk index of heavy metals in food crops around the disused coal mine in Ogbete, Enugu metropolis.

HEAVY METALS Unit(mg/kg)	FARM 1 (180m from coal pit)		FARM 2 (113m from pit)		FARM 3 (728m from coal pit)		CONTROL (1366m from pit)	
	Cassava	Cocoyam	Cassava	Cocoyam	Cassava	Cocoyam	Cassava	Cocoyam
	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chromium	1.73	0.00	1.00	0.00	0.00	0.00	0.30	0.00
Zinc	0.003	0.003	0.003	0.007	0.003	0.003	0.003	0.003
Nickel	0.10	0.02	0.02	0.15	0.15	0.05	0.00	0.1
Lead	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 4: Source; Authors' Field work, (2022) and [6]

Hence, the result in **Table 4** emphasized that selected cassava and cocoyam crops in the sampling areas, cassava in farms 1 and 2 (farms closest to the coal pit) were observed with the highest health risk index (HRI). Only Chromium in farm 1 selected cassava crop recorded 1.73 which exceeds the health risk index acceptance limit of 1. Also, cadmium in cassava farm 1 and chromium in cassava crop from farm 2 recorded 1.00 each; this is also on the high side. The trend of HRI in heavy metal ranges from Pb< Zn < Ni < Cd < Cr and Pb = Cd =Cr < Zn < Ni for cassava and cocoyam respectively. The health risk index of heavy metals in cocoyam is very low compared to cassava. The implication is that there is a need for serious regulation on farming within the disused mining site in the study area since the result indicates severe health risks.

Heavy metal uptake by food crops can be determined by factors such as soil physicochemical properties and plant species. In a work by zhuang et. al, (2009) [9], soils obtained around the Dabooshan mining site in Guangdong, China, the heavy metal concentration of 271mg/kg, 349mg/kg, 190mg/kg and 3.13mg/kg for Cr, Zn, Pb and Cd respectively were reported earlier. These concentrations recorded were higher than the heavy metal concentration seen in the present study where the mean concentration of the heavy metals in soil recorded was 0.48mg/kg, 0,067mg/kg, 0,662mg/kg, 0.399 mg/kg and 0.00mg/kg for Pb, Cr, Zn, Ni and Cd respectively. See Figure 2 for clarification of heavy metal concentration in different soil sample analyzed in the present study. However, the increased heavy metal concentration in Guangdong soil could be because it is an active mining site compared to Enugu which is a disused mining site.

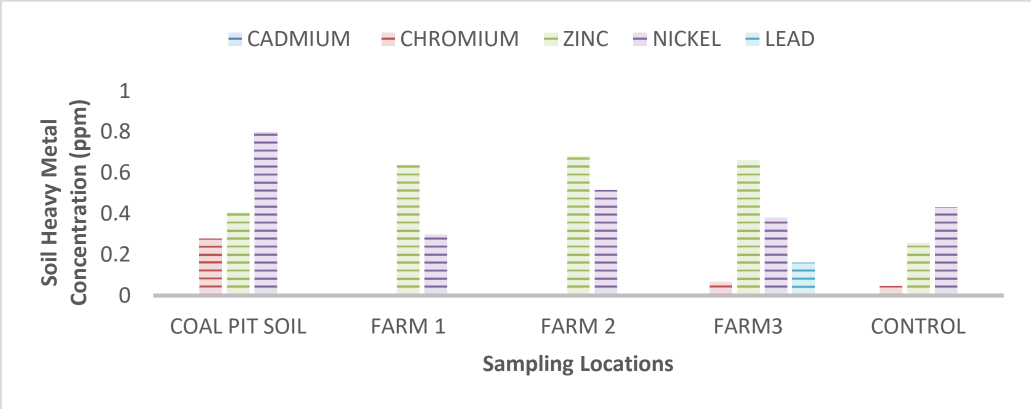

Figure 2. Bar graph of heavy metal concentrations in the soil samples in Ogbete disused Coal Mine (Data sourced from **Table 1**)

Hence, it is evident in **Figure 2** that the soil is not safe for farming activity even though the site is not active mining site which call for continuous monitoring and increase awareness on health implication of farming within and around the disused mining site.

Similar studies also emphasized that bioaccumulation of plants varies from different plants and plants specie, especially in active and non-active mining sites. Comparatively, as recorded by [10], heavy metals are higher in the soil samples of the experimental sites in Pb-Zn in Yelu in Bauchi State except for Cd and Fe which recorded low concentrations. Other contrasting results were recorded by [11] and [12]. In this present study, all the plant samples collected and analyzed from the study sites contained detectable levels of some of the heavy metals (Pb, Cr, Zn, Ni and Cd) at varying proportions. Cassava (Manihot esculenta) from farm 1 recorded the highest concentration of Cadmium and chromium with a concentration of 0.103 and 0.923 respectively. These two heavy metals were classified as chemical hazards; the permissible limits prescribed by WHO are 0.02 and 1.30 for cadmium and chromium respectively. As the highest concentration recorded, this shows that the concentration of cadmium and chromium is relatively below the WHO permissible limit.

High oxidative properties have been associated with chromium toxicity, while cadmium, epigenetic changes in DNA expression and other disorders [21].

Some heavy metals like nickel and zinc recorded their highest concentration in cocoyam

(*Colocasia esculenta*) with a mean concentration of 0.640 and 0.241 for nickel and chromium respectively. Both are also below the WHO permissible limit. In this study, all the heavy metals were relatively below the WHO standard. This conforms to the study by [13]. Their work emphasized that the concentration of heavy metals in the soil and crop samples is 1.0mg/kg in the soil and crop samples of sites A and B and they are all below the values reported in farmlands around refuse dump sites in Obafemi Awolowo University Ile-Ife (the control site).

Interestingly, only Zinc and nickel were absorbed by cocoyam while cadmium, chromium and lead were absent in cocoyam in all sampling sites. Cassava stands out as a better biomarker; this is because of its ability to absorb all the heavy metals around it. A similar result was recorded in the work of [14] on tuber crops cassava, cocoyam, yam and potatoes. The range of heavy metal concentration recorded shows a higher mean concentration of all the heavy metals in cassava while a lower mean concentration was recorded for cocoyam

Lead only appeared in the cassava crop in farm 1 with a mean concentration of 0.005 in farm 1 while there is absent in every other crop sample in the experimental and control sites. This concentration recorded is below WHO Standard. Several grievous health disorders associated with chronic lead occurrence in food crops have raised global concern. These include damage to the central nervous system in children, sperm abnormalities and sterility in men then spontaneous abortion in women [6].

Heavy metal concentration present in the control area may be considered as a result of the farmland being along the roadside as shown in the map. The soil along the roadsides is regarded as the recipient of large amounts of heavy metals varieties of sources including vehicular emissions, Car brakes and tires contribute to the copper and zinc dust along roads. Some works reported a decrease in high concentrations of heavy metals with increasing distance from roadsides [15]. Also, the application of chemicals or sewage sludge and fertilizer can affect the level of heavy metal in soil and crops grown in a given area.

To determine the risk that could be induced by the presence of heavy metals in food crops, the estimated dietary intake of heavy metals is an important tool to utilize. It is observed from Table 3 that the estimated dietary intake in adults ranges from 0.001 to 0.005, which are lower compared to some works such as [16], [17] and [18]. The DIR in these works were higher than that of the present study. Adult's provisional tolerable daily intake of 150.00 and 3.60 mg/kg body weight for Cr, Pb, Ni, Cd, and Cu is 8.38, 0.20,0.28, 0.10, 27.90 mg/person/day respectively (23). The highest daily consumed heavy metal recorded is chromium (0.0052) from cassava crop in farm 1, the sampling site closest to the coal pit. Thus, perennial intake of these contaminated food crops is likely to induce adverse health effects arising largely from chromium exposure. The result revealed the DIR of lead and cadmium to be generally low in all food crops. The low values recorded could be attributed to the fact that the study area is non active mining site.

The health risk index of nickel, lead and zinc were below 1 (HRI < 1) as shown in **Table 4**. Therefore, the health risks of heavy metals exposure through the food chain were of no consequence and generally assumed to be safe. However, Cassava (*M. esculenta*) collected from farm 1 had the highest HRI for Chromium (1.73), followed by chromium (1.00) in the cassava sample collected from farm 2 and cadmium (1.00) in the cassava sample from farm 1. The present results thus indicate that the heavy metals, chromium and Cadmium are the major contributors to potential health risks for the population at Ogbete disused coal mine, Enugu. A study by Agency for toxic substances and disease registry disclosed that oral exposure of chromium could lead to acute tubular necrosis and acute renal failure; people exposed to Cr (VI) were also discovered to suffer from cardiopulmonary arrest and hepatomegaly. Carcinogenic effects such as cancer of the lungs are associated with contact with chromium [25].

Cadmium according to [20] has an extremely long biological half-life in humans, kidney is said to be the main organ targeted by cadmium and chronic exposure leads to renal tubular dysfunction and Kidney stone. Excess cadmium accumulated in the bone can cause some bone lesions and other effects such as osteomalacia and osteoporosis. It has been reported that Post-menopausal Japanese Women residing in regions contaminated with cadmium and exposed through diet suffer from itai- itai, a disease characterized by norm chronic anemia, severe osteoporosis and an average urinary cadmium level of 20-30Ìg/g-creatinine of cadmium in urine [19; 27].

A health risk index of 1 was recorded for cadmium in the control cassava crop. This could be consequential to some anthropogenic activities such as vehicular emission: wears of tires and clutch discs, Car brakes and tires, and slipperiness control as the control farm is positioned along the roadside. Some works reported a decrease in high concentrations of heavy metals with increasing distance from roadsides [15]. Also, the application of chemicals or sewage sludge and fertilizer can affect the level of heavy metal in soil and crops grown in a given area [28].

The maximum HRI for nickel (0.15), zinc (0.007) and Lead (0.00) were recorded for Manihot esculenta. While in colocasia esculenta, 0.15, 0.007, 0.00, 0.00, 0.00 was the highest HIR recorded for nickel, zinc, lead, chromium and cadmium respectively. Since they are all below 1, cocoyam in both experimental and control sites could be said to be safe for consumption. This indicates that cocoyam could be used in bioremediation plants.

Conclusions

From the study, the occurrence of heavy metals (Pb, Cd, Cr, Ni, and Zn) has been confirmed in the soil and crops in farmlands around the Enugu Ogbete coal mine at varying concentrations. The concentration of heavy metals in food crops ranges from Cadmium (0.00 – 0.103 ppm), chromium (0.00- 0.851 ppm), zinc (0.00- 0.187 ppm), Nickel (0.00- 0.851 ppm), and lead (0.00 – 0.015 ppm). Some heavy metals' concentration recorded was below the WHO limits.

However, although the concentration of heavy metals in these food crops obtained was below WHO recommended permissible limit, the leaves of Cassava (M *esculenta) in* Farm 1 and Farm 2 show a high Health Risk index above 1 in chromium and cadmium. This simply implies the consumption of cassava from farms 1 and 2 poses a significant health risk to the populace in Ogbete disused coal area.

The general HRI values of less than one as seen in all heavy metals in cocoyam are lead, zinc and Nickel in cassava will not pose a significant health risk to the children and adults in the area. Cassava in the control farm also recorded a Health risk index of 1, this could be as a result of pollution associated with roadsides accumulated in the soil or leaves of plants [29]. This study, however, determined that there was a potential health risk for the local inhabitants of the Ogbete disused coal mine through the consumption of Chromium and Cadmium contaminated Cassava *(M. esculenta).*

The study therefore recommends the need for continuous monitoring of heavy metal concentration in the Ogbete disused coal mine in Enugu, Nigeria. Hence, the need for restriction and regulation of farming activities in the disused mining area as well as continuous awareness of the health implications of consuming food products contaminated with heavy metals in the local dialect. From the result, cassava could be said to be a better absorber of heavy metals as a higher concentration was recorded in some heavy metals like cadmium, chromium and zinc. A much lesser concentration was recorded in cocoyam. Hence, the study also suggests that cocoyam could be recommended for phytoremediation of soil polluted by cadmium, chromium and zinc.

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