• **Original Article**

Bioaccumulation and health risk assessment of heavy metals in *Musa paradisiaca, Zea mays, Cucumeropsis manii* and *Manihot esculenta* cultivated in Onne, Rivers State, Nigeria

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This study was carried out to investigate heavy metals concentrations: lead (Pb), cobalt (Co), cadmium (Cd), zinc (Zn), nickel (Ni), copper (Cu) and manganese (Mn) in *Musa paradisiaca* (plantain), *Zea mays* (maize), *Cucumeropsis manii* (melon), *Manihot esculenta* (cassava) and soil samples from dumpsites in Onne, Eleme Local Government Area, Rivers State, Nigeria. The plant leaf and soil samples were measured for heavy metals concentrations using atomic absorption spectrophotometer. The health risk index (HRI) of the heavy metals following the consumption of these plant materials by the populace was estimated using standard protocols. The heavy metals concentrations in the leaf samples ranged from 0.012–14.712 mg/kg, whereas those of the soil samples were within the range of 2.543–16.459 mg/kg. Cd concentrations in the soil and leaf samples were above the maximum permissible level according to the World Health Organization (WHO). The bioaccumulation of the heavy metals followed the trend: (*M. paradisiaca*) Zn > Pb > Co > Mn > Cu > Cd > Ni; (*Z. mays*) Mn > Pb > Co > Zn > Cu > Cd > Ni; (*C. mannii*) Mn > Co > Pb > Cu > Zn > Cd > Ni; (*M. esculenta*) Zn > Pb > Mn > Cu > Co > Ni > Cd. The highest bioaccumulation of the heavy metals occurred in *M. esculenta*. The estimated HRI of Pb in *M. esculenta* was greater than 1. HRI > 1 was indicative that the consumer population is not safe. Cassava-based meals from the dumpsites contained Pb at toxic level, whereas Co, Cd, Zn, Ni, Cu, and Mn concentrations in plantain-, maize- and melon-based meals were relatively within safe limits.

Keywords: bioaccumulation, *Cucumeropsis manii*, heavy metals, *Manihot esculenta*, *Musa paradisiaca*, *Zea mays*

Introduction

Musa paradisiaca L. (plantain), which belongs to the Musaceae family, is a perennial herbaceous plant that is widely distributed in the tropical and subtropical regions of the world. *M. paradisiaca* grows up to a height of 9 m above the ground. The pseudostem is characterized by concentrically formed leaves and roughly ellipsoidal fleshy fruits [1,2]. *Zea mays* L. (maize) is a well-known cereal that originated from Mexico, Central America and belongs to the Poaceae family. *Z. mays* is an annual tall herb that possesses widespread fibrous roots [3]. *Cucumeropsis mannii* N. (melon), a member of the Cucurbitaceae family, is an indigenous crop of West Africa and is popularly called "egusi" in this region. *C. mannii* is a tendril creeping an-

nual crop characterized by a shallow fibrous root system. The seeds of *C. mannii* are rich sources of lipids [4]. *Manihot esculenta* C. (cassava) is an annual woody shrub with tuberous roots. The plant is a native of South America and belongs to the Euphorbiaceae family. *M. esculenta* is widely cultivated both as a food crop and cash crop in Africa, Asia and the Caribbean [5,6]. The vast nutraceutical potentials of *M. paradisiaca, Z. mays, C. manii* and *M. esculenta* have been reviewed elsewhere [1-3,5,7].

Heavy metals remain one of the major contaminants of food crops. At trace levels, certain heavy metals contribute to body development, but intake of higher than daily dietary requirement could be detrimental to human health [8]. Heavy metals are non-biodegradable and can accumulate in the soil at toxic levels [9]. These metals are introduced into the environment via different anthropogenic activities such as mining, diffuse sources such as piping, combustion of byproducts and other human activities [10].

Onne, Eleme Local Government Area (L.G.A.), Rivers State,

Nigeria is one of the prominent Nigerian seaports used for oil and gas explorations. Environmental pollution in Onne community has been a problem of great concern over the years. Large amount of black dust, soot, powder, ash or carbon particles settle on just anything including the inhabitants. The sustained black soot deposit in the atmosphere is due to the uncontrolled incineration of crude oil [11]. Oil mining, refining and processing have been the major source of energy globally. These activities are accompanied with the release of large quantities of heavy metals such as lead (Pb), cobalt (Co), cadmium (Cd), zinc (Zn), nickel (Ni), copper (Cu), manganese (Mn), etc. [12]. According to the study carried out by Asia *et al.*, [13] in the Niger Delta, petroleum exploration and production operations caused the release of certain heavy metals such as Pb, Cu, Ni, and Co into the soil and groundwater. Oil spillages, leaking underground storage tanks and pipes have been identified as the major sources of contamination [10] in oil producing areas such as Onne. As a result, higher levels of certain heavy metals was reported in cassava flakes (*garri*) from Onne [14] compared with those produced in non-oil mining area of Yenagoa metropolis [15].

Petroleum exploration and production operations involve the use of various chemicals to ensure the protection of oil wells and the separation of oil from water. Such chemicals can pollute the soil in areas where such operations are not properly regulated in accordance with the guidelines stated by regulatory agencies such as the Department of Petroleum Resources (DPR) and Federal Ministry of Environment of Nigeria [13]. Heavy metals pollute the soil by altering the soil pH, thus making the soil unsafe for agricultural activities [12]. Plants cultivated on such contaminated soils absorb these heavy metals and when consumed, predisposes the consumer to various health hazards.

This study was carried out to investigate heavy metals concentrations: Pb, Co, Cd, Zn, Ni, Cu, and Mn in *M. paradisiaca*, *Z. mays*, *C. manii*, *M. esculenta* and soil samples from dumpsites in Onne. Furthermore, the present study ascertained the bioconcentration factor (BF) and related toxicological indices in order to establish the levels of human exposure to heavy metals within the locations of the dumpsites in relation to health risk indicators associated with the consumption of these food crops.

Materials and Methods

Description of the study area

The study was carried out in Onne Nigeria. (4˚43´0´´N 7˚9´0´´E). The major plants cultivated in the dumpsite areas include cassava, maize, oil palm fruit, yam, fluted pumpkin, melon, and bitter leaf. These dumpsites were chosen for this study because of the oil mining activities in the areas, which are associated with the release of large amount of pollutants into the environment.

Collection and preparation of samples

Fifteen fresh leaf samples of *M. paradisiaca*, *Z. mays*, *C. manii*, and *M. esculenta* were harvested using a knife from sub-areas of the four dumpsites. The coordinates (latitude and longitude) of the collection points of the leaf samples were referenced using GPS map® 76 (Garmin Ltd.): (*M. paradisiaca*) 4˚44´44.876´´N 7˚9´15.672´´E; (*Z. mays*) 4˚44´43.453´´N 7˚9´14.392´´E; (*C. manii*) 4˚44´42.211´´N 7˚9´13.455´´E; (*M. esculenta*) 4˚44´44.997´´N 7˚9´14.653´´E (Figure 1). The leaf samples were washed under flowing current of deionized water to remove soil and dust particles and dried in an oven at 50˚C until they became crispy. The separate dried leaf samples were crushed into fine powder using ceramic mortar and pestle, and stored in well labeled air tight containers pending analysis [16].

Soil samples were collected from sub-areas of the four dumpsites using a soil auger at 10 cm depth (top soil) [17]. Eighteen soil samples from each sub-area were pooled and sieved to remove unwanted soil particles and debris. The prepared soil samples were dried in an oven at 50˚C to constant weight and represented the composite soil samples from the designated dumpsites. The separate composite dried soil samples were stored in corresponding air tight containers.

Digestion and analyses of leaf and soil samples

One gram (1.0 g) of the powdered leaf and soil samples were weighed into separate corresponding test tubes and digested in 24 mL of aqua regia (HCl:HNO$_3$ = 3:1 v/v) for three days as previously described [16, 18]. The concentrations of Pb, Co, Cd, Zn, Ni, Cu, and Mn in the leaf and soil samples were measured triplicate using atomic absorption spectrophotometer (Buck Model 210) according to the methods previously reported [19].

Ratio of plant leaf to soil bioaccumulation of heavy metals

From the results of Pb, Co, Cd, Zn, Ni, Cu and Mn concentrations in *M. paradisiaca*, *Z. mays*, *C. manii*, and *M. esculenta* leaf and soil samples, the ratio of plant leaf to soil bioaccumulation of heavy metal (RBHM) or BF was calculated [20].

$$RBHM = \frac{HMCPS}{HMCSS} \qquad (1)$$

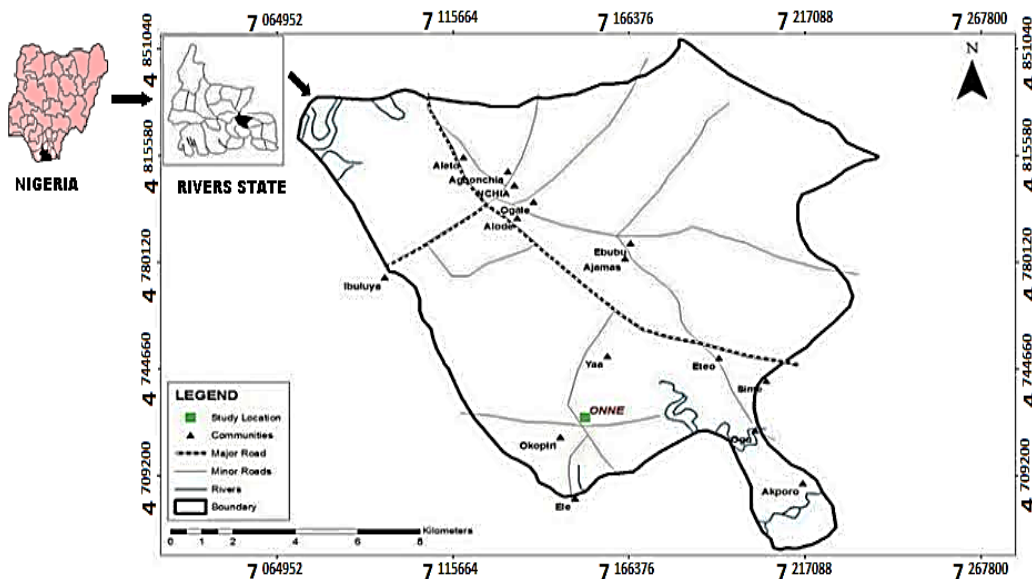where HMCPS is heavy metal concentration of a leaf sample

Figure 1. Map of Eleme L.G.A. showing the study location.

and HMCSS is heavy metal concentration of soil sample.

Daily intake of heavy metals

The daily intake of heavy metals (DIHM, mg/kg person/day) was estimated in relation to the body weights of consumers of *M. paradisiaca, Z. mays, C. manii,* and *M. esculenta*. Because DIHM by individuals is directly proportional to average daily consumption of the plant leaf, DIHM was calculated [21]. Thus:

$$DIHM = \frac{C_{HM} \times D_{FI}}{B_{AW}} \qquad (2)$$

where C_{HM} is heavy metal concentration in plant leaf (mg/kg), D_{FI} is daily consumption of *M. paradisiaca, Z. mays, C. manii,* and *M. esculenta* by adults and children based on related studies [19,21], which was put at estimated averages of 0.345 and 0.232 kg-person/day, respectively, and BAW is average body weights of the consumers based on field estimations using a mobile weighing scale (Hana instrument; China), which was put at 55.9 kg and 32.7 kg for adults and children, respectively [21].

Health risk index

The health risk index (HRI) was estimated as described in previous literature [22].

$$HRI = \frac{DIHM}{ORD} \qquad (3)$$

where ORD: Oral reference dose (mg/kg person/day). The ORD is an estimated exposure of metal to the human body per day associated with no potential hazardous effect during lifetime. The ORD (mg/kg person/day) for Pb, Co, Cd, Zn, Cu,

and Mn used were 0.004, 0.02, 0.001, 0.3, 0.02, 0.04, and 0.033 mg/kg person/day, respectively [22,23]. The consumer population is considered safe when HRI is less than 1 [21].

Data analyses

The data were expressed in terms of range of values in comparison with standard reference quantity according to the World Health Organization (WHO) and Food and Agricultural Organization (FAO). The heavy metal concentrations were expressed as mean ± standard deviation.

Results and discussion

Heavy metal concentrations in the leaf samples

The heavy metals concentrations in *M. paradisiaca, Z. mays, C. manii,* and *M. esculenta* leaf samples from the dumpsites in Onne are presented in Table 1. The heavy metal concentrations in the leaf samples were in the following order: Zn > Co > Mn > Pb > Cu > Cd > Ni for *M. paradisiaca*; Mn > Zn > Co > Pb > Cu > Cd > Ni for *Z. mays*; Mn > Co > Cu > Zn > Pb > Cd > Ni for *C. mannii*; Zn > Mn > Cu > Pb > Co > Ni > Cd for *M. esculenta*. The ranges of the heavy metals concentrations in the leaf samples were: Pb: 0.188±0.05 – 0.608±0.01 mg/kg; Co: 0.426±0.02 – 1.521±0.02 mg/kg; Cd: 0.082±0.02 – 0.101±0.00 mg/kg; Zn: 0.274±0.04 – 14.712±0.20 mg/kg; Ni: 0.012±0.05 – 0.504±0.11 mg/kg; Cu: 0.235±0.11 – 1.967±0.04 mg/kg; Mn: 0.560±0.10 – 3.056±0.06 mg/kg.

All the heavy metal concentrations in the leaf samples were below the maximum permissible level of the WHO, whereas the concentrations of Co (*C. mannii*), Zn (*M. paradisiaca, Z.*

Table 1. Maximum permissible limits (MPL) of heavy metals in soils and plants according to food and agriculture organization and world health organization (WHO/FAO) [24–26] and heavy metal concentrations (HMC) in leaf and soil samples from dumpsites in Onne

Heavy metals	MPL (mg/kg)		Leaf Samples HMC (mg/kg)				Soil Samples HMC (mg/kg)
	Soil	Plant	*M. paradisiaca*	*Z. mays*	*C. mannii*	*M. esculenta*	
Lead (Pb)	85	2	0.447 ± 0.03	0.267 ± 0.00	0.188 ± 0.05	0.608 ± 0.01	2.543 ± 0.99
Cobalt (Co)	ND[b]	1.5	0.875 ± 0.00	0.426 ± 0.02	1.521 ± 0.02	0.515 ± 0.03	8.173 ± 1.96
Cadmium (Cd)	0.8	0.02	0.082 ± 0.02	0.093 ± 0.06	0.097 ± 0.01	0.101 ± 0.00	7.540 ± 4.40
Zinc (Zn)	50	0.6	6.657 ± 0.05	0.787 ± 0.03	0.274 ± 0.04	14.712 ± 0.20	16.459 ± 2.82
Nickel (Ni)	35	10	0.026 ± 0.05	ND	0.012 ± 0.05	0.504 ± 0.11	12.004 ± 1.35
Copper (Cu)	36	10	0.439 ± 0.04	0.235 ± 0.11	0.375 ± 0.01	1.967 ± 0.04	14.791 ± 1.19
Manganese (Mn)	ND[b]	200	0.560 ± 0.10	1.641 ± 0.05	2.847 ± 0.04	3.056 ± 0.06	13.949 ± 3.57

ND: not detected.

mays, M. esculenta), and Cd (*M. paradisiaca, Z. mays, C. mannii, M. esculenta*) were higher than the WHO permissible limits (Table 1). The Mn concentrations in the leaf samples were very low when compared with the WHO permissible level for Mn (200 mg/kg). The low Mn concentration was probably due to leaching of the metal to deeper strata of the soil.

Co at high doses is cytotoxic causing apoptosis, necrosis and genotoxicity [27]. Cd is a highly toxic heavy metal that even at low concentration does not have any useful biological role in living organisms [18,28]. Cd poisoning causes lung cancer, anaemia, kidney failure and bone disorder [29]. Zn is known to play a major role in body development and function, but excessive exposure to Zn can provoke respiratory disorder, epigastric pain, diarrhea, elevated risk to prostate cancer, focal neuronal deficits and nausea [30].

The concentrations of Cd, Zn, Ni, Cu, and Mn in leaf samples of *M. esculenta* from the study area were lower than that reported in leaf and tuber samples from Galena Mining Area in Ishiagu, Ebonyi State, Nigeria [31]. The concentrations of Ni, Zn, Cu and Pb in leaf samples of *M. paradisiaca* from farmlands in Kaani and Kpean in Khana L.G.A. of Rivers State, Nigeria, [32] were higher than those reported in the present study. Additionally, reports by Ajayi and Salami [33] showed relatively higher concentrations of Cu and Zn but lower concentration of Mn in *C. mannii* from a farm at Bode-Saadu in Ilorin, Kwara State, Nigeria, than those reported in the present study. Conversely, the present study reported higher concentrations of Co, Cd, Zn, and Cu in *Z. mays* than those reported by Akenga et al. [34]

Heavy metal concentrations in the soil samples

Table 1 showed the concentrations of Pb, Co, Cd, Zn, Ni, Cu, and Mn in the soil samples collected from four designated points of the dumpsites in Onne. The mean concentrations of the heavy metals followed the order: Zn > Cu > Mn > Ni > Co > Cd > Pb.

All heavy metals concentrations in the soil samples were within the permissible level of WHO [26], with the exception to Cd, which gave a concentration of 7.540 mg/kg as against the WHO maximum permissible level of 0.8 mg/kg. The concentration of Cd in the soil samples from this area was higher than that reported for Shao North Central Nigeria, Nigeria by Ogundele et al.[24] which was 0.033 mg/kg. Also, Opaluwa et al. [35] noted that Cd concentration in soil samples from dumpsites in Lafia Metropolis, Nasarawa State, Nigeria was 0.48 mg/kg, which was lower than that reported in the present study area. These are indications that the soil samples from Onne were highly polluted with Cd. The high concentration of Cd in the soil samples from the area of study is due to the oil mining activities, industrial processing activities, use of fertilizers and pesticides in agricultural activities, sewage sludge and uncontrolled waste disposal in Onne.

The concentration of Zn from soil samples from the present area of study was higher than the Zn concentration reported by Ibe et al. [16] in abandoned municipal waste dumpsites in Owerri, Imo State, Nigeria, which gave a concentration of 1.07 mg/kg. Fosu-Mensah et al. [36] also reported a lower Zn concentration (2.05 mg/kg) from reclaimed waste dumpsites at Korle Lagoon area in Accra, Ghana. The mean Ni concentration (34.78 mg/kg) from a waste disposal site in Ibadan, Nigeria as described by Auta and Morenikeji [37] and that reported by Ofudje et al. [38] from Lagos, Nigeria gave Ni concentration of 64.17 mg/kg. The concentration of Ni in soil samples from the present study area was lower than those described elsewhere [37,38]. A lower concentration of Cu was noted in soil samples from the present study sites compared with the concentration of Cu (18.00 mg/kg) in Corlu-Cerkezkoy highway, Thrace region, Turkey [39]. Additionally, Ibe et al. [16] reported higher concentration of Cu (15.7 mg/kg) in soil samples from Owerri, Imo State, Nigeria. Soil samples from Suburban roadside farmland in Nepal gave Pb concentration of 31.81 mg/kg [40], which was higher than that of the present study. Accord-

ing to Lago-Vila et al., [20] relatively high concentration of Co (110 mg/kg) was reported in soil samples from Moeche, Coruna, Spain.

Ratio of plant leaf to soil bioaccumulation of heavy metals

Among the analyzed four leaf samples, the *M. esculenta* exhibited highest bioaccumulation of Pb, Cd, Zn, Ni, Cu, and Mn, whereas *C. mannii* gave the highest concentration of Co. The ratio of plant leaf to soil bioaccumulation of Cd and Mn was lowest in *M. paradisiaca*. Likewise, the ratio of plant leaf to soil bioaccumulation of Co and Cu were lowest in *Z. mays*, whereas Pb, Zn, and Ni were lowest in *C. mannii*. The pattern of increase in bioaccumulation of heavy metals in the leaf samples were as follows: Zn > Pb > Co > Mn > Cu > Cd > Ni (*M. paradisiaca*); Mn > Pb > Co > Zn > Cu > Cd > Ni (*Z. mays*); Mn > Co > Pb > Cu > Zn > Cd > Ni (*C. mannii*); Zn > Pb > Mn > Cu > Co > Ni > Cd (*M. esculenta*) (Table 2).

The transfer factor of heavy metals from soil to plants is the ratio of the concentration of heavy metals in a plant to the concentration of heavy metal in the soil-RBHM [20]. The transfer factor signifies the extent at which heavy metals in the

soil accumulated in the plants. The RBHM was calculated in order to have a good knowledge of the extent of risk and hazard associated with the ingestion of plants from the study area. The soil-to-plant transfer factor is one of the key components of the measure of level of human exposure to metals in the food chain [16,41,42].

According to Okereke et al., [21] the physicochemical properties of soil and plants could influence the transfer or mobility of metals from soil to plant. These physicochemical properties are on the other hand influenced by industrial activities such as oil mining. Thus, the RBHM of the various heavy metals in this study area might have been influenced by oil mining activities and other industrial processes going on in the area. The RBHM of the heavy metals were noted to vary directly with the heavy metal concentration in the leaf samples. Therefore, it implies that the transfer factor of heavy metals from soil to plants was a determinant of the level of heavy metal pollution of the plants cultivated in the area.

The high RBHM of most of the heavy metals for *M. esculenta* was an indication that the cassava cultivated in Onne were highly polluted by these contaminants and thus can be trans-

Table 2. Ratio of plant leaf to soil bioaccumulation of heavy metals from dumpsites in Onne

Plant samples	Ratio						
	Lead (Pb)	Cobalt (Co)	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Manganese (Mn)
Musa paradisiaca	0.176	0.107	0.011	0.404	2.17×10^{-3}	0.030	0.040
Zea mays	0.105	0.052	0.012	0.048	ND	0.016	0.118
Cucumeropsis mannii	0.074	0.186	0.013	0.017	9.997×10^{-4}	0.025	0.204
Manihot esculenta	0.239	0.063	0.013	0.894	0.042	0.133	0.219

ND: not detected.

Table 3. Daily intake of heavy metals of adults (mg/kg person/day) in Onne

Leaf samples	Daily intake (mg/kg person/day)						
	Lead (Pb)	Cobalt (Co)	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Manganese (Mn)
Musa paradisiaca	0.0028	0.0054	0.0005	0.0411	0.0002	0.0027	0.0035
Zea mays	0.0016	0.0026	0.0006	0.0049	ND	0.0015	0.0101
Cucumeropsis mannii	0.0012	0.0094	0.0006	0.0017	0.0001	0.0023	0.0176
Manihot esculenta	0.0038	0.0032	0.0006	0.0908	0.0031	0.0121	0.0189
Tolerable daily intake [24–26]	0.0036	0.0230	0.0010	0.4300	0.0050	0.5000	0.0110

ND: not detected.

Table 4. Daily intake of heavy metals of children (mg/kg person/day) in Onne

Leaf samples	Daily intake (mg/kg person/day)						
	Lead (Pb)	Cobalt (Co)	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Manganese (Mn)
Musa paradisiaca	0.0032	0.0062	0.0006	0.0472	0.0002	0.0031	0.0040
Zea mays	0.0019	0.0030	0.0007	0.0056	ND	0.0017	0.0116
Cucumeropsis mannii	0.0013	0.0108	0.0007	0.0019	0.0001	0.0027	0.0202
Manihot esculenta	0.0043	0.0037	0.0007	0.1044	0.0036	0.0140	0.0217
Tolerable daily intake [24–26]	0.0036	0.0230	0.0010	0.4300	0.0050	0.5000	0.0110

ND: not detected.

ferred into the human system with the consumption of cassava food products, such as garri, tapioca, fufu, etc. Accordingly, RBHM is very essential in the investigation of human HRI [42, 43].

Daily intake of heavy metals

The DIHM for adults and children population in the study area are shown in Tables 3 and 4, respectively. The estimated DIHM for both adults and children followed the same trend. The DIHM was in the order: Zn > Co > Mn > Pb > Cu > Cd > Ni (*M. paradisiaca*); Mn > Zn > Co > Pb > Cu > Cd > Ni (*Z. mays*); Mn > Co > Cu > Zn > Pb > Cd > Ni (*C. mannii*); Zn > Mn > Cu > Pb > Co > Ni > Cd (*M. esculenta*). Tables 3 and 4 showed that Zn represented the highest DIHM in *M. paradisiaca* for adults and children (0.0411 and 0.0472 mg/kg person/day, respectively) and *M. esculenta* (0.0908 and 0.1044 mg/kg person/day, respectively). Mn intake for adults and children was the highest in *Z. mays* (0.0101 and 0.0116 mg/kg person/day, respectively) and *C. mannii* (0.0176 and 0.0202 mg/kg person/day, respectively). Additionally, Ni intake gave the lowest DIHM (0.0002 mg/kg person/day) following the consumption of *M. paradisiaca* and *C. mannii* (DIHM = 0.0001 mg/kg person/day) for adults and children. Cd gave the lowest DIHM following the consumption of *M. esculenta* and *Z. mays*.

According to the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the tolerable daily intake of Pb, Co, Cd, Zn, Ni, Cu and Mn was set at 0.0036, 0.0230, 0.0010, 0.4300, 0.0050, 0.5000, and 0.0110 mg/kg person/day, respectively [44]. The estimated DIHM was all below the provisional tolerable daily intake level specified by JECFA [44], apart from Pb and Mn. Pb was high in *M. esculenta* for both adults and chil-

dren; Mn was high in *Z. mays* for children only and in *C. mannii* and *M. esculenta* for both adults and children.

The DIHM of Pb, Cd, Ni, and Cu by the consumption of cassava in the present study were noted to be higher than that reported in Alakahia, Obi-Akpor L.G.A., Rivers State, Nigeria [21]. Osu et al., [22] reported higher DIHM for Pb and Mn following the consumption of cassava from crude oil impacted soil in Ikot Abasi L.G.A., Akwa Ibom State, Nigeria. The estimated DIHM of Cd, Zn, and Ni via *Z. mays* consumption from District Bannu, Khyber Pakhtunkhwa, Pakistan [45], were higher than that observed in the present study.

Health risk assessment

Health risk assessment (HRA) defines the basis for establishing health risk posed by the heavy metals by the consumption of *M. paradisiaca*, *Z. mays*, *C. mannii*, and *M. esculenta*. Accordingly, HRA encapsulates the DIHM and HRI. The calculated DIHM and HRI for both adults and children are presented in Tables 3–6.

Tables 5 and 6 represent the HRI of the heavy metals by the consumption of food crops under study for both adults and children in Onne. The HRI of the heavy metals for adults and children was in the order: Pb > Cd > Co > Zn > Mn > Cu > Ni (*M. paradisiaca*); Cd > Pb > Mn > Co > Cu > Zn > Ni (*Z. mays*); Cd > Mn > Co > Pb > Cu > Zn > Ni (*C. mannii*); Pb > Cd > Mn > Zn > Cu > Co > Ni (*M. esculenta*). The range of values of HRI of the heavy metals for adults and children were as follows: 0.7– 0.01 and 0.8–0.01 (*M. paradisiaca*); 0.6–0.016 and 0.7–0.019 (*Z. mays*); 0.6–0.005 and 0.7–0.005 (*C. mannii*); 0.95–0.015 and 1.075–0.18 (*M. esculenta*).

The estimated HRI of the heavy metals were all below one

Table 5. Health risk index of heavy metals for adults in Onne

Leaf samples	Health risk index						
	Lead (Pb)	Cobalt (Co)	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Manganese (Mn)
Musa paradisiaca	0.7	0.27	0.5	0.137	0.01	0.068	0.106
Zea mays	0.4	0.13	0.6	0.016	ND	0.038	0.306
Cucumeropsis mannii	0.3	0.47	0.6	0.006	0.005	0.058	0.533
Manihot esculenta	0.95	0.16	0.6	0.303	0.015	0.303	0.573

ND: not detected.

Table 6. Health risk index of heavy metals for children in Onne

Leaf samples	Health risk index						
	Lead (Pb)	Cobalt (Co)	Cadmium (Cd)	Zinc (Zn)	Nickel (Ni)	Copper (Cu)	Manganese (Mn)
Musa paradisiaca	0.8	0.31	0.6	0.157	0.01	0.078	0.121
Zea mays	0.475	0.15	0.7	0.019	ND	0.043	0.352
Cucumeropsis mannii	0.325	0.54	0.7	0.006	0.005	0.068	0.612
Manihot esculenta	1.075	0.185	0.7	0.350	0.18	0.350	0.658

ND: not detected.

except Pb in *M. esculenta*, which had a HRI of 1.075 in children. HRI <1 indicates that the consumer population is safe from any potential health posed by the heavy metals, whereas HRI >1 implies that the consumer population is not safe [21, 22]. Since it was observed that HRI of Pb following the consumption of cassava by children was 1.075, it implies that Pb could cause severe health risk to children consuming cassava products in Onne. Pb is particularly dangerous to children because their brain tissues and nervous systems are more sensitive to the damaging effects of Pb. Low levels of Pb in the blood of children results in behavioral and learning problems, lower intelligence quotient (IQ) and hyperactivity, slowed growth, hearing problems and anemia [46].

It has been reported that the food chain (soil-plant-man) is the most common and important exposure pathway of heavy metals such as Pb, Cd, and Ni, to human [47]. Thus, reduction in the concentration of pollutants such as Pb in the soil would reduce its health risks to humans. Possible remediation techniques for Pb in soil include chemical immobilization/stabilization methods by adding some non-toxic materials into the soil to reduce the solubility of the heavy metal, mixing the polluted soils with clean unpolluted soils in order to reduce the heavy metal concentration in the soil. Other contemporary remediation methods are electromigration process, washing/leaching/flushing the soil with chemical agents such as cyclodextrins, surfactants, chelating agents and organic acids either *ex situ* or *in situ* [8, 48-50].

Conclusion

The health risk posed by heavy metals to humans and animals can be circumvented by analyzing the level of metal contamination in farmlands. The present study noted a high bioaccumulation of toxic heavy metals from soil sample in *M. esculenta* cultivated in Onne. The HRI of Pb in cassava was reported to be greater than 1, indicating that the consumption of such food will pose a significant health risk to the populace, especially children. It is therefore recommended that the local populace, especially children, of Onne should abstain from cassava-based meals in order to reduce Pb bioaccumulation and concomitant health risks. However, the concentrations of Co, Cd, Zn, Ni, Cu and Mn in plantain-, maize- and melon-based meals were relatively within safe limits.

Conflict of interest

The authors declare no conflict of interest with respect to the publication of this manuscript.

CRediT Author Statement

FOO: Investigation, Writing-Original Draft Preparation, Resources. KCL: Supervision, Conceptualization. PCC: Writing-Reviewing and Editing, Visualization. AWV: Methodology, Resources. CEE: Data Curator, Resources.

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