ISSN: 2639-7536

Research Article

Petroleum and Chemical Industry International

Ecological Impact and Human Health Risk Assessment of Pumpkin and Spinach Cultivated Around Non-Mining Axes of Ebonyi State

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Submitted: 15 Mar 2022; **Accepted:** 05 Apl 2023; **Published:** 13 Aplil 2023

Citation: Chibuike, A., Alu, M. O., Anih, C. B., Obasi, P. N. (2023). Ecological Impact and Human Health Risk Assessment of Pumpkin and Spinach Cultivated Around Non-Mining Axes of Ebonyi State. *Petro Chem Indus Intern, 6*(2), 49-63.

Abstract

The study evaluated human health risks associated with the consumption of pumpkin and spinach cultivated around non-mining areas of the Asu River Group. Eighteen samples were collected and analyzed for As, Pb, and Cd, obtaining fifty-four results. The samples were washed with deionized water, air-dried and oven dries at 105°C for 48 hours, and analyzed using Varian (USA) Atomic Absorption Spectrophotometer. The concentration of Pb, As, and Cd in the vegetable trend follows; Ebonyi south (ES)<Ebonyi central (EC)<Ebonyi north (EN); EN<ES<EC and ES<EC<EN respectively. The Cd, As, and Pb contents were below WHO/FAO, (2007) and EU, (2006) specific limits. The daily intake of metals (DIM), health risk index (HRI), and targeted health quotient (THQ) were computed. The DIM of Pb, As, and Cd was below their respective oral reference dose (RfD) of 0.004, 0.003, and 0.001mg/kg/day. Pb, As, and Cd HRI values for adults, teenagers, and children are in the following order Adult<Teenagers<Children for all samples across the study area. The Pb abundance follows ES<EN<EC in both pumpkin and spinach, and Cd follows EN<EC<EN and EN<ES<EC for pumpkin and spinach respectively. Arsenic HRI in order of EN<EC<EN and EN< ES<EC for pumpkin and spinach respectively. On average, the HRI of Pb, As, and Cd ranges from 0.00312 to 0.0663, 0.00411 to 0.238, and 0.009 to 0.331 mg/kg/bw/day for the vegetables. The HRI and THQ for adults and teenagers were all <1 for As, and Pb while Cd THQ>1 in pumpkin from ES.

Keywords: Ecological Impacts, Food Contaminations, Health Risk, Pumpkin and Spinach, Non-Mining Areas.

Introduction

In Ebonyi State, Asu River Group sediments underlaid most areas dominated by indurated black shales, and inconsistent occurrence of lenses of limestone, sandstone, and siltstone in the area [1]. The shale is the major host rock for the lead-zinc minerals and also characterized by igneous intrusive rocks; the mining lead-zinc deposit and quarrying of aggregates in the area constitute environmental menace having negative social on the habitants [2,3]. Such activities could lead to the mobilization and accumulation of potentially harmful elements (PHEs) in the water, air, soils, and by extension in the food chain which previous work has evaluated around mining fields. These should have engendered high concentrations of PHEs in the soils, stream sediments, and groundwater system recorded in such studies [3,4-11]. Aside mining activities, there was a series of geodynamic activities (Tectonisnm, and magmatism) in the area, which created several fractures within the rocks of the area as the pathway for contaminants migration [10,12-16]. According to Zhao et al., when groundwater water has contact with soil, it triggers a chemical reactivity that can dissolve PHEs present [17,18].

This influences rise in soil contamination, such that food safety has become major public health concern, not just in the aspect of availability but also in the measure of their qualities. During the last few decades, the increasing demand for food safety has stimulated research of this kind to redefine the risk associated with the consumption of food that has a high content of PHEs contaminations [11,19]. Natural and anthopropological environmental influence impacts geochemistry, and toxicology processes of soil. Hence geogenic and anthropological activities are the primary source of metal accumulation in soil, food crops, and vegetables [11].

Vegetables are grown in a natural environment (soil) which made them vulnerable to contamination, hence heavy metals can be absorbed by the crops from different sources such as soil, irrigation water, mineral exploration, and mining activities, natural geological factors such as soil formation, weathering, and climate changes [9,20-25]. Though vegetables constitute an essential part of the human diet due to important mineral element constituents considered to be playing significant roles in healthy diet, wherein they provide vitamins, minerals, antioxidants, and by extension phytochemicals but can also exposed humanity to health risks due to contaminations when it accumulate heavy metals. The consumption of contaminant vegetables has been the source of approximately ninety percent (90%) of total metal intake by human beings [26-28]. This revealed how pertinent it is to understand the primary information concerning geographical and geological activities relative to the trends and accumulations of these PHEs on food and vegetable crops. The presence of these PHEs in these vegetables may help us understand the degree of possible harm to human health which may vary across regions, states, and countries, in connection with their source parameters for contaminants, which is by no means isotropic.

Recent research works have established a positive correlation between anthropological activities, and past and recent natural processes as a factor in increasing metal accumulation in food resources via soil and plant root absorption interplay (Transfer factor) [29,30]. Regarding the concept of food safety, this paper has presented the role of heavy metal accumulation as the route for the transition of toxic chemicals and heavy metals into the human body, through consumption of the vegetables and food crops, which make health risk exposure to be on steady rise [27,31-35].

Human population and urbanization in Ebonyi State have been on a steady rise so the pressure on natural resources (water, soil, and mineral deposits) are expanding tremendously, without proper planning of utilities, safety, and regard for the environment; such that resident dump waste into rivers, land and left mining and quarry pits without reclamation. This does not just create and present a worrisome environment for present agricultural activities but left the state with a contaminated environment to contend with even in several years to come. Knowledge of PHE's interactions with plants is important for environmental safety and for reducing the risks associated with the introduction of trace metals into the food chain. Consequently, a certain degree of metals accumulation can deactivate some vital enzymes leading to the inhibition of some metabolic processes in plants, hence accentuating the accumulation of harmful or potentially harmful element concentration in plant tissue, which by extension triggers health risks when ingested [36].

Though, the relationship between vegetable consumption and human health still faces some arguable concepts reasoning being that any harmful or healthful effect resulting from consumption is a dependable variable on an individual's intake and the consumer's physiological status, [37,38]. In a bid to address that Rezaee, *et al.* (2016) discovered that identifying the real amount of such food intake and its consumption pattern among different groups of society through descriptive studies can be helpful to generalize the results of the research that investigated the relationship between intake and the human health to real life. This defined the structuring of the current research, which focused on the three (3) most important stages of human life (which are childhood, teenage, and adult stages) [34].

Relatively, the current increase in PHEs contamination index of natural ecosystems do not just rephrase, devalued, and exposure human to health challenges, but have presented a worldwide environmental concern rather than a localized or regional problem, hence endangering agricultural systems and by extension creating food insecurity and quality assurance reduction. Though the threat seems to be more radical in developing countries, perhaps due to the long-term use of untreated wastewater for irrigation and uncontrolled mining, quarrying, and disposal of their corresponding waste sporadically. Also, uncontrolled pumping and discharging of untreated water from mining and quarry pits leads to increased concentrations of these metals in soils to a level it becomes unsafe for plant growth and human health when such plant material is consumed. Such an increase will interfere with the nutrient flow and balance preventing plants from reaching their maximum genetic potential for growth, development, and reproduction [39]. As concentrations of these metals increase in the soil, it enables plants to absorb them from the soil, and introduce them into the food chain, raising the risk of metal toxicity concerns for humans and animals that ingested the vegetable [39-41].

The main aim of this work is evaluation of health implications of these selected PHEs concentration (Pb, Cd, and As) in pumpkin (*Telfairia occidentails*) and Spinach (*Amaranthus hybridus*) cultivated in non-mining areas, this become important as all research carried out previously centered aroud mining district which their results reflect hazard. Previous work by Chukwu and Oji (2018); Obasi and Akudinobi, (2015, 2020), Obiora et al. (2016, 2019), Obasi et al., (2023), and Chukwu and Obiora (2023) on the food contamination index in the area centered around mining and quarrying districts within the study area[3,4,6,8.9,42,11,]. No effort has been made to appraise the natural influences on food contamination by replicating the study in areas where there has not been any recorded history of mining activities, as a such study in comparison with previous research around mining areas infers the level of anthropological activities or otherwise on food chain contamination. Hence the need to access contamination codition of non-mining area to acertain the influence of anthropologic and natural environment on food-chain contaminations. In apprasing this, greater interest has been channeled into understanding the daily intake of these metals (DIM) via food chain. Accenuating the nccessisty of accessing the health risk index (HRI), Target health quotient (THQ) that could be incured through the ingestion of a certain quantity of contaminated food resources. This work evaluated two selected vegetables (which are the most consumed vegetable in the study area) cultivated under natural conditions on the outskirt of any mining. The result obtained was compared with previous results obtained from mining areas and their related health implications.

Materials and Method

A total of eighteen (18) vegetable samples were collected in all and analyzed for Pb, As, and Cd content in each of the samples such that eighteen different results were gotten from each senatorial district and a total of fifty-four (54) in all. The samples were collected from the area where there are no mining/quarrying activities currently or history of previous mining or abounded mining sites or waste dump sites around or near the area. The studied vegetables are; Pumpkin (*Telfairia occidentails*) and Spinach (*Amaranthus hybridus*). Nine vegetable farms were selected for this study three from each senatorial district of Ebonyi State such that each comes from a given local government (LGA) for this study, namely:

Ebonyi North (EN)
Ebonyi Central (EC)
Ebonyi South (ES)

The vegetable was grown under natural conditions such that no irrigation process reflecting the farming practice in the study area and the natural compose of decay leaves was used as manure against the application of fertilizers. These were done to remove possibly every form of human influence that could alter natural soil chemistry and its interaction with the crops.

ln Ebonyi north senatorial district vegetable samples were collected from farms in Abakaliki, Ebonyi, and lzzi LGA respectively. In Ebonyi Central, vegetable samples were collected from Ezza North, Ezza South, and lkwo LGAs. While in Ebonyi South, vegetable samples were collected from Onicha, Ohaozara, and lvo LGAs. The vegetable samples were washed with deionized water to remove air pollutants, followed by oven drying at 105°C for 48 hours to remove moisture. The dried samples were pulverized, using an agate mortar and pestle, and later sieved with a 0.5 mm mesh size sieve to obtain a uniform particle size. Each vegetable sample is labeled and stored in a dry plastic container that has been pre-cleaned with concentrated nitric acid to prevent heavy metal contamination before analysis.

Heavy metal analysis was carried out using Varian (USA) AAS (Atomic Absorption Spectrophotometer) according to the method of APHA, (1995) also described in Ji et al., (2022). The following PHEs content was determined: lead (Pb), cadmium (Cd), and arsenic (As). Data analysis was conducted and descriptive statistics including means, minimum and maximum values of heavy metal concentrations for the various samples were calculated.

Health Risk Assessment Parameters

The following parameters and mathematical relationships were used to evaluate the daily intake of metals, health risks, and targeted health quotient that an adult, teenagers (Teens), and children will be exposed to through their consumption of these vegetables.

Daily Intake of Metals (DIM)

The DIM was calculated using equation (1) provided below;

$$DIM=\frac{C_m * C_f * D_{fi}}{B_w} \qquad 1$$

where C_m = metal concentration, C_f = Conversion factor from fresh to dry weight, taken to be 0.085, [42,45].

Df_i = Daily intake of vegetables. The average daily intakes of food crops and vegetables for children, Teens, and Adults were considered to be 0.345, 0.289, and 0.232 kg/person/day, respectively

B_w = Body weight. The average body weight for the Children, teens, and the adult population was given as 16.68 kg, 46.25kg, and 57.03 kg respectively [46-50].

Health Risk Index (HRI)

The HRI has been defined as the ratio of DIM in the food crops to the oral reference dose (RfD) (Adebiyi et al., 2019), and was calculated using equation 2

$$HRI=\frac{DIM}{RfD} \qquad 2$$

RfD for Pb, As, and Cd was given as 0.004, 0.003, and 0.001 respectively (USEPA-IRIS, 2006)

Target Hazard Quotient (THQ)

The health risks faced by local inhabitants from the consumption of Telfairia occidentails and Amaranthus hybridus were evaluated based on the THQ [30,51]. The method of estimating the risk using the THQ was based on equation 3

$$THQ=\frac{(EFr*ED*FI*MC)}{(RfD*BW*AT)}*0.001 \qquad 3$$

where EFr = exposure frequency (365 days $year^{-1}$), [50];
ED = exposure duration (For Children = 7 years; Teens = 25 years; Adults = 70 years), [34]
FI = food ingestion, (45g, 55g, and 65g for children, Teens, and adults respectively [51],
MC = metal concentration in the food (mg kg^{-1}),
RfD = oral reference dose (mg/kg/day),
BW = average body weight
AT = average exposure time for non-carcinogenic effects (for Children, teens and Adults are 2190, 5475, and 18,250 days respectively; Giri et al., 2019)[30,34,50,51,52].

Result and Discussion

Metal Concentration Factor

The concentration of these metals varies considerably within different parts of the State in spinach and pumpkin leaves. The average concentration from Ebonyi north (EN) is 0.216 and 0.172 for Pb, 0.02 and 0.0177 for As, and 0.163 and 0.024 mg/kg for Cd in pumpkin and spinach respectively. Similarly, in Ebonyi central (EC) they have an average of 0.176 and 0.0224 for Pb, 0.0475 and 0.198 for As, 0.211 and 0.0243 mg/kg for Cd; whereas in Ebonyi south (ES) obtained an average of 0.056 and 0.022 for Pb, 0.281 and 0.037 for As, 0.538 and 0.0463 for Cd in Pumpkin and spinach respectively (Table 1).

The concentration of lead (Pb) in the study area follows a trend of ES < EC < EN, whereas arsenic (As) follows EN < ES < EC and cadmium (Cd) concentration follows the same pattern as that of Pb trend ES < EC < EN both in Pumpkin and Spinach vegetables. Lead concentrations were all below the WHO/FAO, (2007) and EU, (2006) specific permissible limits of 0.3 and 0.43 mg/kg respectively. However, the average Cd content in Pumpkin was found to be higher than the specified limit of 0.2 by WHO/FAO and EU except at EN where an average of value 0.163mg/kg was obtained. The samples from Abakaliki and Izzi have Cd > 0.2 in the area. Samples from Ezza north L. G. A (within EC) and Ebonyi L. G. A (within EN) were < 0.02 in Pumpkin. Unlike Pumpkin, Cd content in Spinach was below the specified limit (< 0.02) in all the samples analyzed (Table 1). The reverse in trend of concentration of Cd in the study area found between pumpkin and spinach samples implies that different plants have different absorption capacities of these metals; and their accumulation interplay is relatively based on the influencing factor(s) such as soil PH, acidity, alkalinity, waste management system, the chemistry of water irrigation water and/or type of industrial activities going on the area [2,33,54,55,]. Such that different plant species have a variety of capacities to remove and accumulate heavy metals. A clear observation on has been made by some researchers where certain species accumulate particular heavy metals at a higher ratio, accentuating serious risk when such plant-based foodstuff is ingested [52,56]. Leafy vegetables, such as (cauliflower, cabbage, and spinach), have been observed to grow very well even in the presence of sewage water though some (like radish) were sensitive to sewage water [57,58]. The low concentration of these PHEs (Pb, As, and Cd) in these vegetables against higher concentrations earlier documented in the mining axis of the study area by Chukwu and Oji (2018), Obiora et al. (2019), and Obasi et al. (2023) explains a gap in natural and anthropological activities influence fouling the natural soil metallic component and their contaminations influence on food chain [8,11,42].

Table 1: Heavy Metal Accumulation in Pumpkin and Spinach across the Study Area

Heavy Metal Accumulation from Ebonyi North							
Locations	**site**	**Lead (Pb) (Mg/Kg)**		**Arsenic (As) (Mg/Kg)**		**Cadmium (Cd) (Mg/Kg)**	
		Pumpkin	**Spinach**	**Pumpkin**	**Spinach**	**Pumpkin**	**Spinach**
Ebonyi North	Abakaliki	0.144	0.151	0.017	0.014	0.22	0.028
	Ebonyi	0.197	0.286	0.023	0.012	0.039	0.016
	Izzi	0.306	0.078	0.02	0.027	0.229	0.028
	Mean	0.216	0.172	0.02	0.0177	0.163	0.024
Heavy Metal Accumulation from Ebonyi Central							
Ebonyi Central	Ezza North	0.16	0.222	0.081	0.014	0.39	0.014
	Ezza South	0.14	0.341	0.021	0.28	0.031	0.028
	Ikwo	0.224	0.109	0.406	0.301	0.211	0.031
	Mean	0.176	0.0224	0.0475	0.198	0.211	0.0243
Heavy Metal Accumulation from Ebonyi South							
Ebonyi South	Onicha	0.068	0.015	0.371	0.051	1.367	0.069
	Ohaozara	0.029	0.02	0.207	0.026	0.226	0.044
	Ivo	0.071	0.031	0.265	0.034	0.217	0.026
	Mean	0.056	0.022	0.281	0.037	0.538	0.0463
WHO/FAO, (2007)		0.3	0.3	0.5	0.5	0.2	0.2
EU, (2006)		0.43	0.43	NA	NA	0.2	0.2
NA= Not available							

Health Risk Assessment

The DIM presented in Table 2 and Fig. 1 indicated that children are more vulnerable to metal accumulation through ingestion of Pumpkin and spinach cultivated in the area, followed by Teenagers and Adults respectively. The average DIM of Pb, As, and Cd was all below 0.003mg/kg/day through ingestion of either of the vegetables in the study area. Though, higher metal intake occurs through intake of pumpkin which regrettably happened to be the most consumed leafy vegetable within Ebonyi state, due to its ready availability than other types of vegetables and the local belief that it is a natural blood tonic. Relatively, the DIM of lead, arsenic, and cadmium were all below their respective RfD values of 0.004, 0.003, and 0.001mg/kg/day. This implies on an estimation of human daily exposure it is unlikely to pose an appreciable risk of adverse health effects during a lifetime following Khaled and Muhammad, (2016) perception of RfD [56]. Though they were all below their RfD, when the rate of intake of these metals outweighs their excretion rate it gives the metals chances of possible accumulation in sensitive human organs, this explained the accumulation concept in the body system and subsequently result to health [30,59].

Table 2: Average DIM Across the Study area through Ingestion of Pumpkin and Spinach

Locations	Group	Lead		Cadmium		Arsenic	
		Pumpkin	Spinach	Pumpkin	Spinach	Pumpkin	Spinach
Ebonyi North	Adult	1.11E-04	8.83E-05	8.99E-06	9.08E-06	1.23E-05	1.23E-05
	Teenager	1.15E-04	9.12E-05	1.06E-05	9.38E-06	1.27E-05	1.27E-05
	Children	2.55E-04	2.03E-04	2.37E-05	2.09E-05	2.84E-05	2.84E-05
Ebonyi Central	Adult	9.33E-05	1.15E-04	2.44E-05	1.02E-04	1.08E-04	1.25E-05
	Teenager	9.74E-05	1.19E-04	3.74E-05	1.05E-04	1.12E-04	1.29E-05

	Children	2.14E-04	2.65E-04	8.32E-05	2.36E-04	2.49E-04	2.88E-05
Ebonyi South	Adult	2.88E-05	1.13E-05	1.45E-04	1.90E-05	3.10E-04	2.38E-05
	Teenager	2.97E-05	1.28E-05	1.49E-04	2.53E-05	3.20E-04	2.46E-05
	Children	6.62E-05	2.60E-05	3.32E-04	6.65E-05	7.13E-05	5.49E-05

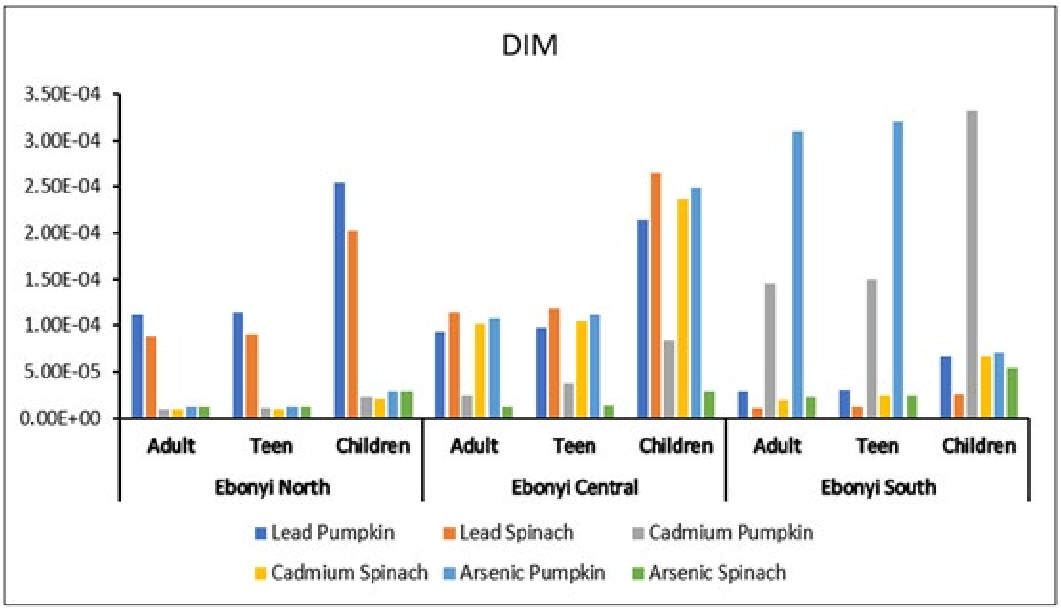

Figure 1: Average DIM of Pb, As, and Cd through intake of Pumpkin and Spinach cultivated across the three senatorial zones.

The HRI was computed using the DIM ratio in the respective vegetables to their RfD, equation 2 [60,61]. Just like DIM, the HRI associated with the consumption of pumpkin and spinach relative to Pb, As, and Cd content for adults, teenagers, and children follows the Adult < Teenagers < Children trend for all samples across the study area (Table 3 and Fig. 2a-c). The Pb HRI index follows ES < EN < EC; Cd has, EN < EC <EN and EN < ES < EC for pumpkin and spinach respectively. While arsenic has a similar HRI distribution pattern in pumpkin and spinach respectively as that cadmium in the area (EN < EC <EN and EN < ES < EC). On an average scale, HRI associated with Pb, As, and Cd in the area ranges from 0.00312 to 0.0663, 0.00411 to 0.238, and 0.009 to 0.331 mg/kg/bw/day for the vegetables. When HRI > 1 for any metal in a food crop, it indicates that the consumer of such foodstuff faces a significant health risk of non-carcinogenic effects (USEPA 2002; Nabulo et al, 2012; Abdu et al., 2011; Khaled and Muhammad, 2016; Obasi et al., 2023). There has been a report of an HRI value for Cd and Pb that is above the permissible limits in spinach irrigated with sewage water [56].

However, from the HRI result of the present study, there is no immediate foreseeable health risk associated with ingesting the individual pumpkin and spinach cultivated in places where there is no presence of abounded/active mining, quarry, and waste dump sites relative to Pb, As and Cd content since their HRI < 1 (Fig. 2 and Table 3). Correlating the HRI across the zones, the Cd in pumpkin indicated the highest risk in ES, with EC following the same trend for all subjected individuals. In Cd spinach, EC indicated the highest risk factor followed by ES with children being the most exposed among the study age group/age bracket. Pumpkin and spinach from non-mining zones of EN prove to be most safe in terms of associated health risks regarding Cd, As, and Pb contents (Fig. 3).

Table 3: Average HRI Across the Study Area through Ingestion of Pumpkin and Spinach

Locations	Group	Lead		Cadmium		Arsenic	
		Pumpkin	Spinach	Pumpkin	Spinach	Pumpkin	Spinach
Ebonyi North	Adult	0.0277	0.0221	0.009	0.00909	0.0279	0.00411
	Teen	0.0286	0.0228	0.0106	0.00937	0.0288	0.00425
	Children	0.0638	0.0507	0.0237	0.0209	0.0641	0.00944
Ebonyi Central	Adult	0.0234	0.0288	0.0245	0.1021	0.0362	0.0113
	Teen	0.0243	0.0298	0.0374	0.106	0.0373	0.0117
	Children	0.0536	0.0663	0.186	0.235	0.0831	0.0261
Ebonyi South	Adult	0.00716	0.00312	0.144	0.019	0.103	0.00793
	Teen	0.00744	0.0032	0.149	0.0253	0.107	0.0082
	Children	0.0169	0.0065	0.331	0.0635	0.238	0.0183

Though at the mining axes of Enyigba and Ishiagu, there have been reports that Cd, As, and Pb HRI > 1 by , this implies that high concentrationfound in those arise from anthropologic related activiries [2,3,8,9,42]. Unlike Zinc, cadmium, arsenic, and lead are not essential mineral elements when it comes to bodybuilding and metabolism, so their presence in food are considered rather contributing to health hazards, even at extremely low concentrations [17,36,62,63]. Therefore, prolonged human exposure to these metals through consumption of these vegetables may get to unsafe concentrations which may lead to the disruption of numerous biological and biochemical processes in the human body, especially when daily FI rate is high as it has been the case in the study area[63,64]. The real danger accompanying ingesting foods contaminated by PHE's embedded in the efficacy of the PHEs to accumulate in delicate parts of the human body, this implies that the metal may not necessarily be present a health risk at first, but with long time exposure, it could lead to the development of diverse impairment [2,9,62].

This bioaccumulation usually gradually leads to the alteration of some organs' functionality which will lead to the failure of those organs if not identified in time and take drastic measures to mitigate such bioaccumulation [59,64]. The accumulation influences the body's biochemistry and body fluid chemistry, hence PHEs accumulation in the body even in a small amount can upset the body chemistry [64,65]. This follows their high affinity for the body system and non-decomposition nature [9,66]. Continuous intake of pumpkin vegetables will likely impose some risk to human health, even for people living outside mining areas not because of the present concentration of the PHE's in the food material of the area but through bioaccumulation phenomenon. This put heavy metals on the page as being one of the most important types of contaminants that can be found in human and plant tissues. Comparing the result of this research with that of those earlier research works around the abounded mining, active mining site, quarry area, and waste dump sites [8,9,66-70] revealed a significant gap of high HRI between the current (this study) result and previous results (mining areas). Hence establishing the influence of anthropological activities in fouling the natural soil, irrigation water, and food crops through the release of harmful mineral elements than natural processes.

Since crops especially leafy vegetables grown around those heavy metal-contaminated soils accumulate higher amounts of metals than those grown in uncontaminated soils. Hence, it could be concluded that heavy metal accumulation in food is more of human activities' influence on the ecosystem than natural enrichment processes. Just like HRI, THQ has served the purpose of parameters used for evaluating the health risk associated with the consumption of metal-contaminated food crops[71]. THQ assessment usually serves confirmatory test purposes for HRI of PHEs in the food chain. The average THQ revealed that Pb and AS have no foreseeable health risks to the local population across EN, EC, and ES as their THQ < 1 for the samples studied. Lesser Arsenic content was found in spinach compared to pumpkin; it has a THQ value range of 0.00941 to 0.208 mg/kg/day whereas pumpkin has 0.0105 to 0.295 mg/kg/day. Lead has a similar THQ trend (ES < EN < EC) relationship as that of Arsenic, with a range value of 0.0081 to 0.214 mg/kg/day (Fig. 4 and Table 4).

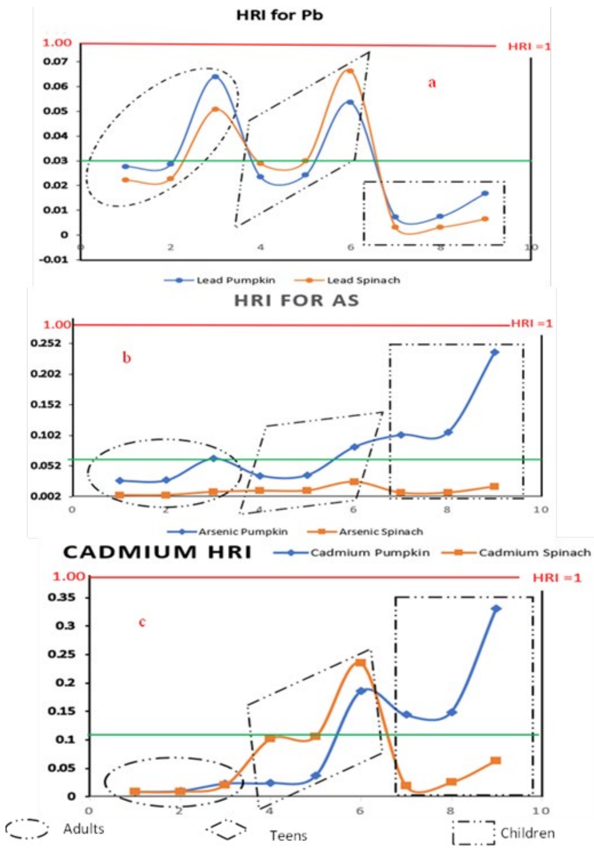

Figure 2a-c: The HRI of Pumpkin and Spinach for Adults, Teens, and Children(a) Ebonyi North (b) Ebonyi Center (c) Ebonyi South.

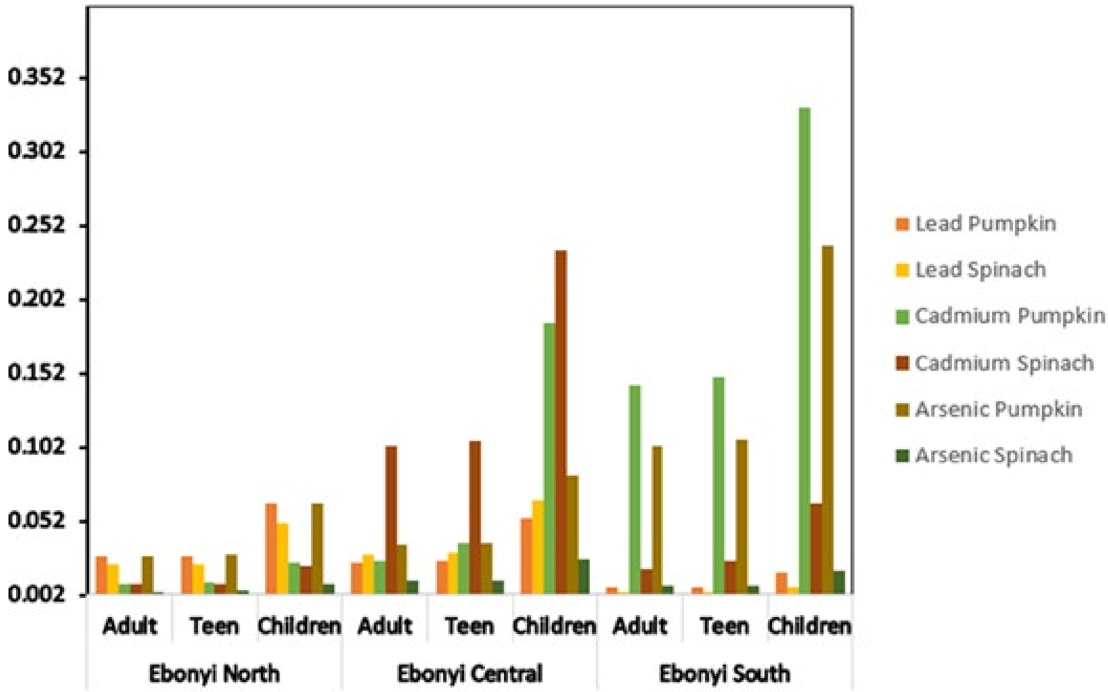

Figure 3: A Bar chart showing the HRI exposure due to Cd, As, and Pb content in Pumpkin and spinach among the different Age groups.

However, Cadmium content trends followed EN < EC < EC, in spinach with a value range of 0.0383 to 0.146 mg/kg/day whereas in pumpkin it ranges from 0.261 to 1.901 mg/kg/day. The Cd health quotient in ES revealed health concerns in the consumption of pumpkin mostly in children as THQ > 1 (Table 4 and Fig. 6).

From their respective ranges (Pb, As, and Cd) of THQ values, it revealed that Cd is of a greater health concern than Pb and As in the study area (Fig. 4, 5, and 6; Table 4). This perhaps explains why there have been high recorded cases of cancer in the state. The real danger is based on the fact that pumpkin is the most consumed leafy vegetable in every household across the state.

Table 4: Average THQ Across the Study Area through Ingestion of Pumpkin and Spinach

Locations	Group	Lead		Cadmium		Arsenic	
		Pumpkin	Spinach	Pumpkin	Spinach	Pumpkin	Spinach
Ebonyi North	Adult	0.08097	0.0631	0.2614	0.0383	0.0105	0.00941
	Teen	0.107	0.0723	0.322	0.0476	0.0132	0.0117
	Children	0.17	0.1351	0.512	0.0755	0.021	0.0185
Ebonyi Central	Adult	0.0668	0.0788	0.336	0.0388	0.0901	0.106
	Teen	0.0899	0.111	0.418	0.0482	0.112	0.131
	Children	0.214	0.176	0.664	0.0766	0.178	0.208
Ebonyi South	Adult	0.0206	0.0081	0.963	0.0739	0.149	0.0197
	Teen	0.0278	0.0237	1.196	0.0919	0.186	0.0245
	Children	0.0441	0.0173	1.901	0.146	0.295	0.0388

For a description of the optimal human risk and environmental health effects related to exposure to contaminants, health risk assessment parameters were used to provide a systematic form of quantitative and semi-quantitative descriptive models relative to metal concentrations in the vegetables in the study area.

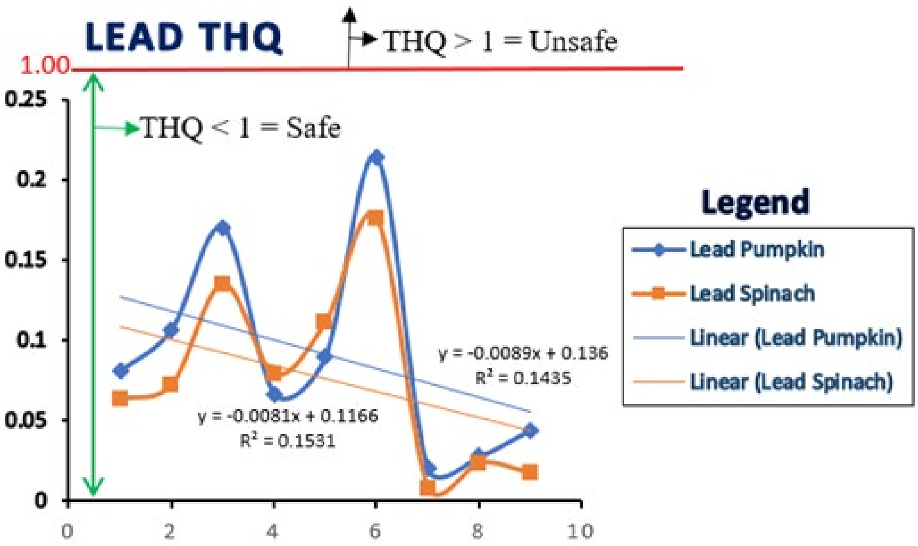

Figure 4: Graphical Display of the Average THQ as a Result of Pb in the Study Vegetables

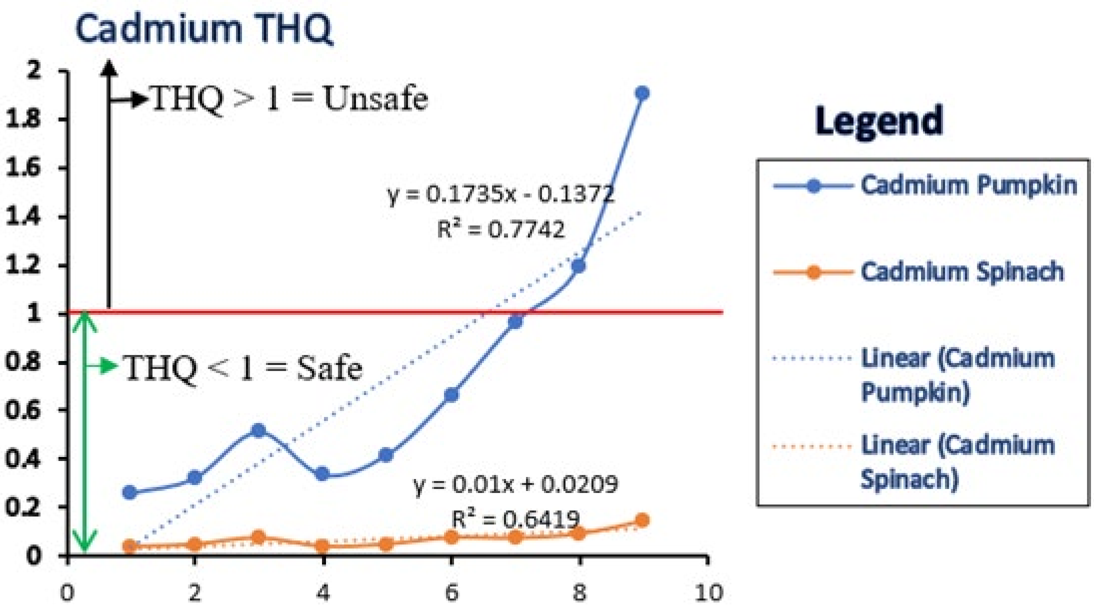

Figure 5: Graphical display of the average THQ as result Cd in the study Vegetables

An important number of the results obtained in this study were below the limit and suggested possible no metal contamination through the ingestion of Spinach and pumpkin cultivated on natural soil without irrigation, and where there are no mining/quarry activities or history of abounded mining, quarry site and/or waste dump site in the State except for pumpkin in ES following the average Cd content with THQ > 1. According to HRI and THQ results, Pumpkin has a higher concentration of these metals than spinach in the area. This implies that toxicity in crop plants can be minimized by certain plants' ability to avoid (exocytosis) or tolerate stress [72]. The non-essential Pb, As, and Cd in living organisms' biochemical activities (mostly humans), may cause health problems, which apart from their content being higher than the threshold limit recommended for health safety; even where they are less, the possibility of bioaccumulation rising from continuous ingestion on food containing these metals is eminent. This bioaccumulation may result in adverse health effects when they have been ingested in an amount higher than the safe limit [29,59,73]. Because the accumulation gradually alters the body metabolism balance, therefore, leading to increasing activities of certain body organs or malfunctioning function of such organ(s) which if not checkmated will result in organ failure.

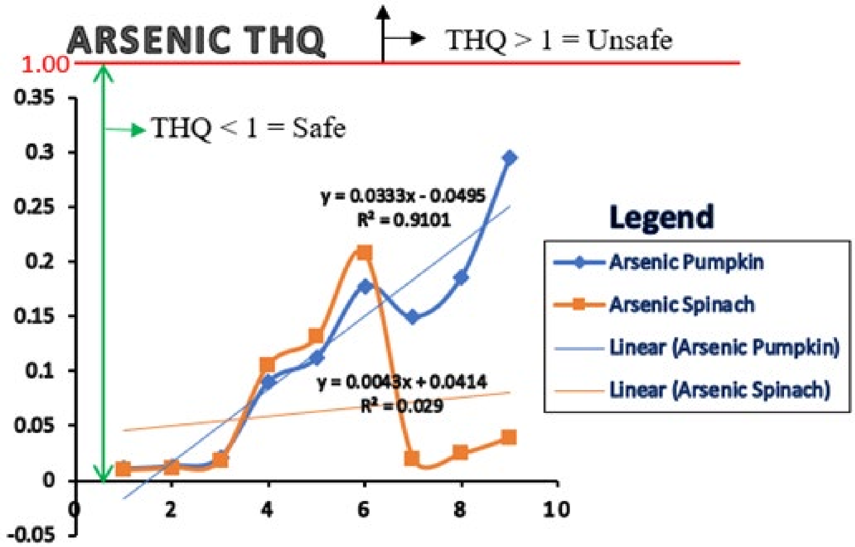

Figure 6: Graphical display of the average THQ as a result of Arsenic in the study Vegetables.

The worrisome issue remained that the populace is not just exposed to these potential health risk metals through only one channel and for the fact that some researchers have noted that Cd, As, and Pb can introduce health problems even at low concentrations [52,75]. Though, the total ingested dose of PHEs is not always equal to their percentage of body-absorbed pollutant dose in reality since some fraction of the ingested PHEs may be excreted, and the remainder accumulates in body tissues where they can affect human health [76,77]. A Series of studies have shown that virtually all known food substances and water contain one or more of these metals in varying degrees. The troubling question then becomes how many and what quantity of these vegetables and other food substances and water containing these potential poisons (heavy metals) do we take per day which may or may not impose harm?

Possible Sources and Mechanism of Phes Transfer into Plant Tissues and Food Crops

Since there are no immediate critical risks associated with vegetables cultivated outside mining areas, this research and other similar works hence suggest the potent sources of these heavy metals in food crops in Ebonyi state lie in anthropological activities (mining and quarry activities) and to a lesser extent lithologic type (Organic rich shale), soil type (Clayey rich soil) and past geodynamics, within the area. These factors amongst other anthropological processes could have led to the release and accumulation of these heavy metals, which might be more related to the presence PHEs found in the assessed vegetable in this current study. Also, weathering activities enhance the enrichment and retain the ability of these heavy metals in soil and plants. Hence, the contaminants often result from both natural and anthropogenic sources [8]. Natural sources mostly depend on the host rocks and characterizing geodynamics of the local geology like volcanic, tectonic, and magmatic evolution of the Lower Benue Trough activities and other chemical evolution such as weathering hence releasing hydrochemical facies (elements) that accumulate in soil and water resource. The anthropogenic sources are most traceable to uncontrolled and improper waste disposal following man day to day activities, perhaps due to industrialization, urbanization, mining, and municipal and domestic activities, amongst others [2,6].

Cadmium occurs naturally in the environment, it has been known to be present as an impurity in phosphate-rich rocks and can be transferred to plant tissues and edible parts due to its high mobility [24,53]. There are other natural processes/channels through which Cd can be released into the environment, processes such as the combustion of fossil fuel, incineration of municipal or industrial wastes, or land application of sewage sludge or fertilizer [4,79].

Just like cadmium and arsenic, lead can be introduced into the environment (soil) through both natural and anthropological activities; which can result from mining activities, weathering, the use of lead-containing additives in petrol, the release of lead into the air by the processing industry and as well as concentrations in water constitutes different proportion of total Pb accumulation in soil and uptake by the plant [4,6,9,27,29,42,71,80]. Inorganic lead resulting from mines, smelters, welding of lead-painted metal, and battery plants also enhance Pb release to the environment and its accumulation in vegetable/plant tissues.

The pH has been identified also as a factor that influences the bioavailability and the transport of heavy metals in the soil, and according to PHE's mobility has an inverse relationship with soil pH due to the precipitation of carbonates, hydroxides, and/or the formation of insoluble organic complexes [50,81]. Though Khaled and Muhammad, (2016) observed heavy metal contents increasing significantly with a decrease in the pH, this might be the case because the soil and water in the area are more acidic than alkali in nature as documented by Obasi and Akudinobi, (2015; 2020)[4,6]. The low level of these metals in this study verifies that the high level of PHEs found in crops cultivated in the state is an integral result of anthropological activities and farming culture (use of pesticides, insecticides, and fertilizers) in the area.

Ingestion of vegetables and cultivation around mining and quarry areas may even be a death trap, due to the high release of these metals from mining pits, and abandonment of mining pits without reclamation. Also, the indiscriminate pumping of water from active mining and quarry pits into farmlands and stream channels without treatment leads to metal accumulation in soil which subsequently increases their concentration in the food chain; coupling with the dominance of clay-rich minerals and soil in the study area which will help to retain these metals in the different horizon of the soil profile than necessary. Though apart from heavy metals accumulation in vegetables via absorption from contaminated soils, another source is the deposition of particulate matter exposed to polluted air on vegetables [27,82].

Child Susceptibility and Health Risk Associated with Cd, As, and Pb Through Spinach and Pumpkin Consumption in the Area

The result of this work revealed that children are more vulnerable to these heavy metals through vegetable ingestion. The risk may rise to acute, sub-acute, and chronic depending on the metal accumulation (Pb, AS, and Cd) through the effects of ingestion. It has been captured, that since children consume more food per kilogram of body weight than adults, the hazard quotient if contaminated also follows suit, relative to the quantity of food ingested mostly when contaminated [83-85]. Also, in Child development, organs, and tissues are more vulnerable to the toxic effects of these metals than their adult counterpart. Child exposure to lead or methylmercury during the gestation period or early childhood will cause serious damage to the developing brain with consequent loss of intellectual potential, while an adult experiencing the same exposure will suffer no considerable effects on his/her intellectual capacity [85,86]. These developmental influences alter children's response to toxins and initiate changes that may be complex and some integrated activities that lead to the expression of unique processes such as differentiation, organogenesis, morphogenesis, rapid and controlled cell division, and developmental stage-specific gene activities [83,84,87].

In children, just as their bodies keep developing, their food-consuming capacity and body weight generally increases unlike adults, children are at particular risk of illness from exposure to chemical hazards in food. Unacceptably high exposures perhaps could be avoided by applying environmental safety measures and monitoring levels of hazardous substances in food [85].

Lead Effect

Though lead does not show to impose any health risk currently through the consumption of pumpkin and spinach cultivate in non-mining/quarrying and area devoid of any physiographic signs of possible mineralization in the study area; which perhaps is the reason for the low accumulation of Pb in the studied vegetables. Yet Pb even in minute quantity still have associated health risk, hence it stands to be one of the most dangerous heavy metals to children and even adult by extension. It has been documented that aside from acute Pb toxicity, the most dangerous effect of being exposed to it, is chronic neurotoxicity mostly in children. At the beginning of the central nervous system development during an early stage of life (two-three years); exposure to Pb toxicity could be severe, increasing the risk of mild mental retardation, attention deficit hyperactivity disorder, and other developmental disabilities [85,88-91]. Aside from food ingestion, there are many pathways through which children can be exposed to PHEs, such as drinking water, use of lead-glazed ceramics in cooking, and ingestion of paint chips (usually connected with pica-syndrome typical of poor nutrition) [85,91]. However, cumulative exposure from all of these sources should not exceed the provisional tolerable weekly intake (PTWI) of 25 μg/kg body weight/week [85,86].

Arsenic Effect

Just like Pb, the HRI and THQ of Arsenic were less than 1 but the risk lies in the fact it is ubiquitous, as can be found in air, water, fuels, and marine life. The daily human intake of arsenic contained in food is in the range of 0.5–1 mg [85]. The trouble is that once arsenic gets into the body it binds to hemoglobin, plasma proteins, and leukocytes and becomes redistributed to the liver, kidney, lung, spleen, and intestines [91]. Chronic exposure to arsenic over weeks and months can have severe effects due to its neurotoxicity, cardiovascular and renal toxicity, and carcinogenicity and survivors may have severe disabilities (secondary) to organ damage [85,91]. It might be difficult to estimate the exact extent of arsenic hazard impact on the food chain relative to a child's health due to the long latency periods that may occur between exposure and outcome [85].

Cadmium Effect

Unlike As and Pb, Cadmium HRI and THQ indicated a certain level of health concern mostly in children through the consumption of pumpkin vegetables mostly those from ES > EC > EN. The cd content in these vegetables when ingested could cause acute gastrointestinal effects, such as vomiting and diarrhea [92]. According to Frery et al. (1993), the main problem of chronic exposure to Cd is kidney damage, which will happen to perturb the phosphorus and calcium metabolism hence accentuating the possibility of kidney stone health risk [85]. Maternal exposure to Cd can result in low birth weight and an increase in spontaneous abortion [63,93,94].

Conclusion

From the gap in contamination quiet from this work and previous works conducted in mining districts, it could be conclusively stated that anthropologic activities are the main cause of food chain contamination rather than natural processes. In general, as noted from the result, the health risk associated with the consumption *Telfairia occidentals* and *Amaranthus hybridus* across the non-mining axes in the study area follows Children > Teenagers > Adults, the decrease in risk exposure order from children to adult follows the order of food ingestion rate (45g, 55g and 65g for children, Teens, and adults respectively) which when proportioned gives the ratio of FI rate of 3.67: 3: 2.54 for children, Teens, and adults respectively. Hence, this result contributes to addressing the question of the relationship between individual FI rates and consumers' physiological status.

The background knowledge of metal concentrations in vegetables could only be achieved if the controlling of the dependable processes and factors that influence the heavy metal accumulation in plant tissues could be defined. In the study area, since spinach has a lesser accumulation of these toxic/potential toxic heavy metals in their tissues relative to pumpkin, it implies that it is perhaps less risky to consume spinach cultivated in the area than Pumpkin and also suggests that different plants have different heavy metal accumulation and exhalation capacity. Though, this statement is only based on the metal accumulation factor, not from a health standpoint of view of this research. The relatively non-decomposing nature of PHEs and their ability to upset body chemistry and biochemical processes has subjected the human organs (mostly organs like kidneys and liver) to a cold war of balancing toxins via the food chain.

Understanding the above dangers will prompt humanity to consider environmental protection as everyone's duty relative to food safety and quality assurance. perhaps through periodic checking/monitoring of the soil and plant and regulating the level of metals entering the soil and vegetables as a requisite measure of assessing potential health hazards to be faced by humanity. The proponents of consumer culture as the parameter of assessing the toxic quotient measure should keep in mind that this metal intake is not limited to a particular food resource/item (water is another serious pathway of PHEs intake) and the likelihood of daily consumption of material(s) that contains one or more of these PHEs is unavoidable. The result of this research serves as baseline data for the revaluation of health hazard and call for regulatory agencies to rise to their responsibility as it affects monitoring the activities of miners in the area. We recommend the use of an integrated intensive study approach (including surface and groundwater, soils, and plants sample) for better quantification of the results throughout Ebonyi State and the country at large.

Declarations: This work has not been submitted to any other journal for possible publication currently

Code availability: Not applicable

Data availability and material: Data was not attached.

Competing interests: The authors declare that they have no competing interests of any kind regarding the publication of this paper.

Funding: No funding was received from any organization or individual for this research.

Consent for publication: Not applicable.

Acknowledgments: Not applicable.

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