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Potential Health Risk from Heavy Metals via Consumption of Leafy Vegetables in the Vicinity of Warri Refining and Petrochemical Company, Delta State, Nigeria

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ABSTRACT

This study aimed to investigate the concentrations of lead (Pb), cadmium (Cd), nickel (Ni) and chromium (Cr) in the commonly grown and frequently consumed vegetables in two communities around the Warri Refining and Petrochemical Company, Delta State, Nigeria and to estimate the potential human health risks via consumption. Leafy vegetable samples comprising of Telfairia occidentalis (fluted pumpkin), Vernonia amygdalina (bitter leaves), Ocimum gratissmum (scent leaves), Amaranthus hybridus (green African spinach) and Amaranthus viridis (red African spinach) were collected, digested and analysed using Solar Thermo Elemental Flame Atomic Absorption Spectrophotometer (model: S4=71096). Results from the study were used to estimate the human health risk of these heavy metals. The result showed that the mean concentrations and (range) of total Pb, Cd, Ni, and Cr were 0.059 (0.019-0.178), 0.076 (0.010-0.230), 1.037 (0.411-2.531), and 1.337 (0.383-2.331) mg/kg, respectively. The concentration of Pb, Cd, and Ni were below the permissible limits recommended by WHO/FAO, EU and CHINA. The concentration of Cr in all the samples exceeded the limits set by EU and CHINA, but was below the limit recommended by FAO/WHO. The human health risk was calculated using toxicological indices such as Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI) and Lifetime Cancer Risk (LCR). From the results, the EDI of Pb, Cd, Ni and Cr were mostly below the Tolerable Daily Intake of metals, the THQ in the analysed samples were less than 1, the HI were also less than 1. The LCR of Pb and Cd were within the predicted permissible lifetime risks for carcinogens as stated by USEPA. The result from this study shows that there may be slight heavy metals toxicity.

Keywords: *Heavy metals; Human health risk; Food safety*

Abbreviations: *EDI: Estimated Daily Intake; THQ: Target Hazard Quotient; H: Hazard Index; LCR: Lifetime Cancer Risk; CR: Carcinogenic Risk; CSF: Cancer Slope Factor*

INTRODUCTION

Green leafy vegetables are major constituent of Nigerian diets, especially in the south-south region of the country. These vegetables are essential sources of vitamins, minerals, anti-oxidant and dietary fibre. In recent years consumption of vegetable has increased due to awareness of their food values as a result of exposure to other cultures and proper education [1].

However, high demand for food safety has necessitated research regarding the risk associated with consumption of food stuffs and vegetables contaminated by pesticides, heavy metals and other toxins [2]. Therefore, the effect of heavy metal contamination of vegetables cannot be underestimated as these foodstuffs are important components of human diet. It has also been reported that heavy metal contamination of food is one of the most important aspects of food quality assurance [3]. These heavy metals are in general not biodegradable and have long biological half-lives with a potential for accumulation in different body organs, leading to unwanted side effects. Plants take up heavy metals by absorbing them from airborne deposits on the parts of the plants exposed to the air from the polluted environments as well as from contaminated soils through root systems. The advancements in technology that has improved life standards, has raised new environmental safety challenges due to increasing industrialization and urbanization without proper emission controls and pollution control have put human lives at risk [4]. Also, the heavy metal contamination of fruit and vegetables may occur due to their irrigation with contaminated water. Heavy metals are potentially toxic to crops, animals and humans when contaminated soils and water are used for crop production [5]. Wide spread of heavy metal contamination has raised public and scientific interest hence special attention is given to them throughout the world due to their toxic effects even at very low concentrations [6]. In Nigeria, the use of polluted water in the immediate surroundings of big cities for growing vegetables is a common practice. Although this water is considered to be rich source of organic matter and plant nutrients, however, it also contains sufficient amount of soluble salts and heavy metals like Fe, Mn, Cu, Zn, Pb, Ni, Sn, Hg, Cd, Cr, As, Al [7]. When such water is used for cultivation of crops for a long time, these heavy metals may accumulate in soil and maybe toxic to the plants and also cause deterioration of soil [8].

There are many similar studies conducted in the other parts of the world to assess the heavy metal contamination of fruits and vegetables obtained from market sites. There are reports that the green leafy vegetables collected from different market sites of Kathmandu Area in India showed Pb and Cd levels higher than the maximum permissible limits set by FAO/WHO for human consumption [9]. Meanwhile, Shuaibu et al. [10] reported that the levels of Pb, Cd, Fe, Cr and Cu in four different samples of green leafy vegetables purchased from Katsina Central Market in Nigeria, contains levels of Cu, Zn, Fe and Pb below the WHO/FAO safety limits. On the other hand, Zamor et al. [11] reported contamination in five randomly collected samples of leafy vegetables from two markets in Metro Manila, Philippines and found that most of the leafy vegetables were contaminated with Pb, though the concentrations were below the safe limits of WHO and FAO.

Low-level prenatal exposure to Pb among unborn foetuses can lead to decreased intelligence and delayed cognitive function [12]. However, report from another recent Nigeria-based study showed that prenatal Pb exposure was significantly associated with crown rump length at birth [13], whereas increased levels of heavy metals in leafy vegetables from selected markets in Guyana and Libreville, Gabon has been attributed to atmospheric deposition. Furthermore, Metal concentrations in four leafy vegetables sold in markets of Abraka, Delta State, Nigeria was investigated by Agbogidi et al. [14]. Since a number of studies have shown the heavy metal contaminations of fruits and vegetables collected from various countries, hence there is a need to analyse these food items to ensure that the levels of these trace elements comply with permissible limits specified by local and international regulatory bodies. Therefore, this study was carried out to investigate the concentration of Pb, Cd, Ni and Cr in edible portion of vegetables commonly grown and consumed in two communities around the vicinity of Warri Refining and Petrochemical Company, Delta State, Nigeria and to assess the potential health risk to the consumers.

MATERIALS AND METHODS

Sample collection

Green leafy vegetables were collected from two oil impacted communities in Delta State namely; Ugbokodo and Jeddo communities. These two communities were randomly selected giving priority to the communities located around Warri Refining and Petrochemical Company which is a major refinery in Nigeria thus giving off high levels of effluent. The green leafy vegetables collected were bitter leaves (*Vernonia amygdalina*), scent leaves (*Ocimum gratissmum*), green African spinach (*Amaranthus hybridus*), Jute leaves (*Corchorus olitorius*), curry leaves (*Ocimum basilicum*), fluted pumpkin leaves (*Telfairia occidentalis*), plumed cockscomb leaves (*Celosia argentia*) and red African spinach (*Amaranthus viridis*). Samples were collected in clean polyethylene bags before sending them to the laboratory for analysis.

Methods

Sample preparation and analysis

Pre-treatment: Samples collected from the communities were washed thoroughly with running tap water as prevalent during normal cooking process, to remove soil, dirt and other air-borne pollutants. The edible parts were chopped in to small pieces. Edible parts of vegetables were then oven dried until a constant weight was obtained. They were then cooled to ambient temperature, crushed by a clean pestle and mortar to obtain homogenized samples. The ground samples were then stored at room temperature in airtight sealed polyethylene bags until required for analysis using Atomic Absorption Spectrometry (AAS). A total volume of 100 ml of H_2SO_4, HNO_3, and HClO was mixed together in the ratio of 40%:40%:20%, respectively. Then 5 g of each sample was weighed into a conical flask and 2 ml of the mixed acid was added to each of the samples in the conical flask and transferred into a Kjedhal flask. The mixture was heated on a hot plate (1300°C, 30 mins^{-1} hr) in the fume cupboard until the solution became transparent and semi-dried. It was allowed to cool, afterwards and then transferred to a 50 ml volumetric flask and made up to mark by adding deionized distilled water. Blanks were also prepared using the same procedure.

Health Risk Assessment of Heavy Metals in the Study Population: To assess the health risks associated with the ingestion of heavy metals from vegetables, the EDI of heavy metals, THQ, HI and Total Carcinogenic Intake were calculated.

EDI of metals (Mg/person/day): The Daily Intake of Metals (DIM) was calculated to averagely estimate the daily metal loading into the body system of a specified body weight of a consumer. The health risks associated with the consumption/intake of heavy metal via oral exposure were calculated based on the formula below.

$$\mathbf{EDI = C_{metal} \times D_{food\ intake} / BW_{average}}$$

Where, C_{metal}=metal concentration in vegetables in mg/kg; $D_{food\ intake}$=daily intake of food in kg/person; $BW_{average}$=average body weight in kg/person (70 kg for Adult)

An average daily consumption of 0.35 kg of vegetable was assumed for adults in this study. This value was adapted based on the report of Song et al. [15], 2015 and also considering that vegetable is widely consumed as a major part of the diet. Average adult body weight was considered to be 70 kg.

5.2.2 Non-Carcinogenic Health Effect

Calculation of THQ: Non-carcinogenic risk estimation of heavy metals consumption was determined using THQ values. THQ is a ratio of the determined dose of a pollutant to a reference level considered harmful. THQs were calculated according to the methodology described by Singh et al., [16] and United States Environmental Protection Agency [17].

$$\mathbf{THQ = (EFr \times ED \times FIR \times C / RfD_o \times B_{average\ weight} \times AT\eta) \times 10^{-3}}$$

Where, EFr=Exposure Frequency in 365 days $year^{-1}$; ED=Exposure Duration in 53 years (equivalent to an average lifetime of a Nigerian); FIR=average daily consumption in Kg $person^{-1} day^{-1}$; C=concentration of metal in food sample in mg/kg; RfD_o is reference dose in mg/Kg/day; ATη=average exposure time for non-carcinogens in days (19,345).

The following reference doses were used (Pb=4.0×10^{-3}, Cd=0.001, As=0.0003, Ni=0.02, Zn=0.3, Cr=1.5, Fe=0.7, Mn=0.014, Cu=0.04). Doses were calculated using the standard assumption for an integrated risk analysis and an average adult body weight of 70 kg [18,17]. In addition, based on EPA guidelines, it was assumed that ingested doses were equal to absorbed contaminant doses [17,19].

Hazard Index (HI): HI is used to evaluate the potential risk to human health when more than one heavy metal is involved [20]. HI was calculated as the sum of Hazard Quotients (HQ). Since different pollutants can cause similar adverse health effects, it is often appropriate to combine HQs associated with different substances, hence the HI was calculated using the formula,

$$\mathbf{HI = \Sigma THQ\ (THQ_{Pb} + THQ_{Cd} + THQ_{Ni} + THQ_{Cr} \ldots\ldots\ldots THQn)}$$

Carcinogenic health effect: Carcinogenic Risk (CR) for carcinogen, which USEPA identifies by a weight-of-evidence classification of the chemical, the estimated daily dose and the Cancer Slope Factor (CSF) are multiplied together to find the LCR posed by the chemical. CSFs are estimates of carcinogenic potency and are used to relate estimate daily dose of a substance over a lifetime exposure to the lifetime probability of excess tumours.

The Ingestion CSFs evaluate the probability of an individual developing cancer from oral exposure to contaminants levels over a lifetime. Ingestion CSFs are expressed in units of mg/kg/day.

Lifetime probability of contracting cancer due to exposure to carcinogenic chemicals is calculated as follows:

$$\mathbf{CR = EDI \times CSF_{ing}}$$

Where, CR=Carcinogenic Risk; EDI=Estimated Daily Intake of each heavy metal (mg/kg/day); CSF_{ing}=Ingestion CSF (mg/kg/day)

USEPA [21] states that 10^{-6} (1 in 1,000,000) to 10^{-4} (1 in 10,000) represent a range of permissible predicted lifetime risks for carcinogens. Chemical for which the risk factor falls below 10^{-6} may be eliminated from further consideration as a chemical of concern. The risk associated with the carcinogenic effect of target metal is expressed as the excess probability of contracting cancer over a lifetime of 70 years (Table 1).

Table 1: Toxicological characteristics of the investigated heavy metals.

USDOE (2011) USEPA (2011a) FAO/WHO (1993)	Ingestion reference dose	Ingestion carcinogenic slope factor
Metals	**RfD_{ing} (Mg/kg/day)**	**CSF_{ing} (Mg/kg/day)**
Chromium (Cr)	1.5	0.5
Cadmium (Cd)	0.001	0.38
Lead (Pb)	0.0035	0.0085
Nickel (Ni)	0.02	0
RƒD=Reference Oral Dose; CSF=Cancer Slope Factor		

RESULTS

The result of the concentration of Pb, Cd, Ni and Cr in leafy vegetable samples is presented in Table 2. The results from the study showed that Pb concentrations in the analysed leafy vegetables from communities under study ranged from 0.011 to 0.178 mg/kg, with the highest level recorded in *A. hybridus* (0.178 mg/kg) from Jeddo community while the lowest level was recorded in *A. hybridus* (0.011 mg/kg) in Ugbokodo community. Cadmium concentrations in the analysed leafy vegetables from communities under study ranged from 0.010 to 0.230mg/kg, with highest level recorded in *A. hybridus* (0.230 mg/kg) from Jeddo community while the lowest level was recorded in *V. amygdalina* (0.010 mg/kg) from Jeddo community (Table 2). Nickel concentrations in the analysed leafy vegetables from communities under study ranged from 0.411 to 2.531 mg/kg, with the highest level recorded in *A. hybridus* (2.351 mg/kg) from Jeddo community while the lowest level was recorded in *A. viridis* (0.411 mg/kg) from Ugbokodo community, and Chromium concentrations in the analysed leafy vegetables from communities under study ranged from 0.383 to 2.331 mg/kg with the highest level recorded in *T. occidentalis* (2.331 mg/kg) from Ugbokodo community while the lowest level was recorded in *A. viridis* (0.383 mg/kg) from Ugbokodo community.

Table 2: Concentration of heavy metals in leafy vegetable samples.

Location	Samples	Heavy metal concentration (mg/kg)			
		Pb	Cd	Ni	Cr
UGBOKODO	*T. occidentalis*	0.019 ± 0.003	0.101 ± 0.001	0.680 ± 0.001	2.331 ± 0.001
	V. amygdalina	0.061 ± 0.008	0.060 ± 0.002	0.520 ± 0.001	1.462 ± 0.002
	O. gratissimum	0.021 ± 0.001	0.031 ± 0.001	1.249 ± 0.001	1.870 ± 0.001
	A. hybridus	0.011 ± 0.001	0.060 ± 0.002	0.781 ± 0.001	1.350 ± 0.001
	A. viridis	0.029 ± 0.001	0.061 ± 0.001	0.411 ± 0.002	0.383 ± 0.002
JEDDO	*T. occidentalis*	0.061 ± 0.008	0.070 ± 0.001	1.063 ± 0.002	1.748 ± 0.002
	V. amygdalina	0.080 ± 0.002	0.010 ± 0.001	1.391 ± 0.002	1.430 ± 0.002
	O. gratissimum	0.040 ± 0.001	0.051 ± 0.001	0.931 ± 0.002	1.311 ± 0.001
	A. hybridus	0.178 ± 0.002	0.230 ± 0.001	2.531 ± 0.001	0.540 ± 0.002
	A. viridis	0.091 ± 0.001	0.089 ± 0.001	0.809 ± 0.001	0.942 ± 0.001
Total Mean		0.059	0.076	1.037	1.337
FAO/WHO		0.3	0.2	4	2.3
EU		0.3	0.2	2.3	0.3
China		0.2	0.2	-	0.5

EDI of Heavy Metals in the adult population: The result of the EDI of metals for exposed population is presented in Table 3. The calculated EDI for Pb ranged between 7E-05 to 0.0009 mg/kg with the highest EDI level recorded in *A. hybridus* from Jeddo community (0.0009 mg/kg), while the lowest level of calculated EDI for Pb was recorded in *A. hybridus* (7E-05 mg/kg) from Ugbokodo community. The calculated EDI result for Cd ranged between 4E-05 to 0.0011 mg/kg with *A. hybridus* from Jeddo recording the highest level (0.0011 mg/kg), while the lowest level of calculated EDI for Cd was recorded in *V. amygdalina* (4E-05 mg/kg) from Jeddo community. The calculated EDI result for Ni in the exposed population ranged from 0.0021 to 0.0127 mg/kg with the highest level recorded in *A. hybridus* (0.0127 mg/kg) from Jeddo, while the lowest level of calculated EDI for Ni was recorded in *A. viridis* (0.0021 mg/kg) from Ugbokodo community. The calculated EDI result for Cr in the exposed populations ranged from 0.0019 to 0.0117 mg/kg with the highest recorded in *T. occidentalis* from Ugbokodo community, while the lowest level of calculated EDI for Cr was recorded in *A. viridis* (0.0019 mg/kg) from Ugbokodo community.

Table 3: EDI of heavy metals (mg/kg/day/Bw) via consumption of leafy vegetables in exposed population.

Location	Samples	EDI of heavy metals (mg/kg)			
		Pb	Cd	Ni	Cr
UGBOKODO	*T. occidentalis*	0.0001	0.0005	0.0034	0.0117
	V. amygdalina	0.0003	0.0003	0.0026	0.0073
	O. gratissimum	1.00E-04	0.0001	0.0062	0.0093
	A. hybridus	7.00E-05	0.0003	0.0039	0.0067
	A. viridis	0.0002	0.0003	0.0021	0.0019
JEDDO	*T. occidentalis*	0.0003	0.0004	0.0053	0.0087
	V. amygdalina	0.0004	4.00E-05	0.0069	0.0072
	O. gratissimum	0.0002	0.0003	0.0047	0.0066
	A. hybridus	0.0009	0.0011	0.0127	0.0027
	A. viridis	0.0004	0.0005	0.0041	0.0047
TDI		0.0036[1]	0.00036[2]	0.0028[3]	0.3[4]

[1]EFSA (2010); [2]EFSA (2011); [3]EFSA(2014); [4]EFSA (2015)

EFSA – European Food and Safety Agency

THQ and HI of leafy vegetables in adult population: The result of the THQ and HI is shown in Table 4. The THQ result of Pb in adult population ranged from 0.018 to 0.225 mg/kg with the highest level recorded in *A. hybridus* (0.225 mg/kg) from Jeddo community, while the lowest level was recorded in *A. hybridus* (0.018 mg/kg) from Ugbokodo community. Cadmium ranged from 0.040 to 1.130 mg/kg with *A. hybridus* from Jeddo recording the highest level (1.130 mg/kg), while the lowest level was recorded in *V. amygdalina* (0.040 mg/kg) from Jeddo community. Nickel ranged from 0.104 to 0.633 mg/kg with *A. hybridus* from Jeddo community recording the highest value, while the lowest level was recorded in *A. viridis* (0.104 mg/kg) from Ugbokodo community. Chromium ranged from 0.001 to 0.008 mg/kg with *T. occidentalis* from Ugbokodo community recording the highest level, while the lowest level was recorded in *A. viridis* (0.001 mg/kg) from Ugbokodo community.

HI of leafy vegetables in adult population: HI is the summation of the THQ. Since the diseases caused by different heavy metals may have similar effects, it is therefore necessary to also calculate for the HI. HI greater than 1 indicates that there may be health concerns whereas, HI less than 1 indicates that there may not be health concerns. The result of the HI values ranged from 0.455to 1.990 mg/kg with the highest HI value recorded in *A. hybridus* (1.990 mg/kg) while the lowest HI was recorded in *A. viridis* (0.455 mg/kg) from Ugbokodo community. The result of the HI shows that all the HI values were less than one (<1) with the exception of *A. hybridus* (1.990 mg/kg) from Jeddo community which recorded a value greater than 1.

Table 4: THQ and HI of leafy vegetables in exposed population.

Location	Samples	THQ				HI
		Pb	Cd	Ni	Cr	
UGBOKODO	*T. occidentalis*	0.03	0.495	0.171	0.008	**0.704**
	V. amygdalina	0.07	0.315	0.131	0.005	**0.521**
	O. gratissimum	0.024	0.13	0.312	0.006	**0.472**
	A. hybridus	0.018	0.295	0.196	0.004	**0.512**
	A. viridis	0.04	0.31	0.104	0.001	**0.455**
JEDDO	*T. occidentalis*	0.073	0.365	0.266	0.006	**0.709**
	V. amygdalina	0.095	0.04	0.346	0.005	**0.486**
	O. gratissimum	0.044	0.27	0.233	0.004	**0.551**
	A. hybridus	0.225	1.13	0.633	0.002	**1.99**
	A. viridis	0.111	0.49	0.204	0.003	**0.808**

THQ>1 means that the exposed population may be at risk of heavy metals toxicity

THQ <1 means that the exposed population may not be at risk of heavy metals toxicity

Life Cancer Risk of leafy vegetables in adult population: CR also known as LCR is the lifetime probability of an individual developing any type of cancer due to carcinogenic daily exposure to a contaminant over a life time. The LCR is obtained using the CSF which evaluates the probability of an individual developing cancer from oral exposure to contaminant levels over a period of a lifetime as described by Agency for Toxic Substance and Disease Registry [22] and it is contaminant specific [23]. Ingestion CSFs are expressed in units of (mg/kg/day). USEPA [21] states that10^{-6} (1 in 1,000,000) to 10^{-4} (1 in 10,000) represent a range of permissible predicted lifetime risks for carcinogens. Chemical for which the risk factor falls below 10^{-6} may be eliminated from further consideration as a chemical of concern.

The total LCR of Pb, Cd and Cr are presented in Table 5. The result shows the LCR of vegetables exposed to heavy metals contamination over a lifetime exposure of toxicants for adult population. The LCR values of Pb, Cd, and Cr ranged from 8.5E-07 to 1.7E-06 mg/kg/day, 3.8E-05 to 1.14E-04 mg/kg/day and 9.5E-04 to 1.35E-03 mg/kg/day, respectively, having their highest values in *O. gratissimum* (1.7E-06) from Jeddo community for Pb, *V. amygdalina*, A. hybridus, *A. viridis* (1.14E-04) from Ugbokodo community and *O. gratissimum* (1.14E-04) from Jeddo community for Cd, and *A. hybridus* (1.35E-03) from Jeddo community for Cr.

Table 5: Total Cancer Risk (CR) in the adult population.

	Samples	Pb	Cd	Cr
UGBOKODO	*T. occidentalis*	8.50E-07	1.90E-04	5.85E-03
	V. amygdalina	2.55E-06	1.14E-04	3.65E-03
	O. gratissimum	8.50E-07	3.80E-05	4.65E-03
	A. Hybridus	5.95E-07	1.14E-04	3.35E-04
	A. viridis	1.70E-06	1.14E-04	9.50E-04
JEDDO	*T. occidentalis*	2.55E-06	1.52E-04	4.35E-03
	V. amygdalina	3.40E-06	1.52E-05	3.60E-03
	O. gratissimum	1.70E-06	1.14E-04	3.30E-03
	B. Hybridus	7.65E-06	4.18-04	1.35E-03
	A. viridis	3.40E-06	1.90E-04	2.35E-03

DISCUSSION

Concentration of heavy metals in leafy vegetables: Ingestion of contaminated food accounts for more than ninety percent of human exposure routes to these harmful compounds [24]. Therefore, intake of food contaminated with heavy metals is detrimental and can result to acute or chronic intoxication. The present study has shown the contamination profile of leafy vegetables commonly consumed in selected communities of South-South part of Nigeria and the possible health implications.

The result from the study showed that Pb concentration for all the samples were below the permissible limits as set by WHO/FAO, EU (0.3 mg/kg) and China (0.2 mg/kg). Lead (Pb) is known to induce cardiovascular diseases, increased blood pressure, reduced cognitive development and intellectual performance in children and the impairment of renal tubular functions which manifest in aminoaciduria and glucosuria. Lead (Pb) has been reported as a severe cumulative body toxin which enters the body through food, air and water and cannot be eliminated by washing the vegetables [11,25].

However, the levels of Cd recorded in all the samples were below the WHO/FAO, EU and China safe limit of 0.2 mg/kg for Cd consumption in vegetables. However, *A. hybridus* from Jeddo community recorded Cd level above the permissible limits set by WHO/FAO, EU and China [26]. There are reports that most common sources of cadmium in plants and vegetables are sewage sludge application, deposition from fossil fuel combustion, phosphate fertilizers, etc. [27]. Therefore, high Cd levels observed in *A. hybridus* from Jeddo community may be ascribed to waste water irrigation of vegetables cultivated within the vicinity of the Petrochemical Plant. Accumulation of Cd has been reported to induce kidney dysfunction, skeletal damage and reproductive deficiencies. Intranasal exposure to Cd has also been attributed to olfactory dysfunction. The concentration of Ni for all the samples in the present study was found to be lower than the estimated maximum guideline (4.0 mg/kg and 2.3 mg/kg) set by FAO/WHO and EU respectively. Nickel is essential for growth and reproduction in livestock and man, but could be carcinogenic in high amount in the body. At minimal levels, Ni act as a cofactor for the enzyme Urease but at very high concentration can be deleterious to health.

The concentration of Cr in all the samples in the study population was above the permissible limits (0.3 mg/kg and 0.5 mg/kg) set by EU and China respectively. Chromium (III) is an essential nutrient that helps the body utilize sugar, protein and fat, though it might be detrimental to health at high doses. Studies have shown that chromium (VI) is cytotoxic and able to induce DNA damaging effects such as chromosomal abnormalities, DNA strand breaks, DNA fragmentation and oxidative stress in Sprague-Dawley rats and human liver carcinoma cells [28].

EDI of heavy metals: The EDI result shown in Table 3 were compared with the recommended tolerable daily intake of metals (TDI) established by the Institute of medicine [29,30]. The EDI of Pb which ranged from (7E-05 to 0.0009) in all the analysed samples from all the communities were below the TDI except for *T. occidentalis* (0.0005) from Ugbokodo community, *T. occidentalis* (0.0004), *A. hybridus* (0.0011), and *A. viridis* (0.0005), all from Jeddo community which exceeded the TDI. The EDI of Ni which ranged from (0.0026 - 0.0127) exceeded the TDI of Ni except for *V. amygdalina* (0.0026) from Ugbokodo community which falls below the TDI. The TDI of Cr which ranged from (0.0019-0.0117) were all below the TDI.

THQ in exposed population: From the result of THQ shown in Table 5, the THQ of Pb which ranged between (0.018-0.225) were all less than 1, which may indicate that there may not be health concerns of Pb. The THQ of Cd which ranged from (0.040-1.130) were all less than 1 which may also be an indication that there may not be health concerns of Cd except for *A. hybridus* (1.130) from Jeddo community which was greater than 1. The THQ of Ni which ranged between (0.104-0.633) was all less than 1, which may indicate that there may not be health concerns resulting from Ni. The THQ of Cr which ranged from (0.001-0.008) was all less than 1, which may indicate that there may not be health concerns resulting from Cr**.**

HI in exposed population: The HI which ranged from 0.455-1.990 was less than 1 except for *A. hybridus* (1.990) which was greater than 1 as shown in Table 5. Generally, HI<1 means that there may not be any health concerns of heavy metals contamination while HI>1 means that there may be health concerns of heavy metals contamination [31]. From the result of the HI, the exposed population may not be at risk of Pb, Cd, Ni, and Cr.

CR in exposed population: (ATSDR) [20] states that 10-6 (1 in 1,000,000) to 10-4 (1 in 10,000) represent a range of permissible predicted lifetime risks for carcinogens. Chemical for which the risk factor falls below 10-6 may be eliminated from further consideration as a chemical of concern. The CR result in Table 5 shows that the ingestion of Pb in all the analysed samples from the whole communities ranged from (8.5E-07 to 1.7E-06) and were within the predicted permissible lifetime risks for carcinogens as recommended by USEPA [20]. This finding is an indication that Pb may be a chemical of concern that could result to cancer due to carcinogenic daily lifetime exposure to Pb. The ingestion of Cd which ranged from (3.8E-05 to 1.14E-04) in all the analysed samples were within the predicted permissible lifetime risks for carcinogens and it is suggestive that Cd may be a chemical of concern that could result to cancer due to carcinogenic daily lifetime exposure to Cd. The ingestion of Cr showed a range from (9.5E-04 to 1.35E-03) in almost all the analysed samples. These values exceeded the predicted permissible lifetime risks for carcinogens except for *A. viridis* (9.5E-04) from Ugbokodo community which was within the predicted permissible lifetime risks for carcinogens. This may indicate that Cr may also be a chemical of concern that could result to cancer due to carcinogenic daily lifetime exposure to Cr.

CONCLUSION

In conclusion, the results of this present study further confirms the significant health risks associated with consumption of vegetables grown in open-fields in the vicinity of industrial plants. Furthermore, numerous reports have linked excessive bio-accumulation of heavy metals to various health challenges. Therefore, there is the need for policy makers, relevant government agencies and other concerned stakeholders to continually monitor, control and take necessary policy decisions so as to mitigate measures that would limit the level of exposure of heavy metals to consumers of vegetables in the communities under study and ultimately prevent these avoidable health risk concerns.

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