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(RESEARCH ARTICLE)

A comparative study on the metal loads and related human health risks of toxic metals between the vegetables from Southern and Northern regions of Nigeria consumed in Akwa Ibom State

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Abstract

Vegetables are consumed in both the developing and developed countries of the world due to their high nutritive values, however they also contain some high levels of toxic substances including metals. This research examined the variations in toxic metal loads between the vegetables from the southern and northern parts of Nigeria consumed in Akwa Ibom State. This study also assessed the sources of these toxic metals in the studied vegetables from both regions of the country. The cancer and non-cancer health risks related to the consumption of these vegetables by the adults and children populations were investigated. The results showed higher levels of As, Cd, and Ni in vegetables from the North than in the South; the levels of Cr were higher in vegetables from the South, whereas the levels of Pb varied between the vegetables from both regions. The difference in the variations in toxic metal levels was significant at $p < 0.05$ for As and Ni. The study identified two major separate factors responsible for the accumulation of toxic metals in the studied vegetables from both regions. The results also revealed that the consumers of these vegetables were not exposed to serious cancer and non-cancer health risks however, were exposed to more Cd via the consumption of *Solanum lycopersicum.* It was also observed that the consumers were more expose to the carcinogens through the consumption of vegetables from the north and the children were more susceptible.

Keywords: Vegetables; Cancer and non-cancer risks; Toxic metals; Multivariate analysis, Akwa Ibom State; Nigeria

1. Introduction

Globally, vegetables have played a major role in human diets by providing protein, vitamins, carbohydrate, minerals, essential elements, and water to the human body. Hitherto, the consumption rate of vegetables in most countries of the world including Nigeria was low [1, 2]. Recently, there has been a rise in the consumption of vegetables nevertheless, it is not optimal [3, 4]. FAO [5] reported that inadequate consumption of vegetables has resulted in ailments such as birth problems, low immune systems, mental and physical disorders, and several other associated human health problems. This according to Ruel *et al*. [6] could be attributed to insufficient information on the benefits of consuming vegetables in the proper proportion. Studies have shown that the consumption of proper amounts of vegetables can increase the human life span, reducing incidences of cancer and cardiovascular problems [7, 8]. Vegetables are consumed mainly for both their nutritive and medicinal values though, high levels of toxic metals have been reported in their edible portions [9, 10, 11]. Basically, the quality of vegetables has been negatively and significantly affected by (i) Untreated wastewater [12, 13], (ii) animal wastes and wastes from dumpsites used as organic manure [14, 15, 16, 17], (iii) extensive use of pesticides and inorganic fertilizers [18, 19], and (iv) vehicular and industrial emissions [20, 21, 22]. Consequently, the level of toxic metals in vegetables is expected to be high enough to affect the nutritive value and health of the consumers [23, 24].

In Akwa Ibom State, vegetables are cultivated mostly at the subsistence level using animal wastes and inorganic fertilizers. Some farmers also cultivate their vegetables at abandoned dumpsite sites and by the roadside. Consequently,

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the quantity of vegetables may not be enough for the consumers thus, vegetables such as beans, tomato, carrot, ginger, garlic, water melon, garbage, groundnut, cucumber, onions are sourced mainly from the northern part of Nigeria. It has also been reported that vegetables are cultivated in the North under extensive application of fertilizers due to low soil fertility [25, 26, 27]. Accordingly, the level of toxic metals is expected to be high in the vegetables consumed in Akwa Ibom State. Nevertheless, vegetables contain the essential elements like Fe, Cu, Zn, Se, Mo, Mn, and Co but when their levels are higher than what is required it becomes toxic to the consumers [28, 29]. Vegetables also accumulated metals such as As, Cd, Cr, Pb, and Hg which are highly toxic and carcinogens in nature [30, 31]. However, most of the previous studies concentrated mainly on the levels of metals in vegetables cultivated and consumed in the study area without assessing the quality of others from the northern part of Nigeria [32, 33, 34]. The associated human health risks related to the consumption of these vegetables were also not investigated in the previous studies [35, 36]. Hitherto, the sources of these toxic metals in the vegetables consumed in the study area were also not ascertained.

Consequently, this study was undertaken to compare specifically the rate of toxic metals accumulation by vegetables from both the southern and Northern parts of Nigeria. This work also evaluated the cancer and non-cancer health risks related to the consumption of vegetables from both regions of the country. It is hoped that the results of this study shall reveal the level of metal loads in vegetables from the southern and northern regions of Nigeria consumed in Akwa Ibom State. It is also envisaged that; the outcome of this investigation shall expose the human health risks associated with the consumption of the studied vegetables. This study shall ultimately give the consumers the opportunity to decide on the source of vegetables to be consumed by them. The multivariate analysis shall also identify the actual source of these toxic metals thereby exposing the negative impact of agrochemicals used by the farmers.

2. Material and methods

2.1. Sample collection and preparation

Five (5) different vegetables namely; Cucumber (*Cucumis sativus*), garden egg (*Solanum melongema*), groundnut (*Arachis hypogaea*); pepper (*Capsicum annum*), and tomato (*Solanum lycopersicum*) from the southern and northern parts of Nigeria were obtained for this research. Vegetables from the southern part of Nigeria were bought from women at Akpan Adem Market in Uyo, while vegetables from the North were purchased from Hausa men at Itam market where goods from the North are normally sold. Both locations are in Uyo Metropolis Akwa Ibom State, Nigeria. These vegetables were taken to the Laboratory and washed first with tap water and later with distilled water to remove all dirt on them. These vegetables were cut into pieces using a clean stainless knife to avoid contamination and air dried for three (3) days and later in an oven at 60°C for 24 hours. The dried samples were ground using a porcelain mortar and sieved with a 20-mesh sieve.

2.2. Digestion of samples and analysis

1g of the dried sample was mixed with a mixture of HNO_3 and $HClO_4$ (ratio 5: 1) until a transparent solution was obtained. The solution was filtered using a Whatman no. 42 filter paper into 50 mL volumetric flask and stored for analysis [37]. The concentrations of some toxic metals namely: As, Cd, Cr, Ni, and Pb were determined in the filtrate using an Agilent 710 Inductively Coupled Plasma Optical Emission Spectrometer (ICP-OES) following the procedures of AHPA [38].

2.3. Health Risk Assessment

The potential health risks related to the exposure of both the adult and children populations to toxic metals through the consumption of vegetables from the southern and northern parts of Nigeria were assessed by the estimated daily intake rate (EDIM), non-cancer and cancer risks as reported by Jan *et al*. [39] and Bello *et al*. [40].

2.3.1. Determination of estimated daily intake rate of the toxic metals (EDIM)

The estimated daily intake of toxic metals in the vegetables was determined using equation (1).

$$EDIM = \frac{Cmetal \times Cfactor \times Cfood\ intake\ (DIM)}{Average\ body\ weight} \quad (1)$$

Where Cmetal = Toxic metal concentration ($mgkg^{-1}$) in the studied vegetables, Cfactor = Conversion of fresh vegetables to dry (0.085), DIM = Daily vegetable intake rate (65 $gday^{-1}$), average body weight (70 kg for adult and 20 kg for children).

2.3.2. Determination of hazard quotient (HQ)

The hazard quotient (HQ) of the toxic metals was computed using equation (2).

$$HQ = \frac{\text{EDIM}}{\text{RfD}} \text{-----} (2)$$

Where EDIM = Estimated daily intake rate of the toxic metals and RfD stands for the oral reference dose of the metals. The RfD values for As, Cd, Cr, Ni, and Pb are 3.0E-04, 5.0E-04, 3.0E-03, 2.0E-02, and 4.0E-03 mg/kg/day, respectively [41].

2.3.3. Estimation of Total chronic hazard index (THI)

The total chronic hazard index of the toxic metals was obtained using equation (3).

$$\text{THI} = \Sigma HQ = HQAs + HQCd + HQCr + HQNi + HQPb \text{-----} (3)$$

Where THI = Total hazard index and HQ is the hazard quotient.

According to USEPA [42] when the value of HI is less than 1, the consumers of the studied vegetables are not exposed to health hazard but when HI is equal to or more than 1, then the consumers are at serious risk of metal toxicity.

2.3.4. Determination of cancer risk (CR)

The cancer risk (CR) associated with exposure of consumers to the toxic metals was determined using equation (4).

$$CR = CSF\ x\ EDIM \text{-----} (4)$$

Where CSF = Cancer slope factor; EDIM is the estimated daily intake rates of the toxic metals. According to USEPA [43] the values of CSF are 1.5, 0.38, 0.5, 1.7, and 0.0085 mg/kg/day for As, Cd, Cr, Ni, and Pb, respectively. The acceptable range of predicted lifetime risk for carcinogens is 10^{-4} to 10^{-6} [44].

The total cancer risk (TCR) of toxic metals was computed using equation (5) below.

2.3.5. Determination of total cancer risk (TCR)

$$\text{Total cancer risk} = \Sigma\ \text{CR} \text{-----} (5)$$

Where CR = Cancer risk.

2.4. Statistical analysis

The results of this study were subjected to statistical analysis and the mean, standard deviation, and one-way ANOVA were obtained using of IBM SPSS Statistics 20. The principal component analysis of the results obtained for the toxic metals was carried out using Varimax Factor analysis. The similarities and differences among the toxic metals were identified with Cluster analysis (CA) using the Hierarchical Cluster Dendrogram plots with IBM SPSS Statistics 20.

3. Results and discussion

3.1. Accumulation of toxic metals in the studied vegetables from southern and northern Nigeria

Arsenic (As) in the studied vegetables varied between 0.001 and 0.006 mgkg^{-1} with an average value of 0.003±0.002 mgkg^{-1}. The highest level of As was obtained in *Capsicum annum* from the northern part of Nigeria while the lowest level was obtained in *Cucumis sativus* and *Solanum melongema* from the South. The levels of As obtained is lower than 0.07 – 1.15 mgkg^{-1} and 0.09 – 0.36 mgkg^{-1} reported by Okorosaye-Orubite and Igwe [48] and Islam *et al*. [49], respectively. Generally, the levels of As in the vegetables from the North were significantly higher than in vegetables from the South at $P < 0.05$ (Table 2). The high levels of As in vegetables from the North could be attributed to irrigation with contaminated underground water, coal mining, and excessive use of agrochemical in the North [50, 51]. Nevertheless, the mean value of As reported is lower than 0.10 mgkg^{-1} recommended limit for vegetables by FAO/WHO (2011).

Consequently, the consumption of these vegetables from both parts of Nigeria may not result in serious health problems related to As toxicity but; bioaccumulation should be avoided.

The concentrations of cadmium (Cd) in the vegetables ranged from 0.011- 0.075 $mgkg^{-1}$ with a mean value of 0.040±0.022 $mgkg^{-1}$. The highest level of Cd was obtained in *Capsicum annum* while the lowest was in *Cucumis sativus* both from the North. The range of Cd reported is lower than 0.01 – 0.17 $mgkg^{-1}$ and 0.34 to 5.44mg/kg obtained by Yang *et al*. [52] and Akan *et al*. [53], respectively. However, the obtained range is higher than below detectable limit (BDL) reported in vegetables by Mehari *et al*. [54]. The concentrations of Cd were generally insignificantly higher in the vegetables from the South than in the North except for *Capsicum annum* but, not significant at $P < 0.05$ (Table 2). The observed variations could be attributed to the difference geogenic and anthropogenic factors [16, 55, 56]. The mean concentration of Cd obtained for vegetables from both parts of the country is lower than 0.10 $mgkg^{-1}$ stipulated for vegetables by FAO/WHO [47]. Hence, the consumers may not experience Cd related health problems however, as a toxic metal the level in vegetables should be monitored properly and controlled.

Chromium (Cr) levels in the studied vegetables varied between 0.001 and 0.006 $mgkg^{-1}$ with an average value of 0.003±0.002 $mgkg^{-1}$. The lowest Cr level was obtained in *Solanum melongema* and *Solanum lycopersicum* from the North while, the highest was in *Capsicum annum* from the South. This is much below 0.46 -1.20 $mgkg^{-1}$ and 0.266 – 2.27 $mgkg^{-1}$ reported by Islam *et al*. [57] and Ratul *et al.* [58], correspondingly. However, the mean value obtained is consistent with the 0.003 $mgkg^{-1}$ reported in vegetables by Chang *et al*. [59]. The results also indicated higher but insignificant ($P < 0.05$) levels of Cr in all the studied vegetables from the South than their counterparts from the North (Table 2). This could be attributed to the natural and anthropogenic factors [60, 61, 62]. The mean value of Cr reported is below the 0.10 $mgkg^{-1}$ limit by FAO/WHO (2012). Accordingly, the consumers of these vegetables may not experience any health hazards relating to Cr toxicity as reported by Oliveira [63].

Concentrations of nickel (Ni) in the vegetables ranged from 0.005 to 0.021 $mgkg^{-1}$ with average value of 0.011±0.005 $mgkg^{-1}$. The highest level of Ni was obtained in *Cucumis sativus* from the North while the lowest was reported in *Arachis hypogaea* from the South. The range of Ni obtained is lower than 0.411-2.531 $mgkg^{-1}$ and 0.062 - 0.307 $mgkg^{-1}$ reported by Isiuku and Enyoh [64] and Chukwuemeka and Hephzibah [65], respectively. The levels of Ni in vegetables from the North were significantly higher at $P < 0.05$ than those from the South (Table 2). This could be a consequence of natural factor, intensive mining activities and application of phosphate fertilizers in the North [66, 67]. However, the mean value of Ni is lower than 0.20 $mgkg^{-1}$ recommended limit for vegetables by FAO/WHO [46]. Hence, the consumption of these vegetables from both regions may not result in serious health risks as reported by Kumari *et al*. [66]. Nevertheless, the bioaccumulation of Ni in the vegetables should be avoided.

Lead (Pb) in the studied vegetables varied between 0.002 and 0.042 $mgkg^{-1}$ with a mean concentration of 0.010±0.012 $mgkg^{-1}$. *Solanum melongema* had the highest level of Pb while the lowest level was obtained in *Arachis hypogaea* all from the North. The range of Pb obtained in the studied vegetables is below 0.119 – 1.596 $mgkg^{-1}$ and 3.63–7.56 $mgkg^{-1}$ reported by Tasrina *et al*. [68] and Gebeyehu and Bayissa [24], respectively. Though, the range is higher than below detectable limit (BDL) reported by Latif *et al*. [69]. The concentrations of Pb in the studied vegetables varied between the North and South. This could be attributed mainly to the diverse human activities (anthropogenic factor) that generate Pb in the two regions [70]. The mean value of Pb reported in this study is lower than 0.10 $mgkg^{-1}$ limit for vegetables by FAO/WHO [46]. Thus; the consumption of these vegetables may not pose serious health risk associated with Pb toxicity. Though, as a highly toxic metal its availability in the environment should be closely monitored and controlled to forestall bioaccumulation and attendants´ problems stated by Latif *et al*. [69].

The general results indicated that *Capsicum annum* has very high potential of absorbing more As, Cd, and Cr from a contaminated environment than other vegetables. Whereas, *Cucumis sativus* and *Solanum melongema* showed higher capabilities for accumulating Ni and Pb, respectively from the environment. Consequently, these vegetables could be applied for phytoremediation of environment contaminated with the respective metals.

Table 1 Level of Trace metals in vegetables from the southern and northern parts of Nigeria.

		As	Cd	Cr	Ni	Pb
Cucumis sativus	South	0.001	0.015	0.004	0.007	0.009
	North	0.003	0.011	0.002	0.021	0.012
Solanum melongema	South	0.001	0.053	0.004	0.010	0.007
	North	0.004	0.020	0.001	0.016	0.042
Arachis hypogaea	South	0.002	0.041	0.005	0.005	0.005
	North	0.005	0.037	0.002	0.009	0.002
Capsicum annum	South	0.002	0.028	0.006	0.006	0.005
	North	0.006	0.075	0.002	0.013	0.004
Solanum lycopersicum	South	0.003	0.064	0.004	0.008	0.006
	North	0.004	0.058	0.001	0.017	0.003
Min		0.001	0.011	0.001	0.005	0.002
Max		0.006	0.075	0.006	0.021	0.042
SD		0.002	0.022	0.002	0.005	0.012
Mean		0.003	0.040	0.003	0.011	0.010
MRL		0.10[a]	0.10[c]	0.10[b]	0.20[b]	0.10[b]

Min = Minimum; Max = maximum; SD = Standard deviation; MRL = Maximum recommended limit; FAO/WHO [45][a;] FAO/WHO [46][b]; FAO/WHO [47] [c].

Table 2 Analysis of Variance (ANOVA) between and within the metals determined.

		Sum of Squares	df	Mean Square	F	Sig.
As	Between groups	.000	1	.000	16.900	.003
	Within groups	.000	8	.000		
	Total	.000	9			
Cd	Between groups	.000	1	.000	.000	1.000
	Within groups	.004	8	.001		
	Total	.004	9			
Ni	Between groups	.000	1	.000	40.909	.000
	Within groups	.000	8	.000		
	Total	.000	9			
Cr	Between groups	.000	1	.000	7.580	.025
	Within groups	.000	8	.000		
	Total	.000	9			
Pb	Between groups	.000	1	.000	.666	.438
	Within groups	.001	8	.000		
	Total	.001	9			

3.2. Multivariate Analysis of toxic metals in the studied vegetables

The principal component analysis (PCA) was utilized in this study to recognize the factors responsible for the accumulation of toxic metals in the studied vegetables [71, 72]. Results in Table 3 indicate two key factors responsible for the accumulation of toxic metals in vegetables from the South with Eigen values > 1 with 87.08% of the total variance. Factor one contributed 49.89% of the total variance with significant negative loadings on As and Cr and strong positive loadings on Ni and Pb (Table 4). This could be the impact of anthropogenic activities on the metal load of the studied vegetables [16, 73]. Factor two contributed 37.19% of the total variance with strong positive loadings on As and Cd (Table 4). This represents the negative impact of agrochemicals on the quality of the vegetables as reported by Azeez *et al*. [74] and Benson *et al*. [18].

Table 3 also revealed two main factors responsible for the accumulation of toxic metals in vegetables from the northern part of Nigeria with Eigen values > 1 and a 78.82% of the total variance. Factor one contributed 56.53% of the total variance with significant positive loadings on As and Cd. Factor one also indicated strong negative loadings on Ni and Pb (Table 4). This represents the negative impacts of agrochemicals on the quality of the studied vegetables. Factor two contributed 22.29% of the total variance with strong negative loading on Cr and moderate positive loading on Pb (Table 4). This could indicate the impact of natural and anthropogenic factors on the metal loads of the vegetables [75, 76]. Accordingly, the different sources of toxic metals to the studied vegetables from both the South and the North have been identified.

Table 3 Total Variance Explained for the toxic metals in the studied vegetables from South and North

Component	Vegetables from the South								
	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.49	49.89	49.89	2.49	49.89	49.89	2.28	45.52	45.52
2	1.86	37.19	87.08	1.86	37.19	87.08	2.08	41.56	87.08
	Vegetables from the North								
1	2.83	56.53	56.53	2.83	56.53	56.53	2.40	47.96	47.96
2	1.12	22.29	78.82	1.12	22.29	78.82	1.54	30.86	78.82

Extraction Method: Principal Component Analysis

Table 4 Matrix of the major principal component

	Vegetables from the South		Vegetables from the North	
	Component		Component	
	1	2	1	2
As	-0.659	0.600	0.914	0.298
Cd	-0.054	0.984	0.811	0.318
Cr	-0.832	-0.406	0.495	-0.780
Ni	0.741	0.523	-0.778	-0.260
Pb	0.904	-0.305	-0.695	0.499

The Cluster analysis (CA) was used to identify the similarities and differences among the toxic metals determined in the vegetables from South and North [77]. The Cluster analysis for the toxic metals in vegetables from the South and North are demonstrated in figures 1 and 2, respectively. Figure 1 reveals two major clusters namely: (i) The cluster linking all the toxic metals determined except Cd and (ii) Cluster 2 linking Cd only.

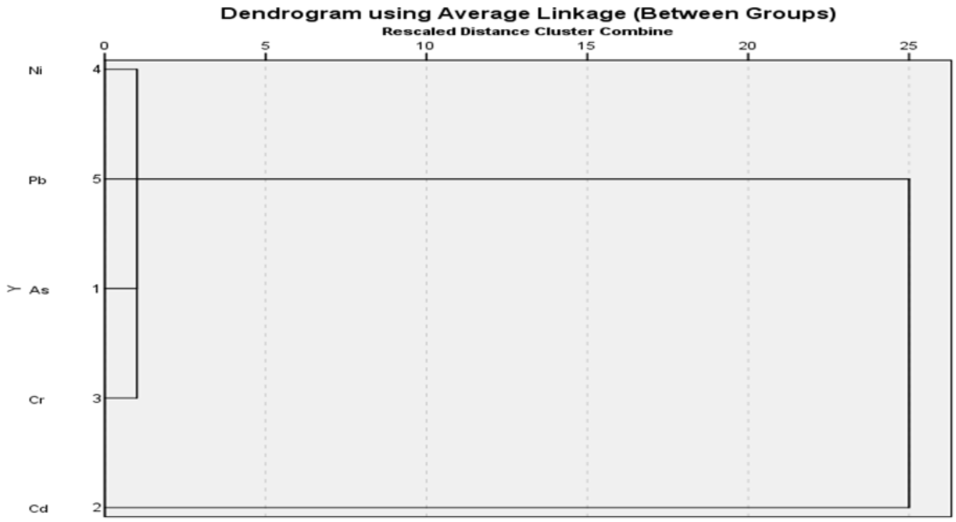

Figure 1 Hierarchical clusters formed among toxic metals in the vegetables from the South

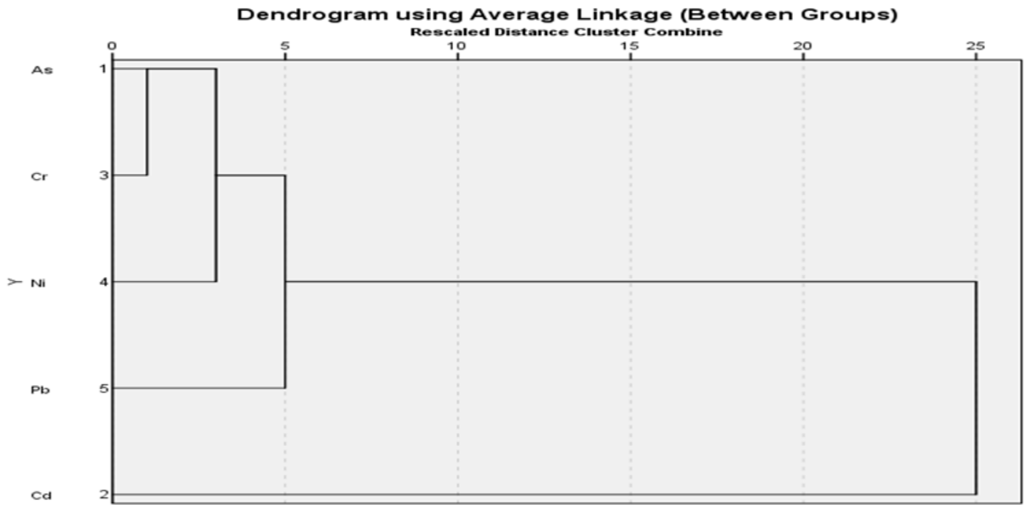

Figure 2 Hierarchical clusters formed among toxic metals in the vegetables from the North.

Figure 2 indicates four main clusters namely: (i) Cluster one linking As and Cr together (ii) Cluster two linking Ni alone (iii) Cluster three involving Pb only and (iv) Cluster iv relating Cd only. This shows the similarities and differences among the toxic metals in a common and separate cluster, respectively. This has also indicated that these toxic metals related differently in the vegetables from the South and North. This could be attributed to the variations in the geogenic and anthropogenic factors impacting on the studied vegetables from the different parts of the Country.

3.3. Health risk assessments

3.3.1. The estimated daily intake of toxic metals via the consumption of the studied vegetables

The results of the estimated daily intake of toxic metals studied (EDIM) for the adults and children populations are shown in Tables 5 and 6, respectively. According to Islam *et al.* [49] the daily intake rate of a metal gives an insight on the deficiency or the extent to which consumers are exposed to the metals under investigation. Vegetables are widely consumed in Nigeria thus, assessing the degree to which the consumers are exposed to toxic metals via them is a necessary channel for health risk assessment. The results obtained revealed that the EDIM values for all the metals via the consumption of vegetables from both regions and ages were below their recommended oral reference doses by USEPA [41]. However, the consumers of vegetables from the North were more exposed to the health hazards associated with these metals than those consuming vegetables sourced from the South. The results also indicated that children were more susceptible to health risks relating to these toxic metals than the adult's population. The low EDIM values of these metals via the consumption of the vegetables should not be neglected because these metals could be harmful even at a very low concentration.

Table 5 EDIM of toxic metals in vegetables from the southern part of Nigeria (Adults)

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	8.0E-08	8.0E-08	1.6E-07	1.6E-07	2.4E-07
Cd	1.2E-06	4.2E-06	3.3E-06	2.2E-06	5.1E-06
Cr	3.2E-07	3.2E-07	4.0E-07	4.8E-07	3.2E-07
Ni	5.6E-07	8.0E-07	4.0E-07	4.8E-07	6.4E-07
Pb	7.2E-07	5.6E-07	4.0E-07	4.0E-07	4.8E-07
	Vegetables from the North				
AS	2.4E-07	3.2E-07	4.0E-07	4.8E-07	3.2E-07
Cd	8.8E-07	1.6E-06	3.0E-06	6.0E-06	4.6E-06
Cr	1.6E-07	8.0E-08	1.6E-07	1.6E-07	8.0E-08
Ni	1.7E-06	1.3E-06	7.2E-07	1.0E-06	1.4E-06
Pb	9.6E-07	3.4E-06	1.6E-07	3.2E-07	2.4E-07

Table 6 EDIM of toxic metals in vegetables from the southern part of Nigeria (Children)

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	2.8E-07	2.8E-07	5.6E-07	5.6E-07	8.4E-07
Cd	4.2E-06	1.5E-05	1.1E-05	7.8E-06	1.8E-05
Cr	1.1E-06	1.1E-06	1.4E-06	1.7E-06	1.1E-06
Ni	2.0E-06	2.8E-06	1.4E-06	1.7E-06	2.2E-06
Pb	2.5E-06	2.0E-06	1.4E-06	1.4E-06	1.7E-06
	Vegetables from the North				
AS	8.4E-07	1.1E-06	1.4E-06	1.7E-07	1.1E-06
Cd	3.1E-06	5.6E-06	1.0E-05	2.1E-05	1.6E-05
Cr	5.6E-07	2.8E-07	5.6E-07	5.6E-07	2.8E-07
Ni	5.9E-06	4.5E-06	2.5E-06	3.6E-06	4.8E-06
Pb	3.4E-06	1.2E-05	5.6E-07	1.1E-06	8.4E-07

3.3.2. The non-carcinogenic risks associated with the exposure to toxic metals via the studied vegetables

Results for the non-carcinogenic risk related to the exposure to the toxic metals via the consumption of vegetables from the South and northern parts of Nigeria are shown in Tables 7 and 8, respectively. The non-carcinogenic risks are presented in terms of the hazard quotient (HQ) values associated with the exposure to the metals. The HQ values for all the toxic metals were below 1 thus, the consumption of these vegetables might not result in any non-carcinogenic hazard

[78]. The results for the adult consumers of vegetables from the South and North varied from 1.0E-05 to 1.02E-02 and 4.0E-06 to 1.20E-02, respectively. The highest HQ values for the adult consumers of vegetables from both regions were obtained for Cd while Pb had the lowest values. The results obtained revealed that adult population consuming the vegetables from the North were more exposed to the non-carcinogenic risk via the consumption of these vegetables. Results for the children consuming these vegetables from the South and North ranged from 3.5E-05 to 3.58E-02 and 1.4E-05 to 4.20E-02, respectively. The highest HQ values for children consuming vegetables from the South and North were recorded for Cd while Pb had the lowest. The study indicated that children consuming vegetables from the northern part of Nigeria were more exposed to the non-carcinogenic risk than those consuming vegetables from the South. The general results revealed that children consuming the studied vegetables were more exposed to the non-carcinogenic risk than the adult consumers. As stated by Li *et al*. [79] children consuming vegetables from the North are more exposed than the other classes of people since HQ varies directly with the associated risk.

Results for the total chronic hazard index (THI) related to the exposure to these toxic metals through the consumption of vegetables from the South and northern parts of Nigeria are shown in Tables 5 and 6, respectively. The THI values for all the toxic metals were lower than 1. Consequently, the consumers of these vegetables from both regions might not be exposed to serious health risk. The THI values for the adult population consuming vegetables from the South and North ranged from 2.71E-03 to 1.1E-02 and 2.67E-03 to 1.37E-02, correspondingly. Hence, the adult population consuming vegetables from the North were more vulnerable to health risk than those consuming vegetables from the southern part of Nigeria. The THI values for the children population consuming vegetables from the South and North varied from 9.49E-03 to 3.88E-02 and 9.34E-03 to 4.78E-02, respectively. Thus, children consuming vegetables from the North were more vulnerable to the health risks associated with the exposure to these metals than all the other classes of the consumers. The highest THI values for both the adult and children population consuming vegetables from the South and North were recorded for *Solanum lycopersicum* and *Capsicum annum,* respectively with Cd as the greatest contributor. Thus, both the children and adult consumers of vegetables from the South and North were more exposed to Cd toxicity and children consuming vegetables especially *Capsicum annum* from the North were more vulnerable. The bioaccumulation of Cd in these vegetables should carefully monitored and controlled to avoid the associated health problems reported by Huang *et al.* [80] and Rahimzadeh *et al*. [81] on the consumers.

Table 7 HQ of toxic metals in vegetables from the southern part of Nigeria (Adults)

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	2.67E-04	2.67E-04	5.33E-04	5.33E-04	8.00E-04
Cd	2.40E-03	8.48E-03	6.56E-03	4.48E-03	1.02E-02
Cr	1.07E-04	1.07E-04	1.33E-04	1.60E-04	1.07E-04
Ni	2.80E-05	4.00E-05	2.00E-05	2.40E-05	3.20E-05
Pb	1.80E-05	1.40E-05	1.00E-05	1.00E-05	1.20E-05
THI	2.71E-03	8.80E-03	7.10E-03	5.05E-03	1.10E-02
	Vegetables from the North				
AS	8.00E-04	1.07E-03	1.33E-03	1.60E-03	1.07E-03
Cd	1.76E-03	3.20E-03	5.92E-03	1.20E-02	9.28E-03
Cr	5.33E-05	2.67E-05	5.33E-05	5.33E-05	2.67E-05
Ni	8.40E-05	6.40E-05	3.60E-05	5.20E-05	6.80E-05
Pb	2.40E-05	8.40E-05	4.00E-06	8.00E-06	6.00E-06
THI	2.67E-03	4.40E-03	7.29E-03	1.37E-02	1.04E-02

Table 8 HQ of toxic metals in vegetables from the southern part of Nigeria (Children)

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	9.33E-04	9.33E-04	1.87E-03	1.87E-03	2.80E-03
Cd	8.40E-03	2.97E-02	2.30E-02	1.57E-02	3.58E-02
Cr	3.67E-04	3.67E-04	4.67E-04	5.67E-04	3.67E-04
Ni	9.80E-05	1.40E-04	7.00E-05	8.40E-05	1.12E-04
Pb	6.30E-05	4.90E-05	3.50E-05	3.50E-05	4.20E-05
THI	9.49E-03	3.08E-02	2.50E-02	1.77E-02	3.88E-02
	Vegetables from the North				
AS	2.80E-03	3.73E-03	4.67E-03	5.60E-03	3.73E-03
Cd	6.16E-03	1.12E-02	2.07E-02	4.20E-02	3.25E-02
Cr	1.87E-04	9.33E-05	1.87E-04	1.87E-04	9.33E-05
Ni	2.94E-04	2.24E-04	1.26E-04	1.82E-04	2.38E-04
Pb	8.40E-05	2.94E-04	1.40E-05	2.80E-05	2.10E-05
THI	9.34E-03	1.54E-02	2.55E-02	4.78E-02	3.65E-02

3.3.3. Cancer risks associated with the exposure to toxic metals by both adults and children populations via the consumption of the studied vegetables

Results for the cancer risks related to the exposure of the adult and children populations to carcinogens via the consumption of vegetables from both regions of Nigeria are displayed in Tables 9 and 10, respectively. The cancer risks associated with the adult population for the exposure to toxic metals via the consumption of vegetables from the South and North ranged from 3.40E-09 to 1.94E-06 and 1.36E-09 to 2.89E-06, respectively. This ranges are below 10^{-6} – 10^{-4} recommended by USEPA [44] as the permissible range thus, the adult population consuming vegetables from both regions may not develop cancer during their lifetime of 70 years. However, the adult population consuming vegetables from the North were more exposed to carcinogens. The cancer risk associated with the children exposed to toxic metals through the consumption of vegetables from the South and North varied from 1.18E-08 to 6.84E-06 and 4.76E-09 to 1.00E-05, respectively. These values are lower than the upper limit of 1×10^{-4} hence, the children consuming vegetables from both regions might not been exposed to cancer risk. Nevertheless, children population consuming vegetables from the North could be more susceptible to carcinogens than others.

The total cancer risks the likelihood of a consumer developing cancer for being exposed to numerous toxic metals through the consumption of the studied vegetables. Results for the total cancer risks for the adult and children populations consuming vegetables from both parts of Nigeria are shown in Tables 9 and 10, respectively. The total cancer risk for the adult population consuming vegetables from the South and North ranged from 1.69E -06 to 3.55E-06 and 3.04E-06 to 4.78E-06, respectively. Whereas, the total cancer risk for the children consuming vegetables from the South and northern parts of Nigeria varied from 5.99E-06 to 1.24E-05 and 1.04E-05 to 1.60E-05, respectively. These values are within the safe range by USEPA thus, the consumers of these vegetables might not be exposed to cancer in their lifetime. Though, the total cancer risk for children associated with the consumption of the studied vegetables from the North may result to cancer owing to the daily lifetime exposure so it calls for concern.

Table 9 Cancer risks of toxic metals related to the exposure of adult population via the vegetables.

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	1.20E-07	1.20E-07	2.40E-07	2.40E-07	3.60E-07
Cd	4.56E-07	1.60E-06	1.25E-06	8.36E-07	1.94E-06
Cr	1.60E-07	1.60E-07	2.00E-07	2.40E-07	1.60E-07
Ni	9.52E-07	1.36E-06	6.80E-07	8.16E-07	1.09E-06
Pb	6.12E-09	4.76E-09	3.40E-09	3.40E-07	4.08E-09
ΣCR	1.69E-06	3.25E-06	2.37E-06	2.47E-06	3.55E-06
	Vegetables from the North				
AS	3.60E-07	4.80E-07	6.00E-07	7.20E-07	4.80E-07
Cd	3.34E-07	6.08E-07	1.14E-06	2.28E-06	1.75E-06
Cr	8.00E-08	4.00E-08	8.00E-08	8.00E-08	4.00E-08
Ni	2.89E-06	2.21E-06	1.22E-06	1.70E-06	2.38E-06
Pb	8.16E-09	2.89E-08	1.36E-09	2.72E-09	2.04E-09
ΣCR	3.67E-06	3.37E-06	3.04E-06	4.78E-06	4.65E-06

Table 10 Cancer risks of toxic metals related to the exposure of children population via the vegetables**.**

	Vegetables from the South				
	Cucumis sativus	*Solanum melongema*	*Arachis hypogaea*	*Capsicum annum*	*Solanum lycopersicum*
AS	4.20E-07	4.20E-07	8.40E-07	8.40E-07	1.26E-06
Cd	1.60E-06	5.70E-06	4.18E-06	2.96E-06	6.84E-06
Cr	5.50E-07	5.50E-07	7.00E-07	8.50E-07	5.50E-07
Ni	3.40E-06	4.76E-06	2.38E-06	2.89E-06	3.74E-06
Pb	2.13E-08	1.70E-08	1.19E-08	1.19E-08	1.45E-08
ΣCR	5.99E-06	1.14E-05	8.11E-06	7.55E-06	1.24E-05
	Vegetables from the North				
AS	1.26E-06	1.65E-06	2.10E-06	2.55E-07	1.65E-06
Cd	1.18E-06	2.13E-06	3.80E-06	7.98E-06	6.08E-06
Cr	2.80E-07	1.40E-07	2.80E-07	2.80E-07	1.40E-07
Ni	1.00E-05	7.65E-06	4.25E-06	6.12E-06	8.16E-06
Pb	2.89E-08	1.02E-07	4.76E-09	9.35E-09	7.14E-09
ΣCR	1.27E-05	1.17E-05	1.04E-05	1.46E-05	1.60E-05

4. Conclusion

This research has been able to identify the disparity in the levels of As, Cd, Cr, Ni, and Pb between the vegetables from the southern and northern Nigeria consumed in Akwa Ibom State. The study revealed higher levels of some toxic metals in vegetables from one region than the other. It has also identified the factors responsible for the accumulation of these toxic metals in the vegetables from each region. The results have indicated that the consumers of vegetables from the northern part were more exposed to both the cancer and non-cancer risks and the children population were more vulnerable. The study has also revealed that the consumers of *Solanum lycopersicum* were more exposed to Cd toxicity and the associated risks especially the ones cultivated in the northern part of Nigeria. The negative impact of extensive applications of agrochemicals on the quality of vegetables cultivated.

Compliance with ethical standards

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There is no conflict of interest associated this study and this article.

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