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Contribution To The Heavy Metal Contents Of Vegetables And Their Associates Human Health Risks In Northern Nigeria

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Abstract
Background: *Heavy metal contamination of vegetables has become a global phenomenon, prompting intermittent monitoring to mitigate associated health implications. This study investigates heavy metal contamination in vegetables from northern Nigeria (Adamawa, Jigawa, Kano, and Taraba) focusing on As, Cd, Cr, and Pb.*
Materials and Methods: *Retail vegetables samples that includes cabbage, carrot, cucumber, okra, onion, pepper, scotch bonnet, and tomato were collected from three different locations in Adamawa, Jigawa, Kano, and Taraba states. These were processed, and analyzed for heavy metals using AAS.*
Results: *Results showed that As concentrations exceeded WHO's maximum residual limits in Jigawa, Kano, and Taraba, with a peak of 0.862 mg/kg in pepper from Jigawa. Pb was found in all samples, with the highest concentration of 1.000 mg/kg in onions and tomatoes from Adamawa. Cd and Cr remained within safety limits. Health risk assessments revealed no immediate risks, though children in Kano and Jigawa showed higher exposure to As. Cancer risk evaluations highlighted Kano's elevated risks, particularly for children.*
Conclusion: *These results stress the need for stricter pollution control and agricultural regulations to mitigate potential health risks associated with consumption of these vegetables.*
Keywords: *Adamawa, Jigawa, Kano, Taraba, Northeast, Northwest, Heavy metal, Vegetables*

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I. Introduction

Pesticides play a critical role in modern agricultural system by enhancing productivity and ensuring food security, particularly in areas with high agricultural activities. They help in controlling pests, improving soil quality, and managing plant diseases, thus supporting higher agricultural output to meet the needs of the ever-expanding global population [1,2]. In Northern Nigeria, agriculture is the primary source of income, with the region's agricultural produce not only feeding local populations but also supplying the nation, and neighboring countries [3,4]. Northern farmers like any other heavily rely on pesticides to manage their pests, weeds, and plant diseases, which often leads to the indiscriminate use, and introduction of assorted new pesticide formulations whose chemical compositions may not always be well-understood [5].

Despite these benefits, the overuse and improper application of these pesticides in Northern Nigeria have triggered significant environmental and health distress. Farmers inadequate knowledge and skills in pesticide usage have contributed to excessive application, leading to soil contamination and pollution of soil and water resources [6,7]. There residual effects in soil ecosystems does not only harm non-target organisms and reduce biodiversity, but also results in the bioaccumulation of toxic substances that include heavy metals in food crops, raising concerns about the safety of humans consuming them [3,8].

The contamination of vegetables with heavy metals in Northern Nigeria poses a public health concern, given the region's role as a major food producer and distributor within the country and beyond. However, there is a noticeable gap in research regarding the effect of localized production on the general consumption pattern, given the facts that these vegetables are transported across different consumption states. Without thorough ecotoxicological assessments, local communities may remain vulnerable to consuming contaminated vegetables, which could lead to long-term health complications. Hence, the need to evaluate the associated risks, and protect human health, especially the potential carcinogenic and non-carcinogenic effects, which is crucial for ensuring food safety and reducing heavy metals-related hazards.

II. Materials And Methods

Study Area

This study was conducted across selected states of Northern Nigeria. This region spans about 281,872 square miles, bordering Chad, Niger, Benin Republic, and Cameroon [9]. Northern Nigeria is divided into three major zones that consist of North-West (Kano, Kaduna, Katsina, Kebbi, Sokoto, Zamfara, and Jigawa); North-East (Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe); and North-Central or "Middle Belt," (Benue, Kogi, Kwara, Nassarawa, Niger, and Plateau) [10]. This region is known for its rich cultural heritage, distinct socio-economic characteristics, and profound agricultural powerhouse. According to Statista (2019), about 83.6% of households in the North-East engage in crop farming, and 68.6% own or raise livestock. Overall, about 70% of Nigerian households practice crop farming, with Northern Nigeria being a key contributor to the nation's agricultural output that is vital to the country's food security and economy, with its diverse agro-climatic zones that range from arid to semi-arid, the region produces a wide range of crops, including cereals like millet, sorghum, maize, and rice, which are essential staples for local diets. Legumes such as groundnuts, cowpeas, and soybeans grown for both food and export, root crops like yams, cassava, and sweet potatoes are significant local delicacies. Cash crops, vegetables, fruits, and spices, that include cotton, sesame, tomatoes, onions, and ginger, are also widely cultivated, supported by large-scale irrigation systems to ensure production in areas with limited rainfall.

Sampling Methods

Retail vegetable samples (Cabbage, Carrot, Cucumber, Okra, Onion, Pepper, Scotch bonnet, and Tomato) were collected from three (3) different markets in the cities of Yola (Adamawa State: Kasuwan Gwari, Yola Town Mraket, and Jimeta Modern Market), Dutse (Jigawa State: Dutse Modern Market, Old Dutse Market, and Birnin Kudu Market), Kano (Kano State: Yankaba Market, Kantin Kawri Market, and Yankura market), and Jalingo (Taraba State: Tashan Lau, Sabon-Gari market, and Kasuwan Bera). During the studies, all samples were collected applying the principles of randomization.

Table 1: GPS Coordinates and Zones of Sampling Sites

State	Site A	Site B	Site C	Region
Adamawa	Gwari Market Lat: 9˚17'3.20" Long: 12˚26'4.76"	Yola town Market Lat: 9˚12'13.72" Long: 12˚28'58.04"	Jimeta Main Market Lat: 9˚16'23.76" Long: 12˚26'14.18"	North-East
Jigawa	Dutse Modern Market Lat: 11˚41'39.96" Long: 9˚20'19.95"	Old Dutse Market Lat: 11˚41'30.04" Long: 9˚19'30.23"	Birnin Kudu Market Lat: 11˚26'54.35" Long: 9˚28'51.75"	North-West
Kano	Yankaba Market Lat: 12˚0'39.67'' Long: 8˚34'55.23''	Kantin Kwari Market Lat: 11˚56'39.56'' Long: 8˚36'48.27''	Yan Kura Market Lat: 12˚0'51.69'' Long: 8˚32'3.62''	North-West
Taraba	Tasha Lau Market Lat: 8˚53'26.08" Long:11˚21'43.97"	Sabon-Gari Market Lat: 8˚52'37.05" Long:11˚22'49.57"	Kasuwan Bera Lat: 8˚54'49.7" Long:11˚19'6.5"	North-East

Vegetables samples were selected following the FAO's recommended guidelines for heavy metals analysis. Each whole vegetable, or a bunch of vegetables, were considered as a unit, except for very small to medium-sized samples, where a minimum weight of 1 kg was used, while larger products were weighed at least 2 kg [11]. All samples were then transported to the Biological Sciences Laboratory of ATBU for processing and analysis.

Processing of Samplings

The vegetable samples were first washed thoroughly with running tap water, followed by rinsing with distilled water. The cleaned vegetables were then chopped into small pieces, air-dried in the shade for 24 hours, and then oven-dried at 70°C for another 24 hours. Dried samples were grounded and pulverized through a 2.0mm mesh to obtain a fine powder, which was then packaged in polyethylene bags for heavy metal analysis [11].

Prior to analysis, all samples were digested following the methods outlined by [5]. A tri-acid mixture (70% HNO3, 65% HClO4, and 70% H2SO4 in a 5:1:1 ratio) was added to 1g of powdered sample in a 50ml beaker, which was then heated at 80°C on a hot plate until a translucent solution was obtained. The solution was filtered through Whatman filter paper, diluted to 50 mL with distilled water, and refrigerated for further elemental analysis.

Elemental Analysis

All spectroscopic instrumentations were carried out based on the manufacturers' guidelines for optimum quality control and results. A portion of the diluted and stored 50 mL solution was used to analysed for As, Cd, Cr, and Pb with the help of an atomic absorption spectrophotometer (AAS) Buck scientific 210 GP as described by [12], following all guidelines as described by the manufacturer in [13].

Ecotoxicological Assessments Models used to access toxicity

Pollution index = $PI = \frac{C_{plant}}{C_{standard}}$

Where PI = Pollution Index, C_{plant} = Concentration of Contaminant in plant, $C_{Standard}$ = Standard value of the regulatory limit of the Contaminant, PI values <1 indicates that the material is not yet contaminated, PI values >1 indicates pollution. And, PI values =1 reveals a critical contamination [14].

Pollution index load = PLI = (CF_1 x CF_2 x CF_3 x CF_4 x…………x CF_n).

Obtained PLI values was scored using a scale graded from 1 to 6 as defined below; 0 = none, 1 = none to moderate, 2 = moderate, 3 = moderate to strong, 4 = strong, 5 = strong to very strong, and 6 = very strong [15]

Estimated daily intake = $EDI = \frac{M\ x\ K\ x\ I}{W}$

Where; M = Concentration of contaminant in plants (mg kg^{-1}), K = Conversion factor, I = Daily intake of food item, and W = Average body weight. The conversion factor of 0.085 was used to convert fresh weight of food crops to dry weight [5]. The daily rate of vegetable intake for adults in Nigeria was taken as 0.086kg/d, while the estimated average body weight of an adult was taken as 60kg. For children in Nigeria between the ages of 6 – 12yrs, daily intake and body weight was taken as 0.043kg/d and 29.37kg [5,16].

Hazard quotient = $HQ = \frac{EDI}{RfD}$

Where; EDI = Estimated Daily Intake, RfD = Reference Dose of the contaminant, If the ratio is less than one (1), then the exposed population is considered safe [5,17].

Hazard index $(HI) = \sum HQ$

Where; HI = Hazard Index, HQ = Hazard Quotient, $\sum = summation$ [17]

Cancer risk $(CR) = EDI\ x\ CSF$

Where, EDI = estimated daily intake and, CSF = cancer slope factor. The permissible limits are considered to be 10^{-6} and $<10^{-4}$ for a single carcinogenic element and multi-element carcinogens [18].

Statistical Analysis

Data generated from this study were compared with international standards and also subjected to different toxicology models to determine toxicity, as shown above.

Table 2: International Standards for HMs Used in Determining Health Risks

HMs	CSF	RDI	RfD	Reference
As	1.5	0.13	0.0003	[19,20,21]
Cd	6.1	0.06	0.0005	[18,20,21]
Cr	41	0.02	0.005	[18,20,21]
Pb	8.5	0.21	0.0035	[18,20,21]

HMs = Heavy Metals; CSF = Cancer Slope Factor, RDI = Recommended Daily Intake, RfD = Oral Reference Dose

III. Results And Discussions

Heavy Metal Contamination of Vegetables

The presence of toxic heavy metals, that is, arsenic (As), cadmium (Cd), chromium (Cr), and lead (Pb) in vegetables across four Nigerian states: Adamawa, Jigawa, Kano, and Taraba as revealed in Table 3, showed that, As was undetected in vegetable samples from Adamawa State, but found in a limited number of vegetables in Jigawa, Kano, and Taraba, with the highest concentration of 0.862 mg/kg observed in pepper from Jigawa. Cd was found to be more widely detected, with the highest mean concentration in okra from Taraba at 0.015 mg/kg and the lowest in many vegetables from Adamawa and Jigawa at 0.002 mg/kg. Cr concentrations were recorded across most states, except for certain vegetables in Taraba, with cabbage showing the highest concentration at 0.106 mg/kg. Pb was consistently present in all vegetables across all states, with the highest mean concentration found in onion and tomato from Adamawa as 1.000 mg/kg, while the lowest was in onion from Taraba as 0.009 mg/kg.

These differences in concentrations could be linked to many factors that includes the types of pesticides used, soil preferences for metal retention, and selective absorption by vegetables. These findings aligns with previous studies suggesting that heavy metal contaminants from pesticides and soil composition play a major role in the uptake of heavy metals by crops [22,23,24].

The study also highlighted that all vegetables from Jigawa, Kano, and Taraba exceeded the maximum residual limits (MRLs) for As, likely due to extensive pesticide use in the region. Many researches indicate that pesticides in northern Nigeria often contain metals, which contributes to their accumulation in crops [25].

Elevated As levels above WHO's acceptable thresholds were also reported in previous studies from Zaria, Kaduna State, and the Riruwai mining area in Kano [26,27]. The widespread contamination of vegetables with As could be linked to its natural occurrence in the Earth's crust and its persistence in soils and water due to its inorganic forms, which resist degradation [28,29].

This study found that while the concentrations of Cd, Cr, and Pb in vegetables were within the World Health Organization's allowable limits, these metals remain persistently present in the crops. Probably because, Cd in particular, is absorbed by plants from contaminated soils, often exacerbated by industrial activities, polluted irrigation water, and the widespread use of phosphate fertilizers, as observed in northern Nigeria [30]. Similarly, Cr contamination could largely stem from industrial processes like leather tanning and mining, which could be compounded by agricultural runoff [31]. Pb on the other hand, may be primarily introduced to crops through vehicular emissions and industrial discharges, making it a pervasive environmental pollutant. This consistent presence of Pb in vegetables not only raises concerns about the health implications for consumers but also highlighted a broader global issue, as evidenced by studies from regions like Egypt and Brazil, where industrial and urban activities contribute to similar contamination [32,33].

Table 3: Mean Heavy Metal Concentration (mg/kg) of Vegetables during the study

Heavy Metal (HM)	Vegetables	Adamawa State	Jigawa State	Kano State	Taraba State	MRL
As	Cabbage	BDL	BDL	BDL	0.479 ± 0.00	**0.1**
	Carrot	BDL	BDL	0.168 ± 0.12	BDL	
	Cucumber	BDL	BDL	0.278 ± 0.11	0.036 ± 0.00	
	Okra	BDL	BDL	0.417 ± 0.20	BDL	
	Onion	BDL	0.124 ± 0.01	0.112 ± 0.01	BDL	
	Pepper	BDL	0.862 ± 0.02	0.269 ± 0.36	BDL	
	Scotch bonnet	BDL	BDL	0.040 ± 0.07	BDL	
	Tomato	BDL	0.200 ± 0.18	0.360 ± 0.12	BDL	
Cd	Cabbage	BDL	BDL	0.004 ± 0.00	0.008 ± 0.00	**0.3**
	Carrot	BDL	BDL	0.008 ± 0.00	BDL	
	Cucumber	0.002 ± 0.00	0.008 ± 0.00	0.006 ± 0.00	0.009 ± 0.00	
	Okra	BDL	0.012 ± 0.01	0.006 ± 0.00	0.015 ± 0.00	
	Onion	0.002 ± 0.00	0.002 ± 0.00	0.004 ± 0.00	0.012 ± 0.00	
	Pepper	BDL	0.002 ± 0.00	0.003 ± 0.00	0.010 ± 0.00	
	Scotch bonnet	BDL	0.002 ± 0.00	0.004 ± 0.00	0.005 ± 0.00	
	Tomato	BDL	0.004 ± 0.00	0.007 ± 0.00	0.009 ± 0.00	
Cr	Cabbage	0.035 ± 0.00	0.040 ± 0.00	0.067 ± 0.00	0.106 ± 0.00	**1.3**
	Carrot	0.027 ± 0.00	0.031 ± 0.01	0.062 ± 0.00	0.091 ± 0.00	
	Cucumber	0.029 ± 0.00	0.039 ± 0.01	0.073 ± 0.01	0.091 ± 0.00	
	Okra	0.033 ± 0.00	0.039 ± 0.01	0.075 ± 0.00	BDL	
	Onion	0.037 ± 0.00	0.041 ± 0.01	0.080 ± 0.01	0.009 ± 0.00	
	Pepper	0.033 ± 0.00	0.038 ± 0.00	0.084 ± 0.00	0.004 ± 0.00	
	Scotch bonnet	0.043 ± 0.00	0.043 ± 0.00	0.079 ± 0.00	BDL	
	Tomato	0.048 ± 0.00	0.052 ± 0.00	0.091 ± 0.00	0.011 ± 0.00	
Pb	Cabbage	0.045 ± 0.00	0.070 ± 0.02	0.024 ± 0.00	0.066 ± 0.00	**0.3**
	Carrot	0.014 ± 0.00	0.057 ± 0.01	0.061 ± 0.00	0.040 ± 0.00	
	Cucumber	0.012 ± 0.00	0.037 ± 0.00	0.064 ± 0.00	0.013 ± 0.00	
	Okra	0.089 ± 0.00	0.063 ± 0.01	0.029 ± 0.02	0.032 ± 0.00	
	Onion	0.100 ± 0.00	0.045 ± 0.01	0.035 ± 0.01	0.009 ± 0.00	
	Pepper	0.080 ± 0.00	0.055 ± 0.01	0.045 ± 0.01	0.030 ± 0.00	
	Scotch bonnet	0.043 ± 0.00	0.036 ± 0.01	0.051 ± 0.00	0.019 ± 0.00	
	Tomato	0.100 ± 0.00	0.066 ± 0.01	0.030 ± 0.01	0.041 ± 0.00	

As = Arsenic; Cd = Cadmium; Cr = Chromium; Pb = Lead; Values are mean of 3 replicates, MRL = maximum Residual Limit (WHO)

Pollution Index (PI) and Pollution Load Index (PLI)

The PI and PLI values (Table 4) for vegetables in this study reveal a varying level of contamination across different northern Nigerian states. Most vegetables had PI and PLI values below one, indicating that they were not significantly polluted. However, certain vegetables exceeded these thresholds, particularly in Jigawa, where onion (1.240), pepper (8.620), and tomato (2.000) recorded PI values above one due to As contamination. Similarly, in Kano, several vegetables, that includes carrot (1.680), cucumber (2.780), okra (4.170), onion (1.120), pepper (2.690), and tomato (3.600), also had PI values above one. In contrast, only cabbage in Taraba (4.790) exceeded the threshold for PI. While interestingly, all vegetables in Adamawa state showed no pollution, with both PI and PLI values recorded as zero. Despite some vegetables exceeding the PI threshold, the overall pollution load (PLI) remained below one in all the states, signifying there is no substantial pollution in terms of total load.

Comparatively, the study found that vegetables from the Northwestern region were generally more polluted than those from the Northeastern region, with five vegetables in the Northeast (cucumber, okra, onion, pepper, and tomato) surpassing a PI value of one, while only cabbage in the Northwest exceeded this threshold.

The PLI provides a key metric for assessing the overall heavy metal contamination in vegetable. This study revealed notable variations in the PI values across different vegetables, which can be attributed to the differential concentrations of heavy metals in the vegetables, as influenced by the metal content in the soil and the use of polluted water for irrigation [34,35]. Vegetable species also plays a pivotal role in their ability to absorb metals, where certain species exhibit greater capacity for metal uptake due to their unique physiological and biochemical properties, leading to diverse PI values [36]. Additionally, the bioaccumulation factor (BAF), which varies across species and soil types, contributes to the PI values observed in this study [37,38]. Environmental factors such as rainfall and temperature could further influence heavy metals concentrations, with contaminated water irrigation increasing metal uptake by plants, while rainfall may dilute or leach these metals, thus affecting the PI [39,40]. Vegetables with high PI values indicate elevated metal concentrations that could lead to bioaccumulation in the human body, raising potential health concerns [39].

Table 4: Pollution Indices (PI) of Vegetables in Northern Nigeria State

Heavy Metal	Vegetables	Adamawa	Jigawa	Kano	Taraba	Mean ± SD	
						NE	NW
As	Cabbage	0.000	0.000	0.000	4.790	2.395 ± 3.39	0.000
	Carrot	0.000	0.000	1.680	0.000	0.000	0.840 ± 1.19
	Cucumber	0.000	0.000	2.780	0.360	0.180 ± 0.25	1.390 ± 1.97
	Okra	0.000	0.000	4.170	0.000	0.000	2.085 ± 2.95
	Onion	0.000	1.240	1.120	0.000	0.000	1.180 ± 0.08
	Pepper	0.000	8.620	2.690	0.000	0.000	5.655 ± 4.19
	Scotch bonnet	0.000	0.000	0.400	0.000	0.000	0.200 ± 0.28
	Tomato	0.000	2.000	3.600	0.000	0.000	2.800 ± 1.13
	PLI	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Cd	Cabbage	0.000	0.000	0.013	0.027	0.014 ± 0.02	0.007 ± 0.01
	Carrot	0.000	0.000	0.027	0.000	0.000	0.014 ± 0.02
	Cucumber	0.007	0.027	0.020	0.030	0.019 ± 0.02	0.024 ± 0.00
	Okra	0.000	0.040	0.020	0.050	0.025 ± 0.04	0.030 ± 0.01
	Onion	0.007	0.007	0.013	0.040	0.024 ± 0.02	0.010 ± 0.00
	Pepper	0.000	0.007	0.010	0.033	0.017 ± 0.02	0.009 ± 0.00
	Scotch bonnet	0.000	0.007	0.013	0.017	0.009 ± 0.01	0.010 ± 0.00
	Tomato	0.000	0.013	0.023	0.030	0.015 ± 0.02	0.018 ± 0.01
	PLI	**0.000**	**0.000**	**5.91E-7**	**0.000**	**0.000**	**2.96E-7 ± 0.00**
Cr	Cabbage	0.027	0.031	0.052	0.082	0.055 ± 0.04	0.042 ± 0.01
	Carrot	0.021	0.024	0.048	0.070	0.046 ± 0.03	0.036 ± 0.02
	Cucumber	0.022	0.030	0.056	0.070	0.046 ± 0.03	0.043 ± 0.02
	Okra	0.025	0.030	0.058	0.000	0.013 ± 0.02	0.044 ± 0.02
	Onion	0.028	0.032	0.062	0.007	0.018 ± 0.01	0.047 ± 0.02
	Pepper	0.025	0.029	0.065	0.003	0.014 ± 0.02	0.047 ± 0.03
	Scotch bonnet	0.033	0.033	0.061	0.000	0.017 ± 0.02	0.047 ± 0.02
	Tomato	0.037	0.040	0.070	0.008	0.023 ± 0.02	0.055 ± 0.02
	PLI	**4.13E-6**	**7.25E-6**	**9.45E-5**	**0.00**	**2.07E-6 ± 0.00**	**5.69E-6 ± 0.00**

Pb	Cabbage	0.150	0.233	0.008	0.220	0.153 ± 0.10	0.121 ± 0.16
	Carrot	0.047	0.190	0.203	0.133	0.143 ± 0.07	0.197 ± 0.01
	Cucumber	0.040	0.123	0.213	0.043	0.105 ± 0.08	0.168 ± 0.06
	Okra	0.297	0.210	0.097	0.107	0.178 ± 0.09	0.154 ± 0.08
	Onion	0.333	0.150	0.117	0.030	0.158 ± 0.12	0.134 ± 0.02
	Pepper	0.267	0.183	0.150	0.100	0.175 ± 0.07	0.167 ± 0.02
	Scotch bonnet	0.143	0.120	0.170	0.063	0.124 ± 0.05	0.145 ± 0.04
	Tomato	0.333	0.220	0.100	0.137	0.198 ± 0.10	0.160 ± 0.08
	PLI	**4.76E-3**	**7.28E-3**	**8.00E-4**	**4.72E-4**	**3.33E-3 ± 0.00**	**4.04E-3 ± 0.00**

PI = Pollution Index (< 1 = non-contamination; = 1 = critical contamination; > 1 = indicates pollution); PLI = Pollution Index Load (0 = none; 1 = none to moderate; 2 = moderate; 3 = moderate to strong; 4 = strong; 5 = strong to very strong; 6 = very strong)

Human Health Risks

Estimated Daily Intake (EDI) of Contaminants

The EDI values (Table 5 and 6) of heavy metals in vegetables for this study were assessed for both children and adults, which reveals that all contaminated vegetables had EDI values within the recommended limits, thus, posing no significant health risks. However, children generally had slightly higher EDI values compared to adults. In Adamawa and Taraba states (Table 5), for instance, the EDI values for As were absent in children from Adamawa, while in Taraba, the EDI values for children followed the order of As > Cr > Pb > Cd. For adults, the order in Adamawa was Pb > Cr > Cd > As, with individual heavy metal ranges reflecting slight variations in bioaccumulation across the vegetables. Similarly, the EDI values in Taraba showed As to be the highest for children, while Pb had the highest mean value for adults, with both states exhibiting variations in the range of contamination across the different metals. Further analysis of Jigawa and Kano states (Table 6) revealed remarkable differences in the EDI values between children and adults. In Jigawa, children had higher EDI values for As (3.40E-5) and Pb (1.33E-5), while for adults, As was again the highest (1.62E-5), followed by Cr, Pb, and Cd. In Kano, children showed significantly higher EDI values for As (5.46E-5) compared to other metals, and the order of contamination for adults followed As > Cr > Pb > Cd. Despite these varying concentrations, the EDI values across all states for both children and adults remained within the safety limits, ensuring there is no immediate health concerns from the consumption of these vegetables.

The EDI values for heavy metals across all states in this study were within the recommended daily intake (RDI) limits, suggesting no immediate health risks from consumption of these vegetables. Although contamination sources may vary, many studies have shown that vegetables from local markets often display lower contaminant levels due to the mixing of produce from various agricultural sources, which may dilute the concentration of harmful metals [36,38]. Additionally, diverse diet plays some role in mitigating the health risks associated with consuming contaminated vegetables, because the overall intake of contaminants may typically be well-balanced across different foods [37,41]. Estimating procedures for daily intake often use average consumption rates, which may not fully capture individual dietary habits or consumption patterns, leading to potential underestimations for high-consumption individuals [41,42]. Interestingly, children's slightly higher EDI values than adults, put them at greater risk due to their smaller size and higher metabolic rate, which may increase their exposure and absorption of these contaminants [24,43,]. This susceptibility is further exacerbated by the fact that children often consume more food relative to their body weight than adults, making them more vulnerable to the effects of these contaminants [44].

Table 5: Estimated Daily Intake (kgd^{-1}) of Contaminants in North Eastern States

Status	HMs	RDI	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean ± SE
Adamawa State											
Children	As	0.13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Cd	0.06	0.0000	0.0000	2.49E-7	0.0000	2.49E-7	0.0000	0.0000	0.0000	2.49E-7 ± 0.00
	Cr	0.02	4.37E-6	3.37E-6	3.63E-6	4.12E-6	4.62E-6	4.12E-6	5.36E-6	5.99E-6	4.45E-6 ± 0.00

	Pb	0.21	5.61E-6	1.75E-6	1.50E-6	1.11E-5	1.25E-5	9.98E-6	5.36E-6	1.25E-5	7.54E-6 ± 0.00
Adults	As	0.13	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	Cd	0.06	0.0000	0.0000	2.44E-7	0.0000	2.44E-7	0.0000	0.0000	0.0000	2.44E-7 ± 0.00
	Cr	0.02	4.26E-6	3.29E-6	3.53E-6	4.02E-6	4.51E-6	4.02E-6	5.24E-6	5.85E-6	4.34E-6 ± 0.00
	Pb	0.21	5.48E-6	1.71E-6	1.46E-6	1.08E-5	1.22E-5	9.74E-6	5.24E-6	1.22E-5	7.35E-6 ± 0.00
Taraba State											
Children	As	0.13	1.19E-4	0.0000	8.96E-6	0.0000	0.0000	0.0000	0.0000	0.0000	1.60E-5 ± 0.00
	Cd	0.06	1.99E-6	0.0000	2.24E-6	3.73E-6	2.99E-6	2.49E-6	1.24E-6	2.24E-6	2.12E-6 ± 0.00
	Cr	0.02	2.64E-5	2.26E-5	2.26E-5	0.0000	2.24E-6	9.96E-6	0.0000	2.74E-6	1.08E-5 ± 0.00
	Pb	0.21	1.64E-5	9.96E-6	3.24E-6	7.97E-6	2.24E-6	7.47E-6	4.73E-6	1.02E-5	7.78E-6 ± 0.00
Adults	As	0.13	5.23E-5	0.0000	3.93E-6	0.0000	0.0000	0.0000	0.0000	0.0000	7.03E-6 ± 0.00
	Cd	0.06	8.73E-7	0.0000	9.82E-7	1.64E-6	1.31E-6	1.09E-6	5.46E-7	9.82E-7	9.28E-7 ± 0.00
	Cr	0.02	1.16E-5	9.93E-6	9.93E-6	0.0000	9.82E-7	4.36E-7	0.0000	1.20E-6	4.26E-6 ± 0.00
	Pb	0.21	7.20E-6	4.36E-6	1.42E-6	3.49E-6	9.82E-7	3.27E-6	2.07E-6	4.47E-6	1.12E-5 ± 0.00

Table 6: Estimated Daily Intake (kgd^{-1}) of Contaminants in North Western States

Status	HMs	RDI	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean ± SE
Jigawa State											
Children	As	0.13	0.0000	0.0000	0.0000	0.0000	3.09E-5	2.15E-4	0.0000	4.98E-5	3.40E-5 ± 0.00
	Cd	0.06	0.0000	0.0000	1.99E-6	2.99E-6	4.98E-7	4.98E-7	4.98E-7	9.96E-7	9.34E-7 ± 0.00
	Cr	0.02	9.96E-6	7.72E-6	9.71E-6	9.71E-6	1.02E-5	9.46E-6	1.07E-5	1.29E-5	1.00E-5 ± 0.00
	Pb	0.21	1.74E-5	1.42E-5	9.21E-6	1.57E-5	1.12E-5	1.37E-5	8.96E-6	1.64E-5	1.33E-5 ± 0.00
Adults	As	0.13	0.0000	0.0000	0.0000	0.0000	1.35E-5	9.40E-5	0.0000	2.18E-5	1.62E-5 ± 0.00
	Cd	0.06	0.0000	0.0000	8.73E-7	1.31E-6	2.18E-7	2.18E-7	2.18E-7	4.36E-7	4.09E-7 ± 0.00
	Cr	0.02	4.36E-6	3.38E-6	4.26E-6	4.26E-6	4.47E-6	4.15E-6	4.69E-6	5.67E-6	4.41E-6 ± 0.00
	Pb	0.21	7.64E-6	6.22E-6	4.04E-6	6.87E-6	4.91E-6	6.00E-6	3.93E-6	7.20E-6	5.85E-6 ± 0.00
Kano State											
Children	As	0.13	0.0000	4.18E-5	9.62E-5	1.04E-4	2.79E-5	6.70E-5	9.96E-6	8.96E-5	5.46E-5 ± 0.00
	Cd	0.06	9.96E-7	1.99E-6	1.49E-6	1.49E-6	9.96E-7	7.47E-7	9.96E-7	1.74E-6	1.31E-6 ± 0.00
	Cr	0.02	1.67E-5	1.54E-5	1.82E-5	1.87E-5	1.99E-5	2.09E-5	1.97E-5	2.26E-5	1.90E-5 ± 0.00
	Pb	0.21	5.97E-6	1.52E-5	1.59E-5	7.22E-6	8.71E-6	1.12E-5	1.27E-5	7.47E-6	1.05E-5 ± 0.00
Adults	As	0.13	0.0000	1.83E-5	3.03E-5	4.55E-5	1.22E-5	2.93E-5	4.36E-6	3.93E-5	2.24E-5 ± 0.00
	Cd	0.06	4.36E-7	8.73E-7	6.55E-7	6.55E-7	4.36E-7	3.27E-7	4.36E-7	7.64E-7	5.73E-7 ± 0.00
	Cr	0.02	7.31E-6	6.76E-6	7.97E-6	8.18E-6	8.73E-6	9.17E-6	8.62E-6	9.93E-6	8.33E-6 ± 0.00
	Pb	0.21	2.62E-6	6.66E-6	6.98E-6	3.16E-6	3.82E-6	4.91E-6	5.56E-6	3.27E-6	4.62E-6 ± 0.00

Non-Cancer Risks

This study assessed the non-cancer risks associated with consumption of heavy metal contaminated vegetables using the HQ and HI. In Northeastern states (table 7), Adamawa State, revealed that HQ values for children were notably low, with As at 0.00 and other heavy metals like Cd (4.98E-4), Cr (8.89E-4), and Pb (2.15E-3) presenting minimal risk of less than 1. The HI for both children and adults in Adamawa was low, with values of 3.20E-3 and 2.92E-3, confirming minimal non-cancer health risks. On the other hand, Taraba State showed elevated levels of contamination, especially in children with As having the highest HQ at 5.33E-1, followed by Cd (9.83E-2) and Cr (2.15E-3), the HI reached 7.22E-1, suggesting a potential health risk. Although adults had lower exposure, the higher HQ values for As were 2.34E-2, followed by Cd (1.88E-3) and Cr (8.58E-4) indicating that health risks were still a concern. The HI values for Taraba state were also notably higher, with children having a HI of 7.22E-1, and adults 2.84E-2.

In contrast, the Northwestern states of Jigawa and Kano (table 8) showed HQ and HI values all within the safe range of less than 1. In Jigawa, the HQ values for children were 1.23E-1 for As, 1.87E-3 for Cd, 2.00E-3 for Cr, and 3.81E-3 for Pb, while adults showed lower HQ values of 5.38E-2 for As, 8.19E-4 for Cd, 8.81E-4 for Cr, and 1.17E-3 for Pb. The overall HI values for children was 1.31E-1, and for adults, it was 5.66E-2, indicating a low health risk. Similarly, in Kano, HQ values for children were 1.81E-1 for As, 3.98E-2 for Cd, 3.80E-3 for Cr, and 3.00E-3 for Pb, with a HI of 1.91E-1. For adults, the HQ values ranged from 1.21E-1 for As to 1.31E-3 for Pb, resulting in a HI value of 6.18E-2.

These findings reinforce that the non-cancer risks in both states are within acceptable limits, highlighting that, despite regional variations in contamination, the overall dietary exposure to heavy metals poses minimal threat to public health. These regional variations in HQ and HI values across the states emphasize differing levels of health risks associated with consuming locally grown vegetables. While the risks in Adamawa, Taraba, and Jigawa states are moderate, the heightened risks in Kano require urgent attention. This trend has been reported by [23,24,43]. Children are particularly vulnerable to environmental contaminants due to both behavioral and physiological factors. Their higher food consumption relative to body weight increases their exposure to harmful substances, which can accumulate over time. Their tendencies to put their hands in their mouths further complicated their exposure [22,45].

Additionally, their increased outdoor activities expose them more to air pollution and pollutants from household dust and toys. Physiologically, their lower body fat percentage limits their ability to store contaminants, but their detoxification systems are less efficient, making them more prone to the adverse effects of these substances [22,45]. Furthermore, regional discrepancies in non-cancer health risks highlighted the importance of environmental and agricultural factors. In states like Jigawa and Kano, where Pb, Cd, and As are prevalent due to industrial pollution and poor waste management, vegetables pose a higher health risk compared to those from Adamawa and Taraba [43,44]. The soil in these areas contains higher concentrations of toxic elements, exacerbated by agricultural practices like untreated wastewater irrigation and the use of chemical fertilizers [46,47]. This cumulative exposure has significantly increased the health risks, especially for children, due to higher HQ values that suggest potential non-carcinogenic health effects from continuous vegetable consumption [24,44,47].

Table 7: Non-cancer Risks Due to Consumption of Contaminated Vegetables from North Eastern States

Health Risk	HMs	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean ± SD HQ
Adamawa State										
Children	As	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
	Cd	0.0000	0.0000	4.98E-4	0.0000	4.98E-4	0.0000	0.0000	0.0000	4.98E-4 ± 0.00
	Cr	8.74E-4	6.74E-4	7.24E-4	8.24E-4	9.24E-4	8.24E-4	1.07E-3	1.20E-3	8.89E-4 ± 0.00
	Pb	1.60E-3	5.00E-4	4.29E-4	3.17E-3	3.57E-3	2.85E-3	1.53E-3	3.57E-3	2.15E-3 ± 0.00
HI		**2.74E-3**	**1.17E-3**	**1.65E-3**	**3.99E-3**	**4.99E-3**	**3.67E-3**	**2.60E-3**	**4.77E-3**	**3.20E-3 ± 0.00**
Adults	As	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
	Cd	0.0000	0.0000	4.88E-4	0.0000	4.88E-4	0.0000	0.0000	0.0000	4.88E-4 ± 0.00
	Cr	8.52E-4	6.58E-4	7.06E-4	8.04E-4	9.02E-4	8.04E-4	1.05E-3	1.17E-3	8.68E-4 ± 0.00
	Pb	1.57E-3	4.88E-4	4.17E-4	3.09E-3	3.49E-3	2.78E-3	1.50E-4	3.49E-3	1.93E-3 ± 0.00

HI		**2.42E-3**	**1.15E-3**	**1.61E-3**	**3.89E-3**	**4.88E-3**	**3.58E-3**	**1.20E-3**	**4.66E-3**	**2.92E-3 + 0.00**
					Taraba State					
Children	As	3.9667	0.0000	2.99E-1	0.0000	0.0000	0.0000	0.0000	0.0000	5.33E-1 + 0.00
	Cd	3.98E-2	0.0000	4.48E-2	7.46E-2	5.98E-2	4.98E-1	2.48E-2	4.48E-2	9.83E-2 + 0.00
	Cr	5.30E-3	4.50E-3	4.50E-3	0.0000	4.00E-4	1.99E-3	0.0000	5.48E-4	2.15E-3 + 0.00
	Pb	4.69E-3	2.85E-3	9.26E-4	2.28E-3	6.40E-4	2.13E-3	1.35E-3	2.91E-3	1.37E-3 + 0.00
HI		**4.0123**	**7.35E-3**	**3.49E-1**	**7.69E-2**	**6.08E-2**	**5.02E-1**	**2.62E-2**	**4.83E-2**	**7.22E-1 + 0.00**
Adults	As	1.74E-1	0.0000	1.31E-2	0.0000	0.0000	0.0000	0.0000	0.0000	2.34E-2 + 0.00
	Cd	1.80E-3	0.0000	2.00E-3	3.30E-3	2.60E-3	2.20E-3	1.10E-3	2.00E-3	1.88E-3 + 0.00
	Cr	2.30E-3	2.00E-3	2.00E-3	0.0000	2.00E-4	1.00E-4	0.0000	2.00E-4	8.50E-4 + 0.00
	Pb	2.10E-3	1.20E-3	4.00E-4	1.00E-3	3.00E-4	9.00E-4	6.00E-4	1.30E-3	9.75E-4 + 0.00
HI		**1.91E-1**	**3.20E-3**	**1.75E-2**	**4.30E-3**	**3.10E-3**	**3.20E-3**	**1.70E-3**	**3.50E-3**	**2.84E-2 + 0.00**

Values are mean of three replicates; HQ = Hazard Quotient and HI = Hazard Index. Values less than 1 are considered safe

Table 8: Non-cancer Risks Due to Consumption of Contaminated Vegetables from North Western States

HQ	HMs	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean + SD HQ
					Jigawa State					
Children	As	0.0000	0.0000	0.0000	0.0000	1.03E-1	7.17E-1	0.0000	1.66E-1	1.23E-1 + 0.00
	Cd	0.0000	0.0000	3.98E-3	5.98E-3	9.96E-4	9.96E-4	9.96E-4	1.99E-3	1.87E-3 + 0.00
	Cr	1.99E-3	1.54E-3	1.94E-3	1.94E-3	2.04E-3	1.89E-3	2.14E-3	2.58E-3	2.00E-3 + 0.00
	Pb	4.97E-3	4.06E-3	2.63E-3	4.49E-3	3.20E-3	3.91E-3	2.56E-3	4.69E-3	3.81E-3 + 0.00
HI		**6.96E-3**	**5.60E-3**	**8.55E-3**	**1.24E-2**	**1.09E-1**	**7.24E-1**	**8.26E-3**	**1.75E-1**	**1.31E-1 + 0.00**
Adults	As	0.0000	0.0000	0.0000	0.0000	4.50E-2	3.13E-1	0.0000	7.27E-2	5.38E-2 + 0.00
	Cd	0.0000	0.0000	1.75E-3	2.62E-3	4.36E-4	4.36E-4	4.36E-4	8.72E-4	8.19E-4 + 0.00
	Cr	8.72E-4	6.76E-4	8.52E-4	8.52E-4	8.94E-4	8.30E-4	9.38E-4	1.13E-3	8.81E-4 + 0.00
	Pb	1.53E-3	1.24E-3	8.08E-4	1.37E-3	9.82E-4	1.20E0-3	7.86E-4	1.44E-3	1.17E-3 + 0.00
HI		**2.40E-3**	**1.92E-3**	**3.41E-3**	**4.48E-3**	**4.73E-2**	**3.15E-1**	**2.16E-3**	**7.61E-2**	**5.66E-2 + 0.00**
					Kano State					
Children	As	0.0000	1.39E-1	3.21E-1	3.47E-1	9.30E-2	2.23E-1	3.21E-2	2.99E-1	1.81E-1 + 0.00
	Cd	2.00E-3	4.00E-3	3.00E-3	3.00E-1	2.00E-3	1.50E-3	2.00E-3	3.50E-3	3.98E-2 + 0.00
	Cr	3.30E-3	3.10E-3	3.60E0-3	3.70E-3	4.00E-3	4.20E-3	4.00E-3	4.50E-3	3.80E-3 + 0.00
	Pb	1.70E-3	4.30E-3	4.50E-3	2.10E-3	2.50E-3	3.20E-3	3.60E-3	2.10E-3	3.00E-3 + 0.00
HI		7**.00E-3**	**1.51E-1**	**3.32E-1**	**3.56E-1**	**1.02E-1**	**2.32E-1**	**4.17E-2**	**3.09E-1**	**1.91E-1 + 0.00**
Adults	As	0.0000	6.10E-2	1.01E-1	1.52E-1	4.07E-2	9.77E-2	1.45E-2	1.31E-1	1.21E-1 + 0.00
	Cd	9.00E-4	1.70E-3	1.30E-3	1.30E-3	9.00E-4	7.00E-4	9.00E-4	1.50E-3	1.15E-3 + 0.00
	Cr	1.50E-3	1.40E-3	1.60E-3	1.60E-3	1.70E-3	1.80E-3	1.70E-3	2.00E-3	1.66E-3 + 0.00
	Pb	7.00E-4	1.90E-3	2.00E-3	9.00E-4	1.10E-3	1.40E-3	1.60E-3	9.00E-4	1.31E-3 + 0.00

HI		**3.10E-3**	**6.60E-2**	**1.06E-1**	**1.90E-2**	**4.44E-2**	**1.02E-1**	**1.87E-2**	**1.35E-1**	**6.18E-2 ± 0.00**

Values are mean of three replicates; HQ = Hazard Quotient and HI = Hazard Index. Values less than 1 are considered

Cancer Risks (CR) and Total Cancer Risks (TCR)

The CR and TCR associated with vegetable consumption from northeastern states were evaluated for both children and adults (table 9). In Adamawa state, the CR and TCR values for both demographics were within the safe limits of 10^{-4} to 10^{-6}, with children showing a CR values in the order of Cr > Pb > Cd > As, and adults displaying a similar pattern. For children, CR values for Cr, Pb, and Cd ranged from 2.46E-4 to 1.38E-4, 1.06E-4 to 1.28E-3, and 1.52E-6, respectively, while As showed no significant contribution. TCR for children in Adamawa was 2.61E-4, with a range from 3.52E-4 to 1.35E-4, while adults had TCR of 2.37E-4 with a range from 3.08E-4 to 1.50E-4. In Taraba state, CR values for both children and adults were relatively lower, with children's CR ranging from 1.74E-4 to 1.34E-4 for As, 7.56E-5 to 1.21E-5 for Cd, 1.08E-3 to 1.12E-4 for Cr, and 1.39E-4 to 1.90E-5 for Pb. Adults showed similar trends but with lower values overall. TCR for children in Taraba was 5.54E-4 with a range of 1.41E-3 to 4.78E-5, while for adults it was 2.30E-5, ranging from 6.21E-4 to 2.09E-5.

The CR and TCR associated with vegetable consumption in the northwestern states (table 10) showed significant differences between Jigawa and Kano states. In Jigawa state, CR values for both children and adults followed a consistent order, with Cr posing the highest risk (children: 4.11E-4; adults: 1.81E-4), followed by Pb, Cd, and As. The CR for children ranged from 3.23E-4 to 4.64E-5 for As, 1.82E-5 to 3.06E-6 for Cd, 5.24E-4 to 3.17E-4 for Cr, and 1.48E-4 to 7.62E-5 for Pb, while adults showed lower values across all contaminants. TCR in Jigawa was 5.86E-4 for children, with a range between 8.30E-4 and 4.38E-4, while adults had a TCR of 2.96E-4, ranging from 5.32E-4 to 1.92E-4. Contrastingly, Kano state presented lower CR values, with children showing the order of Cr (7.80E-4), Pb (8.99E-5), As (7.05E-5), and Cd (6.77E-6), while adults shows similarly lower values for all contaminants. TCR for children in Kano was 9.30E-4, ranging from 1.12E-3 to 7.42E-4, while adults had a mean TCR of 4.19E-4, with a range between 4.98E-4 and 3.25E-4.

The disparity in cancer risks associated with heavy metal contamination in vegetables from Adamawa, Jigawa, Taraba, and Kano states may be a reflection of regional environmental, agricultural, and industrial influences. In this study, vegetables from Adamawa, Jigawa, and Taraba states showed no significant cancer risks, with contamination levels falling within internationally accepted safety limits. However, vegetables in Kano state, particularly tomatoes, exhibited probable cancer risks, especially for children, which can be attributed to its proximity to mining areas, which are well known sources of contamination [27,48,49].

Kano stands as a region with significant contamination, particularly with As, Cd, and Pb, in vegetables grown around mining zones. Studies have shown that concentrations of these toxic metals in Kano vegetables often surpass the WHO's recommended limits, increasing the likelihood of carcinogenic effects. In contrast, Adamawa, Jigawa, and Taraba states have lower industrial and mining activities, resulting in relatively safe levels of heavy metals in vegetables. Although trace amounts of heavy metals are present, their concentrations remain within limits that pose minimal cancer risks to consumers [43,44,50,51,52].

Numerous studies have highlighted the ongoing concerns about cancer risks related to heavy metal contamination in northern Nigerian vegetables, especially for vulnerable groups like children. A research by [51] found that children consuming vegetables from these regions are at an elevated risk of exposure to carcinogens, especially Cd and Pb. Although the total cancer risk for children was within the EPA's safe range, concerns remain due to continuous exposure over time. Further studies, such as those by [47] and [52], confirmed that children face significantly higher cancer risks from contaminated vegetables than adults, with some areas reporting values exceeding safe thresholds for cumulative lifetime cancer risks.

Table 9: Cancer Risks Due to Consumption of Contaminated Vegetables from North Eastern States

CR	HMs	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean ± SD CR
Adamawa State										
Children	As	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
	Cd	0.0000	0.0000	1.52E-6	0.0000	1.52E-6	0.0000	0.0000	0.0000	1.52E-6 ± 0.00
	Cr	1.79E-4	1.38E-4	1.49E-4	1.69E-4	1.89E-4	1.69E-4	2.20E-4	2.46E-4	1.82E-4 ± 0.00
	Pb	4.77E-5	1.50E-5	1.28E-5	9.44E-5	1.06E-4	8.48E-5	4.56E-5	1.06E-4	5.21E-5 ± 0.00
TCR		**2.27E-4**	**1.53E-4**	**2.79E-4**	**2.63E-4**	**2.97E-4**	**2.54E-4**	**2.66E-4**	**3.52E-4**	**2.61E-4 ± 0.00**

Adults	As	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.00
	Cd	0.0000	0.0000	1.49E-6	0.0000	1.49E-6	0.0000	0.0000	0.0000	1.49E-6 ± 0.00
	Cr	1.75E-4	1.35E-4	1.45E-4	1.65E-4	1.85E-4	1.65E-4	2.15E-4	2.40E-4	1.78E-4 ± 0.00
	Pb	4.66E-5	1.45E-5	1.24E-5	9.18E-5	1.04E-4	8.28E-5	4.45E-5	1.04E-4	6.26E-5 ± 0.00
TCR		**2.22E-4**	**1.50E-4**	**1.59E-4**	**2.57E-4**	**2.90E-4**	**2.48E-4**	**2.60E-4**	**3.08E-4**	**2.37E-4 ± 0.00**
Taraba State										
Children	As	1.74E-4	0.0000	1.34E-4	0.0000	0.0000	0.0000	0.0000	0.0000	3.85E-5 ± 0.00
	Cd	1.21E-5	0.0000	1.37E-5	2.28E-5	1.82E-5	1.52E-5	7.56E-5	1.37E-5	2.14E-5 ± 0.00
	Cr	1.08E-3	9.27E-4	9.27E-4	0.0000	9.18E-5	4.08E-5	0.0000	1.12E-4	3.97E-4 ± 0.00
	Pb	1.39E-4	8.47E-5	2.75E-5	6.78E-5	1.90E-5	6.35E-5	4.02E-5	8.67E-5	6.61E-5 ± 0.00
TCR		**1.41E-3**	**1.01E-3**	**9.82E-4**	**9.06E-5**	**1.29E-4**	**1.20E-4**	**4.78E-5**	**2.12E-4**	**5.54E-4 ± 0.00**
Adults	As	7.85E-5	0.0000	5.90E-6	0.0000	0.0000	0.0000	0.0000	0.0000	1.71E-5 ± 0.00
	Cd	5.33E-6	0.0000	5.99E-6	1.00E-5	7.99E-6	6.65E-6	3.33E-6	5.99E-6	5.66E-6 ± 0.00
	Cr	4.76E-4	4.07E-4	4.07E-4	0.0000	4.03E-5	1.79E-5	0.0000	4.92E-5	1.75E-4 ± 0.00
	Pb	6.12E-5	3.71E-5	1.21E-5	2.97E-5	8.35E-6	2.78E-5	1.76E-5	3.80E-5	2.30E-5 ± 0.00
TCR		**6.21E-4**	**4.44E-4**	**4.31E-4**	**3.97E-5**	**5.66E-5**	**5.24E-5**	**2.09E-5**	**9.32E-5**	**2.30E-5 ± 0.00**

CR = Cancer Risk and TCR = Total Cancer Risk. Values in the range of $10^{-4} – 10^{-6}$ are safe

Table 10: Cancer Risks Due to Consumption of Contaminated Vegetables from North Western States

Cancer Risks	HMs	Cabbage	Carrot	Cucumber	Okra	Onion	Pepper	Scotch Bonnet	Tomato	Mean ± SD CR
Jigawa State										
Children	As	0.0000	0.0000	0.0000	0.0000	4.64E-5	3.23E-4	0.0000	7.47E-5	5.55E-5 ± 0.00
	Cd	0.0000	0.0000	1.21E-5	1.82E-5	3.04E-6	3.04E-6	3.04E-6	6.08E-6	5.69E-5 ± 0.00
	Cr	4.08E-4	3.17E-4	3.98E-4	3.98E-4	4.18E-4	3.88E-4	4.39E-4	5.24E-4	4.11E-4 ± 0.00
	Pb	1.48E-4	1.21E-4	7.83E-5	1.33E-4	9.52E-5	1.16E-4	7.62E-5	1.39E-4	1.13E-4 ± 0.00
TCR		**5.56E-4**	**4.38E-4**	**4.88E-4**	**5.49E-4**	**5.63E-4**	**8.30E-4**	**5.18E-4**	**7.44E-4**	**5.86E-4 ± 0.00**
Adults	As	0.0000	0.0000	0.0000	0.0000	2.03E-5	1.41E-4	0.0000	3.27E-5	2.43E-5 ± 0.00
	Cd	0.0000	0.0000	5.33E-6	7.99E-6	1.33E-6	1.33E-6	1.33E-6	2.82E-6	2.52E-6 ± 0.00
	Cr	1.79E-4	1.39E-4	1.75E-4	1.75E-4	1.83E-4	1.70E-4	1.92E-4	2.32E-4	1.81E-4 ± 0.00
	Pb	6.49E-5	5.29E-5	3.43E-5	5.84E-5	4.17E-5	5.10E-5	3.34E-5	6.12E-5	4.97E-5 ± 0.00
TCR		**2.44E-4**	**1.92E-4**	**5.23E-4**	**2.41E-4**	**2.46E-4**	**3.63E-4**	**2.27E-4**	**3.29E-4**	**2.96E-4 ± 0.00**
Kano State										
Children	As	0.0000	6.27E-5	1.44E-4	1.56E-4	4.19E-5	1.01E-5	1.49E-5	1.34E-4	7.05E-5 ± 0.00
	Cd	6.08E-6	1.21E-5	9.09E-6	9.09E-6	6.08E-6	4.56E-6	6.08E-6	1.06E-6	6.77E-6 ± 0.00
	Cr	6.85E-4	6.33E-4	7.46E-4	7.67E-4	8.16E-4	8.57E-4	8.08E-4	9.27E-4	7.80E-4 ± 0.00
	Pb	5.07E-5	1.29E-4	1.35E-4	6.14E-5	7.40E-5	9.52E-5	1.08E-4	6.35E-5	8.99E-5 ± 0.00
TCR		**7.42E-4**	**8.37E-4**	**9.04E-4**	**9.93E-4**	**9.38E-4**	**9.67E-4**	**9.37E-4**	**1.12E-3**	**9.30E-4 ± 0.00**
Adults	As	0.0000	2.75E-5	4.55E-5	6.83E-5	1.83E-5	4.40E-5	6.54E-6	5.90E-5	3.36E-5 ± 0.00

	Cd	2.66E-6	5.33E-6	4.00E-6	4.00E-6	2.66E-6	2.00E-6	2.66E-6	4.66E-6	2.97E-6 ± 0.00
	Cr	3.00E-4	2.77E-4	3.27E-4	3.35E-4	3.58E-4	3.76E-4	3.53E-4	4.07E-4	3.42E-4 ± 0.00
	Pb	2.23E-5	5.66E-5	5.93E-5	2.69E-5	3.25E-5	4.17E-5	4.73E-5	2.78E-5	3.93E-5 ± 0.00
TCR		**3.25E-4**	**3.66E-4**	**4.36E-4**	**4.34E-4**	**4.11E-4**	**4.69E-4**	**4.10E-4**	**4.98E-4**	**4.19E-4 ± 0.00**

CR = Cancer Risk and TCR = Total Cancer Risk. Values in the range of 10^{-4} – 10^{-6} are safe

IV. Conclusion

This study reveals that vegetables from Jigawa, Kano, and Taraba States show elevated levels of As, Cd, Cr, and Pb, with contamination levels often surpassing WHO safety limits. While the Estimated Daily Intake (EDI) from vegetable consumption generally remains safe, children are disproportionately affected, displaying higher exposure levels, which raises concerns about long-term health risks. Adamawa State, in contrast, presents negligible cancer risks, while Taraba shows higher risks, particularly for children, due to environmental pollution and unsafe agricultural practices. Kano, with its significant industrial activity and unsafe farming practices, stands out for its elevated cancer risk from contaminated vegetables, especially tomatoes. These findings therefore, underscore the need for stricter regulations on pesticide use, improved agricultural practices, and targeted health monitoring, particularly for vulnerable populations (children), to mitigate the risks associated with consumption of heavy metal contaminated vegetables.

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