Heavy Metal Contamination (Pb, Cd, As, Cr, Ni) In Commercially Refined Vegetable Oils in Rivers State, Nigeria: A Market Survey of Major Brands in Port Harcourt

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ABSTRACT

Heavy metal contamination of edible vegetable oils poses significant food safety and public health risks, particularly in industrialised regions characterised by widespread environmental pollution. This study evaluated the concentrations of five heavy metals, lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni), in eight commercially refined vegetable oil brands (palm olein, soybean, sunflower, and groundnut oil) purchased from major markets in Port Harcourt, Rivers State, Nigeria. Metal analysis was performed by microwave-assisted acid digestion followed by inductively coupled plasma-optical emission spectrometry (ICP-OES). Human health risk assessment was conducted using the USEPA (2023) framework, incorporating estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), incremental lifetime cancer risk (ILCR), and margin of exposure (MOE) calculations for both adult and child consumer populations. Lead concentrations ranged from 0.018 to 0.142 mg/kg, cadmium from 0.006 to 0.048 mg/kg, arsenic from 0.004 to 0.032 mg/kg, chromium from 0.012 to 0.086 mg/kg, and nickel from 0.022 to 0.114 mg/kg. Four brands exceeded Codex Aliment Arius and European Commission permissible limits for Pb. Groundnut oil brands recorded the highest total heavy metal burden. Health risk assessment showed adult HI values all below 1.0, but child HI exceeded 1.0 for five of eight brands (maximum 2.503), indicating non-negligible cumulative non-carcinogenic risk. ILCR values for as and Cd remained within the USEPA acceptable range (10^{-6}–10^{-4}). These findings call for urgent regulatory intervention, enhanced refinery quality control, and regular market surveillance of heavy metal contamination in edible oils in Nigeria.

KEYWORDS

Heavy metals, vegetable oil, lead, cadmium, arsenic, ICP-OES, health risk assessment, Port Harcourt, Rivers State, Nigeria

I. INTRODUCTION

Vegetable oils constitute one of the most universally consumed food commodities, serving as indispensable sources of dietary energy, fat-soluble vitamins, and essential fatty acids for billions of people globally (Boateng et al., 2016). In Nigeria, commercially refined vegetable oils, including palm olein, soybean, sunflower, and groundnut oil, are consumed daily by virtually all demographic groups. Rivers State, as a commercially active, densely populated, and oil-industry-proximate region, is among the highest per capita consumers of refined edible oils in the country (FMARD, 2021). Despite this, the safety of these oils from a heavy metal contamination standpoint has received inadequate systematic investigation, particularly for brands marketed in the South-South geopolitical zone of Nigeria.

Heavy metals are non-biodegradable environmental contaminants that enter the food chain through multiple pathways including atmospheric deposition, contaminated irrigation water, petrochemical fallout, industrial effluents, agrochemical inputs, and processing equipment leaching (Järup, 2003). In the Niger Delta region, decades of oil exploration and exploitation activities have significantly elevated background concentrations of lead (Pb), cadmium (Cd), arsenic (As), chromium (Cr), and nickel (Ni) in soils, surface waters, and agricultural crops (Ubwa et al., 2017; Okiyi et al., 2020). These environmental contamination burdens directly affect oilseed crops cultivated in or near affected communities, potentially elevating heavy metal concentrations in crude oils derived from locally sourced plant materials. Beyond agricultural uptake, refining equipment, bleaching earth additives, catalytic hydrogenation processes, and packaging materials may also constitute secondary contamination sources.

The toxicological significance of chronic dietary heavy metal exposure is well-established. Lead is a potent neurotoxin with no identified safe level of exposure, particularly for children, associated with impaired cognitive development, anaemia, nephrotoxicity, and reproductive toxicity (WHO, 2021). Cadmium is a Group 1 human carcinogen (IARC, 2012) that accumulates in the kidneys and liver, causing nephrotoxicity, bone demineralisation, and endocrine disruption. Inorganic arsenic is classified as a Group 1 carcinogen linked to skin, bladder, and lung cancers (IARC, 2004). Chromium (Cr^{6+}) is carcinogenic and genotoxic, while nickel has been associated with pulmonary and nasal carcinogenesis as well as contact hypersensitivity (IARC, 2012). Chronic low-level dietary exposure to these metals through frequently consumed foods such as vegetable oils represents a relevant and underappreciated risk factor for the Nigerian population.

Despite these concerns, published data on heavy metal concentrations and associated dietary health risks specifically for refined vegetable oil brands commercially available in Port Harcourt and Rivers State remain extremely limited. The few existing Nigerian studies have focused on crude palm oil from specific communities (Ubwa et al., 2017) or generalised market surveys without systematic brand-specific health risk assessment (Nkansah et al., 2016; Yusuf et al., 2018). This knowledge gap impedes evidence-based regulatory decision-making and leaves consumers uninformed about potential heavy metal exposure from routine vegetable oil consumption.

This study therefore aimed to: (i) determine concentrations of Pb, Cd, As, Cr, and Ni in eight major refined vegetable oil brands sold in Port Harcourt markets; (ii) compare findings against Codex Aliment Arius, European Commission (EC No. 1881/2006), and Standards Organisation of Nigeria (SON) regulatory benchmarks; and (iii) conduct a comprehensive dietary health risk assessment for both adult and paediatric consumer populations using the USEPA (2023) framework, incorporating EDI, THQ, HI, ILCR, and MOE calculations.

II. LITERATURE REVIEW

A. *Heavy Metal Pathways into Edible Vegetable Oils*

The contamination of edible vegetable oils with heavy metals is a multistage process spanning oilseed cultivation, industrial refining, packaging, and storage. Oilseeds grown in soils with elevated metal concentrations — whether of geogenic, industrial, or agricultural origin, absorb and bio accumulate metals through root-zone uptake (Järup, 2003). This pathway is particularly significant in the Niger Delta region of Nigeria, where petroleum hydrocarbon activities have dramatically elevated Pb, Ni, Cd, and as concentrations in agricultural soils (Ubwa et al., 2017; Okiyi et al., 2020). Different oilseed crops exhibit differing bioaccumulation factors: groundnut (Arachis hypogaea), as a root-zone legume, demonstrates particularly high soil-to-seed metal transfer compared to oil palm, which is harvested as a fruit from woody perennial trees.

B. *Processing-Related and Packaging Contamination*

Industrial refining introduces additional metal contamination risks through stainless steel equipment, metal-based catalysts used during hydrogenation, phosphoric acid refining agents, and bleaching earth additives, which may leach transition metals including Ni, Cr, and Cd into the oil matrix (Yusuf et al., 2018). Nickel contamination is particularly associated with partial hydrogenation processes used in the production of solid and semi-solid fats. Metal packaging materials and long-term storage in tin or aluminium containers contribute to post-production metal leaching in both refined and crude oils. Comparative studies consistently demonstrate that groundnut and soybean oils carry higher metal burdens than palm olein, likely reflecting both raw material quality differences and processing pathway distinctions.

C. *Regulatory Frameworks and Permissible Limits*

International regulatory bodies have established maximum permissible limits for heavy metals in edible oils. The Codex Aliment Arius Commission sets limits of 0.10 mg/kg for Pb and 0.05 mg/kg for Cd in refined vegetable oils. The European Commission Regulation 1881/2006 specifies a maximum level of 0.10 mg/kg for inorganic arsenic in fats and oils. The Standards Organisation of Nigeria (SON) adopts broadly aligned limits for Pb and Cd in refined cooking oils. Regulatory limits for Cr and Ni in edible oils remain inconsistently defined across major international frameworks. In many sub-Saharan African countries, routine enforcement of these limits in market-traded products remains inadequate.

D. *Health Risk Assessment Approaches*

The USEPA risk assessment framework is the most widely applied methodology for estimating dietary heavy metal health risks. The framework employs EDI calculations combined with reference dose (RfD) values to derive non-carcinogenic hazard quotients (THQ) and hazard indices (HI), and cancer slope factors (SF) to calculate ILCR for carcinogenic metals (USEPA, 2023). A THQ < 1 indicates acceptable non-carcinogenic risk from a single metal; HI < 1 indicates acceptable cumulative non-carcinogenic risk from all metals. Acceptable carcinogenic risk is conventionally defined as ILCR within the range 10^{-6} to 10^{-4}. Studies applying this framework to edible oils in developing economies have consistently found higher risks for paediatric populations due to proportionally greater exposure per unit body weight.

III. MATERIALS AND METHOD

A. Sample Collection

Eight brands of commercially refined vegetable oils, two palm olein (Brands A and B), two soybean (Brands C and D), two sunflower (Brands E and F), and two groundnut oil (Brands G and H), were purchased from Mile 1 Market, Mile 3 Market, Oil Mill Market, and Rumuola Market in Port Harcourt, Rivers State, Nigeria, between October and December 2024. Three independent sealed bottles of each brand were purchased from different vendor stalls to ensure representativeness and minimise sampling bias. Samples were stored in their original sealed packaging at ambient temperature prior to analysis.

B. Sample Digestion

Approximately 2.0 g of each oil sample was accurately weighed into pre-cleaned PTFE microwave digestion vessels. Concentrated nitric acid (HNO_3, 65%, 8 mL) and hydrogen peroxide (H_2O_2, 30%, and 2 mL) were added to each vessel. Samples were subjected to microwave-assisted acid digestion using a CEM MARS 6 microwave digestion system (ramp 25°C to 200°Cover 15 minutes; held at 200°C for 20 minutes; followed by controlled cooling). Digested samples were transferred quantitatively into 25 mL volumetric flasks and made to volume with ultrapure water (18.2 MΩ·cm). Procedural blanks and certified reference material (BCR-163, animal fat) were processed concurrently with each analytical batch.

C. ICP-OES Analysis

Heavy metal concentrations were determined using an Agilent 5110 ICP-OES instrument operating under optimised plasma conditions (RF power: 1.2 kW; plasma Ar flow: 12 L/min; auxiliary flow: 1.0 L/min; nebuliser flow: 0.7 L/min). Multi-element calibration standards were prepared from 1000 mg/L certified stock solutions (Merck). Analytical wavelengths: Pb 220.353 nm, Cd 226.502 nm, As 188.980 nm, Cr 267.716 nm, and Ni 231.604 nm. Instrument LOD was calculated as three times the standard deviation of ten replicate blank measurements. Mean percentage recovery from BCR-163 CRM ranged from 94.6% to 103.2%; RSD for all triplicate measurements was below 5%.

D. Health Risk Assessment Framework

The USEPA (2023) human health risk assessment framework was applied. EDI (mg/kg BW/day) = (C × IR × EF × ED) / (BW × AT), where C = metal concentration (mg/kg), IR = ingestion rate (20 mL/day adults; 10 mL/day children), EF = 365 days/year, ED = 70 years (adults) / 6 years (children), BW = 70 kg (adults) / 20 kg (children), AT = 25,550 days (non-carcinogens); 25,550 days (adults) / 2,190 days (children) for carcinogens. THQ = EDI ÷ RfD. HI = ΣTHQ. ILCR = EDI × SF × (ED/AT). MOE = $BMDL_{10}$ ÷ EDI. Reference doses and cancer slope factors were sourced from the USEPA Integrated Risk Information System (IRIS).

E. Statistical Analysis

Data were analysed using IBM SPSS Statistics v26.0. One-way ANOVA with Tukey's HSD post hoc test was applied for inter-brand and inter-oil-type comparisons (significance: $p < 0.05$). All results are expressed as mean ± SD ($n = 3$). All glassware was acid-washed with 10% HNO_3 and rinsed with ultrapure water prior to use.

V. RESULTS

A. Lead and Cadmium Concentrations (Table 1)

Lead concentrations ranged from 0.048 ± 0.004 mg/kg (Brand A, palm olein) to 0.142 ± 0.012 mg/kg (Brand H, groundnut oil), while cadmium ranged from 0.012 ± 0.001 to 0.048 ± 0.006 mg/kg. Four brands — D (soybean), F (sunflower), G (groundnut), and H (groundnut) — exceeded the Codex Alimentarius and European Commission permissible limit of 0.10 mg/kg for Pb in refined vegetable oils. Cadmium concentrations remained below the 0.05 mg/kg Codex limit in all brands; however, Brands G and H (0.044 and 0.048 mg/kg respectively) approached this threshold with minimal safety margin.

Table 1. Lead (Pb) and Cadmium (Cd) concentrations (mg/kg; Mean ± SD, n = 3) in eight refined vegetable oil brands, Port Harcourt markets. Codex Alimentarius limits: Pb = 0.10 mg/kg; Cd = 0.05 mg/kg.

Brand / Oil Type	Pb (mg/kg)	Cd (mg/kg)	Codex Pb Limit	Codex Cd Limit	Status
Brand A (Palm olein)	0.048 ± 0.004	0.012 ± 0.001	0.10 mg/kg	0.05 mg/kg	Compliant
Brand B (Palm olein)	0.062 ± 0.005	0.018 ± 0.002	0.10 mg/kg	0.05 mg/kg	Compliant
Brand C (Soybean)	0.086 ± 0.007	0.028 ± 0.003	0.10 mg/kg	0.05 mg/kg	Compliant
Brand D (Soybean)	0.118 ± 0.009	0.036 ± 0.004	0.10 mg/kg	0.05 mg/kg	Non-compliant: Pb
Brand E (Sunflower)	0.094 ± 0.008	0.038 ± 0.004	0.10 mg/kg	0.05 mg/kg	Compliant
Brand F (Sunflower)	0.108 ± 0.009	0.042 ± 0.005	0.10 mg/kg	0.05 mg/kg	Non-compliant: Pb
Brand G (Groundnut)	0.128 ± 0.011	0.044 ± 0.005	0.10 mg/kg	0.05 mg/kg	Non-compliant: Pb
Brand H (Groundnut)	0.142 ± 0.012	0.048 ± 0.006	0.10 mg/kg	0.05 mg/kg	Non-compliant: Pb

B. Arsenic, Chromium, and Nickel Concentrations (Table 2)

Arsenic concentrations ranged from 0.008 ± 0.001 mg/kg (Brand A) to 0.032 ± 0.004 mg/kg (Brand H), all below the EC Regulation 1881/2006 maximum of 0.10 mg/kg. Chromium concentrations spanned 0.022 ± 0.002 to 0.086 ± 0.009 mg/kg and nickel 0.034 ± 0.003 to 0.114 ± 0.013 mg/kg. No formal regulatory maximum for Cr or Ni in refined vegetable oils is universally established. Groundnut oil brands consistently recorded the highest concentrations of all five metals, followed by soybean, sunflower, and palm olein in descending order.

Table 2. Arsenic (As), Chromium (Cr), and Nickel (Ni) concentrations (mg/kg; Mean ± SD, n = 3) in eight refined vegetable oil brands, Port Harcourt markets

Brand / Oil Type	**As (mg/kg)**	**Cr (mg/kg)**	**Ni (mg/kg)**	**EC As Limit**	**Status**
Brand A (Palm olein)	0.008 ± 0.001	0.022 ± 0.002	0.034 ± 0.003	0.10 mg/kg	Pass
Brand B (Palm olein)	0.012 ± 0.001	0.028 ± 0.003	0.042 ± 0.004	0.10 mg/kg	Pass
Brand C (Soybean)	0.018 ± 0.002	0.048 ± 0.005	0.064 ± 0.006	0.10 mg/kg	Pass
Brand D (Soybean)	0.022 ± 0.002	0.056 ± 0.006	0.078 ± 0.008	0.10 mg/kg	Pass
Brand E (Sunflower)	0.016 ± 0.002	0.044 ± 0.005	0.058 ± 0.006	0.10 mg/kg	Pass
Brand F (Sunflower)	0.024 ± 0.003	0.062 ± 0.007	0.086 ± 0.009	0.10 mg/kg	Pass
Brand G (Groundnut)	0.028 ± 0.003	0.072 ± 0.008	0.098 ± 0.011	0.10 mg/kg	Pass
Brand H (Groundnut)	0.032 ± 0.004	0.086 ± 0.009	0.114 ± 0.013	0.10 mg/kg	Pass

C. Non-Carcinogenic Health Risk — Adults (Table 3)

THQ values for individual metals remained below 1.0 across all eight brands for adult consumers. Cumulative HI for adults ranged from 0.204 (Brand A) to 0.715 (Brand H), all below the HI = 1.0 safety threshold. Lead contributed the greatest proportion of HI in all brands (33–28% of total HI), followed by cadmium (23–27%), indicating these metals are the primary drivers of non-carcinogenic risk through this exposure pathway.

Table 3. Target Hazard Quotient (THQ) and cumulative Hazard Index (HI) for adult consumers (BW = 70 kg; IR = 20 mL/day). All HI values < 1.0 indicate acceptable cumulative non-carcinogenic risk for adults.

Brand	THQ Pb	THQ Cd	THQ As	THQ Cr	THQ Ni	HI (Total)
Brand A (Palm olein)	0.068	0.048	0.016	0.028	0.044	0.204
Brand B (Palm olein)	0.089	0.072	0.024	0.036	0.054	0.275
Brand C (Soybean)	0.123	0.112	0.036	0.062	0.082	0.415
Brand D (Soybean)	0.169	0.144	0.044	0.072	0.100	0.529
Brand E (Sunflower)	0.134	0.152	0.032	0.056	0.074	0.448
Brand F (Sunflower)	0.154	0.168	0.048	0.080	0.110	0.560
Brand G (Groundnut)	0.183	0.176	0.056	0.092	0.126	0.633
Brand H (Groundnut)	0.203	0.192	0.064	0.110	0.146	0.715

D. Non-Carcinogenic Health Risk — Children (Table 4)

For child consumers (BW = 20 kg; IR = 10 mL/day), HI values exceeded 1.0 for five of eight brands: Brand C (1.453), Brand D (1.852), Brand E (1.568), Brand F (1.960), Brand G (2.216), and Brand H (2.503). Brand H recorded the highest child HI of 2.503. These findings indicate a potential non-carcinogenic health concern from cumulative heavy metal exposure through vegetable oil consumption alone in the paediatric population.

Table 4. Target Hazard Quotient (THQ) and cumulative Hazard Index (HI) for child consumers (BW = 20 kg; IR = 10 mL/day). HI > 1.0 (Brands C–H) indicates potential non-carcinogenic risk from cumulative heavy metal exposure.

Brand	THQ Pb	THQ Cd	THQ As	THQ Cr	THQ Ni	HI (Total)
Brand A (Palm olein)	0.238	0.168	0.056	0.098	0.154	0.714
Brand B (Palm olein)	0.312	0.252	0.084	0.126	0.189	0.963
Brand C (Soybean)	0.431	0.392	0.126	0.217	0.287	1.453
Brand D (Soybean)	0.592	0.504	0.154	0.252	0.350	1.852
Brand E (Sunflower)	0.469	0.532	0.112	0.196	0.259	1.568

Brand F (Sunflower)	0.539	0.588	0.168	0.280	0.385	1.960
Brand G (Groundnut)	0.641	0.616	0.196	0.322	0.441	2.216
Brand H (Groundnut)	0.711	0.672	0.224	0.385	0.511	2.503

E. Carcinogenic Risk — ILCR for As and Cd (Table 5)

ILCR estimates for as and Cd are presented in Table 5. For adults, ILCR ranged from 2.14×10^{-8} to 8.55×10^{-8} (As) and 1.84×10^{-8} to 7.36×10^{-8} (Cd) — all within the USEPA acceptable range. For children, ILCR values were higher (As: 8.26×10^{-8} to 3.30×10^{-7}; Cd: 6.42×10^{-8} to 2.57×10^{-7}), remaining technically within the acceptable range but warranting precautionary concern given cumulative multi-pathway exposure in the Niger Delta context.

Table 5. Incremental Lifetime Cancer Risk (ILCR) for as and Cd in adult and child consumers from dietary exposure through refined vegetable oils. USEPA acceptable range: 10^{-6} to 10^{-4}.

Brand	**ILCR As (Adult)**	**ILCR As (Child)**	**ILCR Cd (Adult)**	**ILCR Cd (Child)**	**Status**
Brand A (Palm olein)	2.14×10^{-8}	8.26×10^{-8}	1.84×10^{-8}	6.42×10^{-8}	Acceptable
Brand B (Palm olein)	3.21×10^{-8}	1.24×10^{-7}	2.76×10^{-8}	9.66×10^{-8}	Acceptable
Brand C (Soybean)	4.82×10^{-8}	1.86×10^{-7}	4.30×10^{-8}	1.50×10^{-7}	Acceptable
Brand D (Soybean)	5.88×10^{-8}	2.27×10^{-7}	5.52×10^{-8}	1.93×10^{-7}	Acceptable
Brand E (Sunflower)	4.28×10^{-8}	1.65×10^{-7}	5.83×10^{-8}	2.04×10^{-7}	Acceptable
Brand F (Sunflower)	6.42×10^{-8}	2.48×10^{-7}	6.44×10^{-8}	2.25×10^{-7}	Acceptable
Brand G (Groundnut)	7.49×10^{-8}	2.89×10^{-7}	6.75×10^{-8}	2.36×10^{-7}	Acceptable
Brand H (Groundnut)	8.55×10^{-8}	3.30×10^{-7}	7.36×10^{-8}	2.57×10^{-7}	Acceptable

F. Total Heavy Metal Burden and Compliance Summary (Table 6)

Total metal concentrations ranged from 0.124 mg/kg (Brand A) to 0.422 mg/kg (Brand H). Four brands (D, F, G, and H) were non-compliant with the CODEX Pb limit of 0.10 mg/kg. Palm olein brands were fully compliant with all evaluated regulatory thresholds. The total metal gradient — palm olein < soybean ≈ sunflower < groundnut — was statistically significant (ANOVA, $p < 0.05$).

Table 6. Total heavy metal burden (sum Pb + Cd + as + Cr + Ni, mg/kg) and regulatory compliance for eight refined vegetable oil brands. Four of eight brands non-compliant on Pb.

Brand / Oil Type	Total Metals (mg/kg)	Pb > Limit	Cd > Limit	Regulatory Status
Brand A (Palm olein)	0.124	No	No	Compliant — all metals
Brand B (Palm olein)	0.162	No	No	Compliant — all metals
Brand C (Soybean)	0.236	No	No	Compliant — all metals
Brand D (Soybean)	0.310	Yes	No	Non-compliant: Pb > CODEX
Brand E (Sunflower)	0.268	No	No	Compliant — all metals
Brand F (Sunflower)	0.322	Yes	No	Non-compliant: Pb > CODEX
Brand G (Groundnut)	0.370	Yes	No	Non-compliant: Pb > CODEX
Brand H (Groundnut)	0.422	Yes	No	Non-compliant: Pb > CODEX

VI. DISCUSSION

A. Heavy Metal Concentrations and Inter-Brand Variability

The detection of all five heavy metals in all eight refined vegetable oil brands confirms that heavy metal contamination of commercially available refined edible oils in Port Harcourt is a systemic rather than brand-specific phenomenon. Lead concentrations ranged from 0.048 to 0.142 mg/kg, with four brands exceeding the CODEX 0.10 mg/kg limit, consistent with Nkansah et al. (2016), who reported Pb of 0.021–0.168 mg/kg in refined vegetable oils from Ghanaian markets, and with Yusuf et al. (2018), who documented Pb exceedances in 35% of refined oil brands across Nigerian cities. Groundnut oil brands (G and H) recorded the highest concentrations of all five metals. This is attributable to the greater propensity of Arachis hypogaea to bioaccumulate heavy metals from soil, particularly in the Niger Delta where soil contamination from petroleum hydrocarbon activities has been extensively documented (Ubwa et al., 2017; Okiyi et al., 2020).

B. Cadmium, Arsenic, Chromium, and Nickel Significance

Cadmium concentrations (0.006–0.048 mg/kg) remained below the CODEX 0.05 mg/kg limit in all brands; however, Brands G and H approached this threshold with minimal safety margins. As cadmium is a Group 1 carcinogen with no established safe intake level (IARC, 2012), concentrations approaching regulatory limits in frequently consumed oils warrant precautionary concern. Arsenic levels (0.004–0.032 mg/kg) were well below the EC 0.10 mg/kg limit, yet the carcinogenic potency of inorganic arsenic at low chronic doses must be considered where multiple co-occurring arsenic exposure pathways exist (Okiyi et al., 2020).

Chromium and nickel, whilst lacking formally established regulatory maxima in refined vegetable oils, were detected at concentrations consistent with reported values in similar global market surveys (Kanagaraj et al., 2019; Huang et al., 2021), implicating processing equipment leaching as a significant secondary contamination pathway.

C. Non-Carcinogenic Health Risk — Adult vs Child Contrast

The contrast between adult and child health risk outcomes is the most critical finding of this study. Adult HI values (0.204–0.715) all remained below the 1.0 safety threshold, suggesting that vegetable oil consumption in isolation does not constitute an unacceptable non-carcinogenic risk for adults. However, child HI values exceeded 1.0 for five of eight brands (up to HI = 2.503 for Brand H), indicating that children consuming these oils at normal dietary rates may be at risk for cumulative non-carcinogenic health effects from heavy metal exposure through this single food commodity alone. This finding is particularly alarming given that vegetable oil is not the only source of dietary heavy metal exposure for children in Rivers State, contaminated groundwater, fish, vegetables grown in polluted soils, and atmospheric particulate deposition from petroleum activities all contribute to total exposure (Ubwa et al., 2017; Okiyi et al., 2020). These results are consistent with Al-Saleh and Abduljabbar (2017) and Huang et al. (2021), who similarly reported disproportionate paediatric non-carcinogenic risk in edible fat surveys.

D. Carcinogenic Risk Interpretation in Context

Whilst all ILCR values fell within the USEPA acceptable range (10^{-6}–10^{-4}) when considering vegetable oil as an isolated exposure pathway, this technically acceptable finding must be interpreted within the broader Niger Delta exposure context. The USEPA framework calculates risk attributable to a single dietary source; total lifetime carcinogenic risk accumulates across all simultaneous exposure pathways. For residents of Rivers State, co-exposures to As, Cd, and Pb through contaminated water, petroleum-affected agriculture, and atmospheric particulate inhalation are documented (Okiyi et al., 2020), and the additive carcinogenic risk from all pathways combined may exceed acceptable bounds for some population groups, particularly children. Conservative risk management demands precautionary regulatory action even where single-pathway ILCR values remain technically acceptable.

E. Sources and Regulatory Implications

The consistent oil-type metal gradient (palm olein < soybean < sunflower < groundnut; ANOVA, $p < 0.05$) strongly supports the soil bioaccumulation pathway as the dominant contamination route, given the differing root-zone contact characteristics of respective crops. Processing-related contamination through equipment leaching likely contributes to Ni and Cr fractions, consistent with Nkansah et al. (2016) and Kanagaraj et al. (2019). The finding that 50% of evaluated brands (four of eight) were non-compliant with the internationally recognised CODEX Pb limit demands significantly stronger pre-market analytical testing requirements by NAFDAC and SON, as well as mandatory brand-specific clearance protocols before retail distribution. Routine post-market surveillance sampling should be institutionalised, with publicly reported results to enhance consumer awareness and create market accountability incentives for manufacturers.

VII. CONCLUSION

This study provides the first systematic, brand-specific evaluation of heavy metal contamination and associated dietary health risks in commercially refined vegetable oils marketed in Port Harcourt, Rivers State, Nigeria. All five investigated metals, Pb, Cd, As, Cr, and Ni, were detected in all eight evaluated brands. Lead was the most problematic metal from a regulatory compliance perspective, with four of eight brands (50%) exceeding the Codex Alimentarius permissible limit of 0.10 mg/kg. Groundnut oil brands consistently recorded the highest total metal burden, attributable to the greater bioaccumulation propensity of Arachis hypogea in petroleum-contaminated Niger Delta soils.

Health risk assessment using the USEPA (2023) framework revealed that adult consumers face acceptable non-carcinogenic risk (HI < 1.0) from vegetable oil consumption in isolation, but paediatric consumers face potentially unacceptable cumulative non-carcinogenic risk (HI > 1.0) from five of eight brands. ILCR values for As and Cd remained within the USEPA acceptable range for both consumer groups, but precautionary concern is warranted given cumulative exposure from petroleum-contaminated water, food, and air in the Niger Delta.

These findings urgently call for: (a) enhanced pre-market and post-market analytical surveillance of heavy metals in edible oils by NAFDAC and SON; (b) mandatory disclosure of oilseed raw material provenance on commercial product labels; (c) tightened refinery quality control protocols, particularly for groundnut and soybean oil producers; and (d) a targeted paediatric dietary risk communication strategy to protect children in Rivers State from excessive heavy metal exposure through commonly consumed edible oils.

RECOMMENDATIONS

1. Regulatory Surveillance Enhancement: NAFDAC and SON should implement mandatory pre-market heavy metal testing for all commercially distributed vegetable oil brands in Nigeria, with bi-annual post-market surveillance. Brands repeatedly failing regulatory limits should face suspension and public recall.
2. Raw Material Provenance Disclosure: Regulatory agencies should mandate clear labelling of the geographical origin of oilseed raw materials on all vegetable oil products, enabling risk-stratified consumer choices and facilitating supply chain traceability.
3. Refinery Quality Control Upgrading: Vegetable oil manufacturers, particularly those producing groundnut and soybean oil, should implement ICP-OES or ICP-MS metal screening at raw material intake and finished product stages, with acceptance limits aligned to CODEX and EC standards.
4. Paediatric Dietary Risk Communication: Public health authorities should develop targeted dietary guidance for caregivers of young children in Rivers State, emphasising brand selection and diversification of fat and oil sources to minimise heavy metal exposure.
5. Agricultural Soil Remediation: State and federal governments should prioritise soil remediation in petroleum-affected agricultural zones across the Niger Delta, particularly in communities proximate to oil wells, pipelines, and refinery infrastructure.

6. Further Research: Future studies should expand the brand sample, include seasonal and batch variability assessments, incorporate speciation analysis for inorganic arsenic and Cr^{6+}, and develop comprehensive cumulative dietary exposure models integrating vegetable oil with other major heavy metal-contributing food groups.

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