

# Health Risk Assessment of Heavy Metals in Local and Imported Milk Consumed in Nnewi, Nigeria

Okoro O. Kingsley<sup>1</sup>, Peter A. Akah<sup>2</sup>, Paul Chinwuba<sup>2\*</sup>, Chimaobi O. Ugorji<sup>3</sup>, Daniel L. Ajaghaku<sup>4</sup>, Victor T. Ezeifeh<sup>5</sup>, Patience A. Agbata<sup>1</sup>, Raymond C. Okonkwo<sup>1</sup>

<sup>1</sup>Department of Pharmacology and Therapeutics, Faculty of Medicine, College of Health Sciences, Nnamdi Azikiwe University, Nnewi, Anambra state, Nigeria

<sup>2</sup>Department of Pharmacology and Toxicology, Faculty of Pharmaceutical Sciences, University of Nigeria, P.M.B 410001, Nsukka, Enugu State, Nigeria.

<sup>3</sup>Department of Science Laboratory Technology, Faculty of Physical Sciences, University of Nigeria, P.M.B 410001, Nsukka, Enugu State, Nigeria.

<sup>4</sup>Department of Pharmacology and Toxicology, Faculty of Pharmaceutical Sciences, Enugu State University of Science and Technology, Agbani, Enugu State, Nigeria

<sup>5</sup>Department of Internal Medicine, University of Port Harcourt Teaching Hospital, Rivers State, Nigeria

## Abstract

**Background:** This study performed a risk assessment of heavy metals (Cd, Hg, Pb, Zn, Fe, Cu, and As) in both local and imported milk consumed in Nnewi, Anambra State, Nigeria, to evaluate potential health risks to consumers. **Methods:** A total of 24 milk samples were collected and categorized into four groups: locally produced liquid milk, foreign imported liquid milk, locally produced powdered milk, and foreign powdered milk. The samples were analyzed using atomic absorption spectrometry. **Results:** Local liquid milk contained the highest levels of Cd, Zn, Fe, Pb, and Cu, while imported powdered milk showed the highest concentrations of As and Hg. Significant differences ( $p < 0.05$ ) were found in Cu levels between foreign and local powdered milk, and in Cd, Zn, and Fe levels between foreign and local liquid milk. The estimated daily intake (EDI) of iron from liquid milk exceeded the reference oral dose for all age groups, indicating a potential risk. Although the hazard quotient (HQ) for each metal in powdered milk was below one (suggesting no significant individual risk), the hazard index (HI) revealed that various milk sample groups posed risks to consumers, with all HI values exceeding one and the highest risks observed in females and powdered milk samples. **Conclusion:** Contamination of milk by heavy metals represents a major public health threat. Rigorous monitoring of both domestic and imported milk is essential to assess the contribution of milk to dietary heavy metal intake and to identify potential health risks.

**Keywords:** Risk assessment, Heavy metal, Milk, Contamination, Cadmium, Mercury, Lead

## Introduction

Heavy metals are naturally occurring elements in Earth's crust that cannot be broken down [1-4]. They pose significant health and environmental threats through persistence and bioaccumulation in living organisms [5-7]. Cadmium, mercury, lead, and arsenic rank among the top hazardous substances according to the Agency for Toxic Substances and Disease Registry [8-10]. Milk and dairy products are vital nutritional sources in Nigeria, with increasing consumption [11-14]. These products can become contaminated with heavy metals through environmental exposure, agricultural practices, and industrial emissions [15,16]. Metal pollutants enter the food chain, increasing toxic effects risk [17,18]. Industrialization in Nigeria has caused contamination of land, air, and water with heavy metals, leading to serious health implications [24,25]. While studies have examined heavy metal contamination, comprehensive quality

measurement studies are lacking in Nigeria [19-23], indicating a regulatory and research gap. Heavy metals' environmental presence raises concerns about food supply impact, particularly in dairy products [15,26,27].

This contamination risks public health, as consuming contaminated milk can cause chronic health issues [15,28,29]. The town of Nnewi in Anambra State serves as a critical study location. As a major industrial hub within Nigeria, it faces multiple contamination sources. Its consumption patterns reflect both local and imported dairy products, making it ideal for assessing food safety risks and quality controls in urbanizing Nigerian contexts.

**Address for correspondence:** Paul Chinwuba, Department of Pharmacology and Toxicology, Faculty of Pharmaceutical Sciences, University of Nigeria, Nsukka, Enugu State, Nigeria. Email: [paulchinwuba1@gmail.com](mailto:paulchinwuba1@gmail.com). Telephone: +2347031832066

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This study aims to address this research gap by assessing risks associated with cadmium, mercury, lead, zinc, iron, copper, and arsenic in milk consumed in Nnewi. By analyzing milk samples and calculating health risk indices, this research evaluates milk's contribution to heavy metal intake and identifies health risks within this specific context. The assessment of heavy metals in various milk types will provide data for informing public health policy and monitoring.

## Materials and Methods

### Study Area

This research was conducted in Nnewi, a town located in the Idemili South Local Government Area of Anambra State, Nigeria. The native residents of Nnewi are part of the Igbo ethnic group, and the town is bordered by Nnobi, Ichi, Ukpo, and Amichi [30].

### Ethical Approval

Approval for the study was granted by the Ethics Committee of the Nnamdi Azikiwe University Teaching Hospital (NAUTHEC), located in Nnewi, Anambra State, Nigeria (Ref No: NAUTH/CS/66/VOL.10/2017/129). This research was carried out following the guidelines of the Ethics Committee of the Nnamdi Azikiwe University Teaching Hospital (NAUTHEC), located in Nnewi, Anambra State, Nigeria.

### Sample collection and initial preparation

A total of 24 milk samples were acquired directly from the Super Market in Nnewi and sourced from various representatives. These milk samples were categorized into **four (4) groups** as follows:

**Group I** consisted of locally produced liquid milk, including brands such as Three Crowns, Popular, Peak, Luna, Coast, and Nunu.

**Group II** comprised imported foreign liquid milk, featuring Crystal Valley, Oldeburger, Lactel, Peak, Dano, and Nestle Cream.

**Group III** included locally produced powdered milk with brands such as Three Crowns, Nunu, Cowbell, Peak Milk, Loya, and Lactogen.

**Group IV** consisted of foreign powdered milk, including Oldenburger, Flavor Charm, Marvel, Dano, Good Morning, and Eldorin.

The samples were randomly selected based on their expiration dates to ensure a variety of manufacturing dates for each sample.

### Quality Control

Before and during the experiments, all the equipment and instruments utilized in this study were calibrated to ensure that they functioned

correctly [31]. To eliminate heavy metals from their surfaces, all glassware was treated with 10% concentrated nitric acid (HNO<sub>3</sub>) solution [32]. Equipment, such as volumetric flasks, measuring cylinders, and digestion flasks, were meticulously cleaned with detergent and tap water, followed by rinsing with deionized water [33]. Digestion tubes were immersed in a 1% (w/v) potassium dichromate solution in 98% (v/v) sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), whereas volumetric flasks were soaked in a 10% (v/v) HNO<sub>3</sub> solution for 24 h. After soaking, all items were rinsed with deionized water, dried in an oven, and stored in a dust-free environment until analysis. Before each use, the apparatus was soaked and rinsed with deionized water. The details of the equipment and materials used are described below.

### Preparation of samples

#### Digestion

A 2 g portion of milk was measured and placed in a digestion flask. Subsequently, 20 ml of aqua regia was introduced into the flask, which was sealed with a cork. The mixture was heated until a clear digestion was achieved. After the digestion became clear, it was diluted to 100 ml with distilled water, filtered, and stored in a reagent bottle for elemental analysis using an atomic absorption spectrophotometer (AAS) [34].

### Methods for the analysis of heavy metals in milk samples

At the Biotechnology Laboratory of Nnamdi Azikiwe University in Awka, a Buck Scientific 210/211 VGP Atomic Absorption Spectrometer equipped with a 220GF graphite furnace and a 220AS autosampler was used to analyze heavy metals, including cadmium, zinc, iron, copper, Mercury and lead [35] (Fig. 1).



**Fig. 1** Heavy metal analysis Instrument at the Springboard Laboratory, Awka Anambra State.

**Method Detection Limits and Limits of Quantification**

The sensitivity of the analytical method was evaluated by determining the Method Detection Limit (MDL) and Limit of Quantification (LOQ) for each metal. The MDL was calculated as three times the standard deviation of replicate blank measurements, while the LOQ was derived as ten times the standard deviation. These values, summarized in Table 1, confirm that the method is sufficiently sensitive to detect and quantify the target heavy metals at concentrations relevant to food safety monitoring.

**Table 1: Method Detection Limits (MDL) and Limits of Quantification (LOQ) for heavy metals analyzed by AAS (mg/kg, wet weight)**

Metal	MDL (mg/kg)	LOQ (mg/kg)
Cd	0.01	0.03
Zn	0.10	0.30
Fe	0.20	0.60
Pb	0.05	0.15
Cu	0.05	0.15
As	0.02	0.06
Hg	0.005	0.015

**Risk assessment**

The potential health risks from consuming milk contaminated with metals were assessed using the target hazard quotient (THQ) [36]. The quotient is the ratio of the calculated dose to the reference dose (RD). If this ratio is below 1, the population is considered safe; however, if it is 1 or higher, there is a health risk. This risk assessment method has been validated by researchers [37] and is considered reliable.

The hazard quotient (HQ) was used to evaluate the non-carcinogenic health risks posed by a single metal through dairy consumption [38]. This is the ratio of the calculated dose of a pollutant to its reference dose (RfD), which is determined using the formula

$$HQ = \frac{EDI}{RfD} \dots \dots \dots Eq 1$$

Here, EDI represents the estimated daily intake of heavy metals (mg/[kgday] ) and RfD is the oral reference dose. The RfD values for Pb, Cd, Cu, Zn, As, Fe, and Hg are 0.004, 0.001, 0.04, 0.3, 0.0003, 0.007, and 0.0003 mg/kg/day, respectively [39].

$$EDI = C \times I \dots \dots \dots Eq 2$$

where C is the average concentration of heavy metals in milk samples (mg/kg) and I is the milk intake per kilogram of body weight per day (kg/day/kg). If HQ is less than one, the exposed population is unlikely to experience noticeable adverse effects.

The health index (HI) is employed to estimate the overall non-carcinogenic health risk from multiple heavy metals [40,41]. The HI for a specific receptor/pathway combination, such as diet, can be calculated using the following equation [42].

$$HI = \sum_{i=1} HQ_i \dots \dots \dots Eq 3$$

**Estimated daily intake of metals (mg kg<sup>-1</sup> day<sup>-1</sup>) for both sexes.**

The daily intake of each metal was estimated by multiplying the average concentration of metals by the amount of milk consumed per day [43].

**Milk consumption data (g day<sup>-1</sup> bw<sup>-1</sup>) by age and gender group.**

Singh et al. [44] provided data on milk consumption, including information on milk, fruit juice, and sugar-sweetened beverages across 187 countries. These data were derived from annual food balance sheets compiled by the United Nations Food and Agriculture Organization. To address issues related to measurement comparability, study representativeness, and uncertainties in sampling and modeling, the authors utilized a hierarchical Bayesian model. This method is crucial for effectively integrating and standardizing nationally representative dietary surveys with food availability data. This study examined various milk types, such as skim milk, low-fat milk, whole milk, and other dairy beverages. Our focus in this study was on liquid and powdered milk, which account for approximately 24% and 29% of Nigeria's total milk consumption, respectively, according to the

National Bureau of Statistics (NBS) dairy product consumption data since 2006. To calculate the average daily intake of milk powder and evaporated milk in Nigeria, we applied factors of 0.29 for liquid milk and 0.24 for powdered milk, respectively, to the estimates provided by Singh et al. [44] for each age group and sex. These values were then divided by the body weight of 60 kg.

### Statistical analysis

Data were analyzed using SPSS version 20 and are expressed as mean  $\pm$  standard deviation (SD). The normality of data distribution was confirmed using the Shapiro-Wilk test, and homogeneity of variances was verified with Levene's test. Independent samples t-tests were used to compare metal concentrations between two groups (e.g., foreign vs. local milk). One-way analysis of variance (ANOVA) was applied to compare means across the four milk categories. Where ANOVA indicated significant differences ( $p < 0.05$ ), post-hoc pairwise comparisons were performed using Tukey's HSD test. A p-value  $< 0.05$  was considered statistically significant.

### Results

An independent Student's t-test was employed to compare the average metal concentrations in imported and locally produced milk products. When the p-value for the mean metal concentrations was greater than or equal to 0.05, the differences were deemed not statistically significant. Table 2 lists the heavy metal residues found in both the liquid and powdered milk samples from foreign and local sources. The table reveals a notable difference ( $p < 0.05$ ) in copper levels (0.037) between the foreign and local powdered milk samples. Furthermore, significant differences ( $p < 0.05$ ) were observed in cadmium (0.037), zinc (0.027), and iron (0.014) levels between the foreign and local liquid milk samples. Table 3 outlines the differences in mean concentrations between powdered and liquid milk, with significance assessed using Student's t-test. A significant difference ( $p < 0.05$ ) was found in arsenic (0.625) and mercury (0.260) levels between powdered and liquid milk. Table 4 provides data on milk consumption (in grams per day per body weight) categorized by age and sex, showing a significant difference ( $p < 0.05$ ) in consumption between

powdered and liquid milk across the various age and sex groups. Tables 5 and 6 detail the estimated daily intake (EDI) of metals from powdered and liquid milk for the different age groups. The EDIs of Cd, Zn, Fe, Pb, Cu, As, and Hg (in mg/kg/day) from powdered milk were below the reference daily intake (RDI) for all age groups (Table 5). However, Table 6 indicates that the EDI of iron surpassed the RDI of 0.007 mg/kg/day in all age groups, posing a potential risk to consumers.

**Table 2 Differences between metal concentrations based on methods**

Metals	Foreign (n=6)	Local (n=6)	p value
	POWDERED		
Cd	0.33 $\pm$ 0.29	0.34 $\pm$ 0.27	0.964
Zn	8.37 $\pm$ 5.59	8.63 $\pm$ 3.94	0.927
Fe	7.87 $\pm$ 4.83	7.29 $\pm$ 4.41	0.833
Pb	2.17 $\pm$ 1.00	2.29 $\pm$ 1.32	0.920
Cu	0.46 $\pm$ 0.35	0.99 $\pm$ 0.41	<b>0.037</b>
As	0.39 $\pm$ 0.23	0.43 $\pm$ 0.15	0.785
Hg	0.36 $\pm$ 0.11	0.37 $\pm$ 0.07	0.845
LIQUID			
Cd	1.06 $\pm$ 0.49	2.15 $\pm$ 1.00	<b>0.037</b>
Zn	33.07 $\pm$ 5.79	47.02 $\pm$ 11.81	<b>0.027</b>
Fe	30.24 $\pm$ 6.97	44.48 $\pm$ 9.47	<b>0.014</b>
Pb	6.39 $\pm$ 7.46	10.41 $\pm$ 7.51	0.374
Cu	2.89 $\pm$ 2.38	1.92 $\pm$ 2.15	0.476
As	0.35 $\pm$ 0.13	0.41 $\pm$ 0.07	0.395
Hg	0.39 $\pm$ 0.06	0.41 $\pm$ 0.49	0.471

Differences were considered statistically significant at  $P < 0.05$ .

**Table 3: Differences in the mean concentration between powdered milk and liquid milk**

Metals	Mean $\pm$ S.D		p value
	Powdered	Liquid	
Cadmium	0.34 $\pm$ 0.27	1.61 $\pm$ 0.95	0.001
Zinc	8.50 $\pm$ 4.61	40.04 $\pm$ 11.48	0.001
Iron	7.58 $\pm$ 4.42	37.36 $\pm$ 10.87	0.001
Lead	2.23 $\pm$ 1.96	8.40 $\pm$ 7.44	0.016
Copper	0.73 $\pm$ 0.46	2.41 $\pm$ 2.22	0.025
Arsenic	0.41 $\pm$ 0.19	0.38 $\pm$ 0.11	0.625
Mercury	0.37 $\pm$ 0.08	0.40 $\pm$ 0.05	0.260

Differences were considered significant at p values  $< 0.05$ .

**Table 4: Milk consumption data (g day<sup>-1</sup> bw<sup>-1</sup>) by age and sex**

Gender	Age (Years)			
	20-39	40-59	≥60	Overall
<b>Powdered</b>				
Male	0.41	0.45	0.57	0.50
Female	0.50	0.49	0.63	0.55
<b>Liquid</b>				
Male	0.38	0.37	0.47	0.42
Female	0.42	0.41	0.52	0.45

Differences were considered statistically significant at  $P < 0.05$ .

**Table 5: Estimated daily intake of metals through powdered milk (mg kg<sup>-1</sup> day<sup>-1</sup>)**

Age Group	Metals						
	Cd	Zn	Fe	Pb	Cu	As	Hg
<b>Male</b>							
20-39	1.40x10 <sup>-4</sup>	3.49x10 <sup>-3</sup>	3.11x10 <sup>-3</sup>	9.14x10 <sup>-4</sup>	2.99x10 <sup>-4</sup>	1.68x10 <sup>-4</sup>	1.52x10 <sup>-4</sup>
40-59	1.53x10 <sup>-4</sup>	3.83x10 <sup>-3</sup>	3.41x10 <sup>-3</sup>	1.00x10 <sup>-3</sup>	3.29x10 <sup>-4</sup>	1.85x10 <sup>-4</sup>	1.66x10 <sup>-4</sup>
≥60	1.94x10 <sup>-4</sup>	4.85x10 <sup>-3</sup>	4.32x10 <sup>-3</sup>	1.27x10 <sup>-3</sup>	4.16x10 <sup>-4</sup>	2.34x10 <sup>-4</sup>	2.11x10 <sup>-4</sup>
Overall	1.70x10 <sup>-4</sup>	4.25x10 <sup>-3</sup>	3.79x10 <sup>-3</sup>	1.12x10 <sup>-3</sup>	3.65x10 <sup>-4</sup>	2.05x10 <sup>-4</sup>	1.85x10 <sup>-4</sup>
<b>Female</b>							
20-39	1.70x10 <sup>-4</sup>	4.25x10 <sup>-3</sup>	3.79x10 <sup>-3</sup>	1.12x10 <sup>-3</sup>	3.65x10 <sup>-4</sup>	2.05x10 <sup>-4</sup>	1.85x10 <sup>-4</sup>
40-59	1.67x10 <sup>-4</sup>	4.17x10 <sup>-3</sup>	3.71x10 <sup>-3</sup>	1.09x10 <sup>-3</sup>	3.58x10 <sup>-4</sup>	2.01x10 <sup>-4</sup>	1.81x10 <sup>-4</sup>
≥60	2.14x10 <sup>-4</sup>	5.36x10 <sup>-3</sup>	4.78x10 <sup>-3</sup>	1.40x10 <sup>-3</sup>	4.60x10 <sup>-4</sup>	2.58x10 <sup>-4</sup>	2.33x10 <sup>-4</sup>
Overall	1.80x10 <sup>-4</sup>	4.51x10 <sup>-3</sup>	4.02x10 <sup>-3</sup>	1.18x10 <sup>-3</sup>	3.87x10 <sup>-4</sup>	2.17x10 <sup>-4</sup>	1.96x10 <sup>-4</sup>

RFD: Cd: 0.001, Zn: 0.3, Fe: 0.007, Pb: 0.004, Cu: 0.04, As: 0.0003, Hg: 0.0003 (mg/kg/d)

**Table 6: Estimated daily intake of metals through liquid milk (mg kg<sup>-1</sup> day<sup>-1</sup>)**

Age Group	Metals						
	Cd	Zn	Fe	Pb	Cu	As	Hg
<b>Male</b>							
20-39	6.12x10 <sup>-4</sup>	1.52x10 <sup>-2</sup>	1.42x10 <sup>-2</sup>	3.19x10 <sup>-3</sup>	9.16x10 <sup>-4</sup>	1.44x10 <sup>-4</sup>	1.52x10 <sup>-4</sup>
40-59	5.96x10 <sup>-4</sup>	1.48x10 <sup>-2</sup>	1.38x10 <sup>-2</sup>	3.11x10 <sup>-3</sup>	8.92x10 <sup>-4</sup>	1.41x10 <sup>-4</sup>	1.48x10 <sup>-4</sup>
≥60	7.57x10 <sup>-4</sup>	1.88x10 <sup>-2</sup>	1.76x10 <sup>-2</sup>	3.95x10 <sup>-3</sup>	1.13x10 <sup>-3</sup>	1.79x10 <sup>-4</sup>	1.88x10 <sup>-4</sup>
Overall	6.76x10 <sup>-4</sup>	1.68x10 <sup>-2</sup>	1.57x10 <sup>-2</sup>	3.53x10 <sup>-3</sup>	1.01x10 <sup>-3</sup>	1.59x10 <sup>-4</sup>	2.00x10 <sup>-4</sup>
<b>Female</b>							
20-39	6.67x10 <sup>-4</sup>	1.68x10 <sup>-2</sup>	1.57x10 <sup>-2</sup>	3.53x10 <sup>-3</sup>	1.01x10 <sup>-3</sup>	1.59x10 <sup>-4</sup>	2.00x10 <sup>-4</sup>
40-59	6.60x10 <sup>-4</sup>	1.64x10 <sup>-2</sup>	1.53x10 <sup>-2</sup>	3.44x10 <sup>-3</sup>	9.88x10 <sup>-4</sup>	1.56x10 <sup>-4</sup>	1.64x10 <sup>-4</sup>
≥60	8.37x10 <sup>-4</sup>	2.08x10 <sup>-2</sup>	1.94x10 <sup>-2</sup>	4.37x10 <sup>-3</sup>	1.25x10 <sup>-3</sup>	1.97x10 <sup>-4</sup>	2.08x10 <sup>-4</sup>
Overall	7.25x10 <sup>-4</sup>	1.80x10 <sup>-2</sup>	1.68x10 <sup>-2</sup>	3.78x10 <sup>-3</sup>	1.08x10 <sup>-3</sup>	1.71x10 <sup>-4</sup>	1.80x10 <sup>-4</sup>

RfD: Cd: 0.001, Zn: 0.3, Fe: 0.007, Pb: 0.004, Cu: 0.04, As: 0.0003, Hg: 0.0003 (mg/kg/d)

Table 7 displays the hazard quotient and hazard index for metal intake from powdered milk across different age groups, for both males and females. The table shows that the hazard quotient values for all groups were below 1, suggesting that these populations are unlikely to have significant negative effects from metal exposure. However, the hazard index, as detailed in Table 7, indicates that the groups consuming powdered milk are at risk, with values exceeding one, and the highest index was recorded for females at 2.913. Table 8 outlines the hazard quotient and hazard index for the metal consumption from liquid milk. Similar to powdered milk, the hazard quotient values for all groups were less than 1, implying that these populations were unlikely to experience noticeable adverse effects from metal exposure. Nevertheless, the hazard index, as shown in Table 8, revealed that the groups consuming liquid milk were at risk, with all values surpassing one. The highest hazard index in this category was also found in females, with a value of 6.044.

**Table 7: HQs and HIs of metal consumption via powdered milk**

Age Group	HQ							HI
	Cd	Zn	Fe	Pb	Cu	As	Hg	
<b>Male</b>								
20-39	0.140	0.012	0.444	0.229	0.0074	0.560	0.507	1.899
40-59	0.153	0.013	0.487	0.250	0.0082	0.616	0.553	2.080
≥60	0.194	0.016	0.617	0.318	0.010	0.780	0.703	2.624
Overall	0.170	0.014	0.541	0.280	0.0091	0.683	0.617	2.314
<b>Female</b>								
20-39	0.170	0.014	0.541	0.280	0.0091	0.683	0.617	2.314
40-59	0.167	0.014	0.530	0.273	0.0089	0.670	0.603	2.266
≥60	0.214	0.018	0.683	0.350	0.0115	0.860	0.777	2.913
Overall	0.180	0.015	0.574	0.295	0.0097	0.723	0.653	2.450

HQ > 1 suggests that the exposed population is likely to experience adverse effects from the metals. An HI > 1 indicates that the aggregate exposure of a population to metals is a concern.

**Table 8: HQs and HIs of metal consumption via liquid milk**

Age Group	HQ							HI
	Cd	Zn	Fe	Pb	Cu	As	Hg	
<b>Male</b>								
20-39	0.612	0.051	2.03	0.798	0.023	0.480	0.507	4.501
40-59	0.596	0.049	1.97	0.778	0.022	0.470	0.493	4.378
≥60	0.757	0.063	2.51	0.988	0.028	0.597	0.626	5.569
<b>Overall</b>	0.676	0.056	2.24	0.883	0.025	0.530	0.667	5.077
<b>Female</b>								
20-39	0.676	0.056	2.24	0.883	0.023	0.500	0.667	5.045
40-59	0.660	0.055	2.19	0.860	0.025	0.520	0.547	4.857
≥60	0.837	0.069	2.77	0.987	0.031	0.657	0.693	6.044
<b>Overall</b>	0.725	0.060	2.40	1.093	0.027	0.570	0.600	5.475

HQ > 1 suggests that the exposed population is likely to experience adverse effects from the metals.

An HI > 1 indicates that the aggregate exposure of a population to metals is a concern.

### Discussion

Analysis of both powdered and liquid milk samples from international and domestic sources revealed contamination with various heavy metal residues, posing considerable health hazards. All heavy metals, including essential minerals like iron (Fe) and nonessential metals like lead (Pb) and cadmium (Cd), are toxic when they exceed certain limits. The highest levels of Cd, Zn, Fe, Pb, and Cu were found in local liquid milk, whereas imported powdered milk showed the highest concentrations of As and Hg. The levels of Cd, Zn, Fe, Pb, Cu, As, and Hg in this study surpassed those reported in previous studies [45-50].

Compared to many earlier global surveys, the data reveal a notable rise in copper levels in local powdered milk compared to foreign powdered milk. Furthermore, there was a significant increase in Cd, Zn, and Fe levels in local liquid milk compared to foreign liquid milk [45-50]. The relatively high levels of heavy metals in Nigerian milk may be due to contamination from improper handling, exposure, and processing, which can involve boiling and frying with steel or aluminum cookware [51,52]. Additionally, elevated levels in locally produced milk could be linked to open grazing practices, as cow bodies can act as biological filters for heavy metals like Cd, which may enter milk under certain conditions [53]. Other sources include packaging materials [54], and the significant presence of Cd may result from natural or anthropogenic sources like fertilizers and atmospheric deposition [55,56].

A notable difference was found in arsenic and mercury levels when comparing powdered milk to liquid milk. The estimated daily iron (Fe) intake from liquid milk surpassed the reference oral dose [39], while concentrations of Pb, Cd, Cu, Zn, As, and Hg were comparatively low. This aligns with the study by Salah et al. [57], who also noted high estimated daily Fe intake.

The hazard quotient (HQ) is a valuable metric for assessing risks [58]. The HQ for all metals in powdered milk was below one, indicating that residents are not at significant risk from this single source, though other exposure pathways were not assessed. For liquid milk, all metals had HQ values below one except for iron (Fe), which exceeded one, suggesting a risk. Excessive iron can harm vital organs and increase the risk of various diseases [59]. The HQ for overall lead (Pb) intake via liquid milk in females is also above 1. Elevated Pb levels may result from environmental exposure of lactating cows or contamination from Pb-soldered cans [60,61], and the drying process can increase Pb concentration in powder [62]. The hazard index indicates that various milk sample groups pose risks to consumers, with all values exceeding one.

### Conclusion

Contamination of milk by heavy metals presents a major threat to public health, as the frequent consumption of such tainted products can lead to a range of diseases and lesions. This study revealed that locally sourced milk exhibited higher levels of heavy metal contamination than imported milk, although some differences were not statistically significant. Therefore, it is crucial to implement rigorous and regular monitoring of heavy metal contamination in both domestic and imported milks. This monitoring should aim to evaluate the actual contribution of milk to dietary heavy metal intake and identify potential health risks linked to these metals, their bioaccumulation from long-term exposure, and their movement and excretion in milk.

### Declarations

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