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Health Risk Assessment of Heavy Metals in Infant Formula and Children's Food Marketed in Sokoto, Nigeria

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ABSTRACT

Heavy metals in infant formula and children's foods pose significant health risks, especially to infants and young children, due to their potential for accumulation and toxicity. This study assessed the concentrations of cadmium (Cd), arsenic (As), lead (Pb), chromium (Cr), and aluminium (Al) in commonly consumed infant formulas and children's food products in Sokoto metropolis and evaluated potential health risks. A total of 20 infant formula samples and 50 children's food product samples were collected from shops and supermarkets. Samples were digested and analyzed for metal content using atomic absorption spectrometry. Demographic data on ingestion rates and body weights were collected via structured questionnaires, enabling calculation of health risk indices such as Estimated Daily Intake (EDI), Hazard Quotient (HQ), Hazard Index (HI), and Estimated Cancer Risk (ECR). Results showed heavy metal concentrations in infant formulas ranged from 0.043 mg/kg for Cd to 0.212 mg/kg for As in the 0-6 months age group, and 0.037 mg/kg for Cd to 0.367 mg/kg for As in the 6-12 months age group. In children's foods, concentrations varied from 0.020 mg/kg for Cd in chocolates to 0.598 mg/kg for As in dairy products. HQ values suggested potential non-carcinogenic risks for As and Pb, with ECR values highlighting As (1.34×10^{3}) and Pb (1.14×10^{6}) as major risks for infants aged 6-12 months. These findings underscore the need for ongoing monitoring and stricter regulations to safeguard infant and children's food safety in the Sokoto metropolis.

Keywords: Heavy metals, infant formula, children's food products, health risk assessment

INTRODUCTION

Nutrition in infancy and early childhood is critical for growth and development, impacting both immediate and long-term health outcomes (Thurow, 2016). Exclusive breastfeeding for the first six months, followed by the introduction of complementary foods up to two years or beyond, is recommended to support healthy development and reduce disease risks (HBBF, 2021). When breastfeeding is not an option, infant formula serves as a substitute, ensuring infants receive essential nutrients. However, the safety of infant formulas and children's food products is increasingly concerning due to potential contamination with heavy metals such as cadmium (Cd), arsenic (As), lead (Pb), and mercury (Hg), which may enter the food chain via soil, water, or packaging materials (Lin *et al*., 2022). The Food and Drug Administration (FDA) takes exposure to toxic elements in the food supply very seriously because it stands to protect the health and safety of the youngest and most vulnerable members of the population. Since most of these toxic elements are present in the environment and cannot be completely avoided, thereby causing them to enter the food chain through soil, water, or air, the goal has always been to reduce exposure to these toxic elements in foods to the greatest extent feasible (FDA report, 2021).

Heavy metals pose substantial health risks, especially for infants and young children, whose bodies are still developing and who consume more food per body weight compared to adults. Toxic elements in baby foods may accumulate in the body over time, leading to neurotoxicity, nephrotoxicity, developmental toxicity, and cognitive impairments. In response, agencies like the FDA aim to reduce toxic element exposure in food, but international guidance on acceptable levels for infants is limited (FDA, 2021; Akonnor and Richter, 2021).

In Nigeria, little research has focused on heavy metal contamination in infant formulas and children's foods, highlighting the need for data on potential risks. This study, therefore, investigates heavy metal concentrations in infant formulas and children's foods in Sokoto metropolis and assesses the associated health risks. Findings will inform regulatory standards, aiming to ensure these products meet safety and quality benchmarks.

This study aims to determine the concentration of selected heavy metals (Cd, As, Pb, Cr, and Al) in

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infant formulas and children's foods marketed in Sokoto metropolis and to assess associated health risks. Specifically, it seeks to identify heavy metal concentrations in these products, measure ingestion rates among consumers, and evaluate health risk indices for infants and young children. The hypotheses propose that heavy metal concentrations in these foods do not exceed established safety limits, ingestion rates remain within safe thresholds, and consumption does not pose significant health risks (null hypotheses), while the alternative hypotheses suggest that these concentrations and ingestion rates may exceed safe limits, potentially posing health risks to young consumers.

MATERIALS AND METHODS

Materials

Analytical-grade reagents and distilled water were used in this study, with all glassware thoroughly cleaned and rinsed before use. Key equipment included an analytical balance, laboratory oven, Atomic Absorption Spectrometer (AAS), muffle furnace, and heating block, among others. High-purity chemicals were utilized, including sulphuric and nitric acids, sourced from reputable manufacturers to ensure quality and accuracy in analyses.

Sample Collection

Infant formulas and children's food products were collected randomly from multiple shops and supermarkets across the Sokoto metropolis. To prevent bias, shopkeepers provided products without brand specification. Ten infant formula products were selected, with two batches per product, totalling twenty samples. Additionally, fifty samples of children's food products were collected. Details such as batch number and manufacturing date were recorded for traceability.

Questionnaire Distribution

To assess ingestion rates and obtain body weight data, 500 questionnaires were distributed targeting affluent areas, private schools, and healthcare centers. The surveys captured detailed information on feeding frequency, type of formula or food, and body weight for both infant formulas and children's food products. This data enabled the estimation of ingestion rates, which was vital for evaluating potential health risks associated with heavy metal exposure, with data confidentiality ensured through informed consent.

Sample Preparation

Samples were processed at Usmanu Danfodiyo University's Biochemistry Laboratory. Infant formulas were analysed in powdered form, and children's food products were ground to a uniform powder. Triplicate samples (1 g each) underwent digestion with nitric and sulfuric acids, followed by heating and filtration, to obtain clear solutions for analysis.

Heavy Metal Analysis

Using the Atomic Absorption Spectrometer (Perkin Elmer. 2280), the concentrations of selected heavy metals (Cd, As, Pb, Cr, and Al) in the samples were measured and expressed in mg/kg dry weight.

Estimation of Exposure and Risk Characterization

The potential health risk associated with the ingestion of infant formulas and children's food products contaminated with heavy metals was assessed by evaluating the Estimated Daily Intake (EDI), Hazard Quotient (HQ), Hazard Index (HI) and Estimated Cancer Risk (ECR) using the following formulas;

$$EDI = \frac{Ci \times Ingestion\ Rate}{Body\ weight\ (Kg)} \quad (1)$$

Where Ci is the metal concentration (mg/kg) in the sample, and, ingestion rate is the amount of infant formula or children's food products consumed daily (gram/day).

$$HQ = \frac{EDI}{RfD} \quad (2)$$

Where RfD is the metal reference dose

$$HI = HQ1 + HQ2 + HQ3 \ldots\ldots + HQi = \sum_{n=1}^{i} HQ \quad (3)$$

Where HQ is the hazard quotient of individual metals

$$ECR = EDI \times CSF \quad (4)$$

Where CSF is the cancer slope factor

The health risk was interpreted to its non-carcinogenic and carcinogenic effects based on the guidelines from the regulatory agencies, such as the WHO and USEPA.

Statistical Analysis

Data were expressed as mean ± SEM, and mean values with different superscript letters along the columns were significantly different ($p<0.05$). A t-test was used to compare groups, with significance set at a p-value <0.05. Normality was verified through Kolmogorov-Smirnov and Anderson-Darling tests using Python's SciPy and Statsmodels libraries.

RESULTS

A total of 417 respondents participated in the study, comprising infants and children across three age groups: 0–6 months, 6–12 months, and 12–36 months (Table 1). Among these, both male and female participants were represented. The average body weight increased with age, ranging from 7.2–7.3 kg in the 0–6 month group to 15.4–16.3 kg in the 12–36 month group. The highest number of respondents was recorded in the 12–36 months category (194 children), while the lowest was in the 0–6 months group (58 infants). A slightly higher proportion of females was recorded in all age groups except the youngest, where the gender distribution was nearly balanced.

Table 1: Demographic Data of infants and children

S/N	Age Group	Gender	Average Body Weight	No. of Respondents
1	0-6 months	M	7.2	31
		F	7.3	27
2	6-12 months	M	9.1	58
		F	9.2	107
3	12-36 months	M	16.3	82
		F	15.4	112
				Total = 417

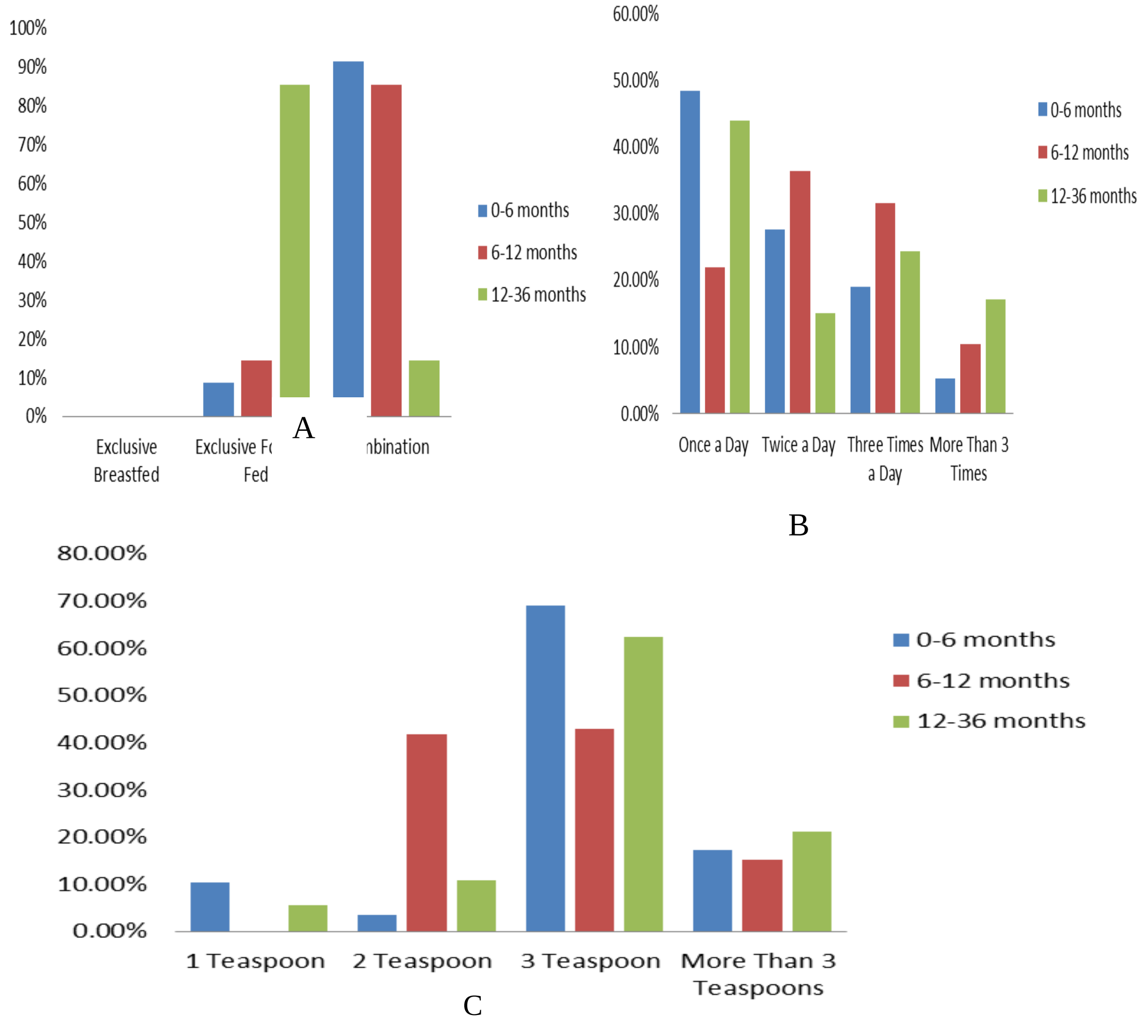

Figure 1: Feeding History of infants and children. (A): feeding method (B): feeding frequency per day (C): feeding quantity.

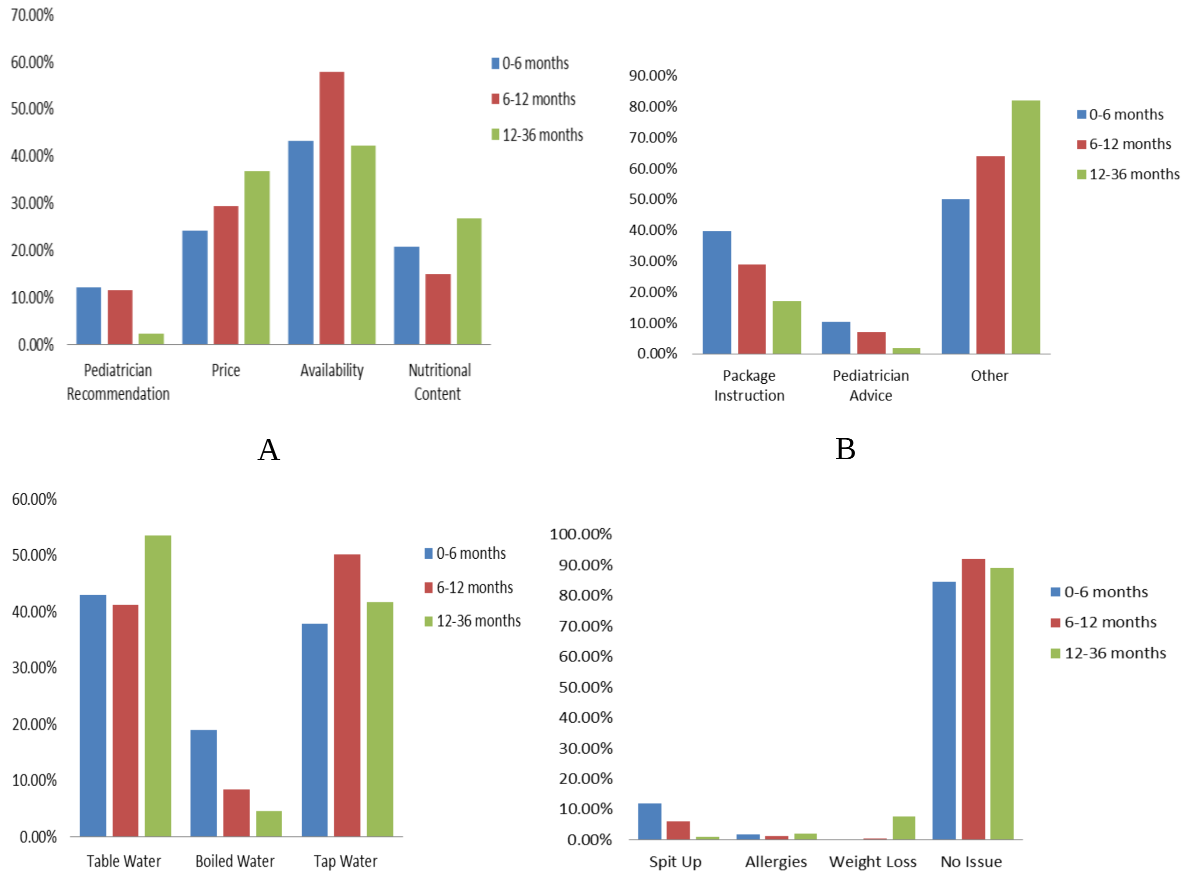

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Figure 2: Feedi ces. A: Factors Influencing Formula Selection I ation Methods C: Water Type Used D: Issues/Concerns.

The concentration of heavy metals (Cd, As, Pb, Cr, and Al) in infant formula samples varied across the three age-specific stages: 0–6 months, 6–12 months, and 12–36 months (table 2). Cadmium (Cd) levels were similar across all stages, with no significant variation. Arsenic (As) was highest in formulas for 6–12 months and was not detected in the 12–36 months group. Lead (Pb) showed a significantly higher concentration in the 6–12 months group compared to others. Chromium (Cr) was generally low, with the lowest value in the 6–12 months group. Aluminium (Al) was highest in 0–6 months samples, followed by 12–36 months, and was lowest in the 6–12 months group. Statistically significant differences ($p < 0.05$) were observed in Pb, Cr, and Al concentrations across the age groups.

Table 2: Heavy Metal Concentration (mg/kg) in Samples of Infant Formula Based on the Age Groups

S/N	STAGE	Cd	As	Pb	Cr	Al
1	0-6 Months	0.043 ± 0.004^{a}	0.212 ± 0.115^{a}	0.048 ± 0.017^{a}	0.128 ± 0.071^{a}	0.189 ± 0.080^{a}
2	6-12 Months	0.037 ± 0.003^{a}	0.367 ± 0.045^{a}	0.320 ± 0.011^{b}	0.047 ± 0.032^{b}	0.085 ± 0.043^{b}
3	12-36 Months	0.050 ± 0.001^{a}	ND	0.086 ± 0.063^{a}	0.145 ± 0.026^{a}	0.118 ± 0.195^{c}

ND=Not Detected. The results were presented as mean ± SEM (n=3 technical replicates). Mean values with different superscript letters along the columns were significantly different ($p<0.05$).

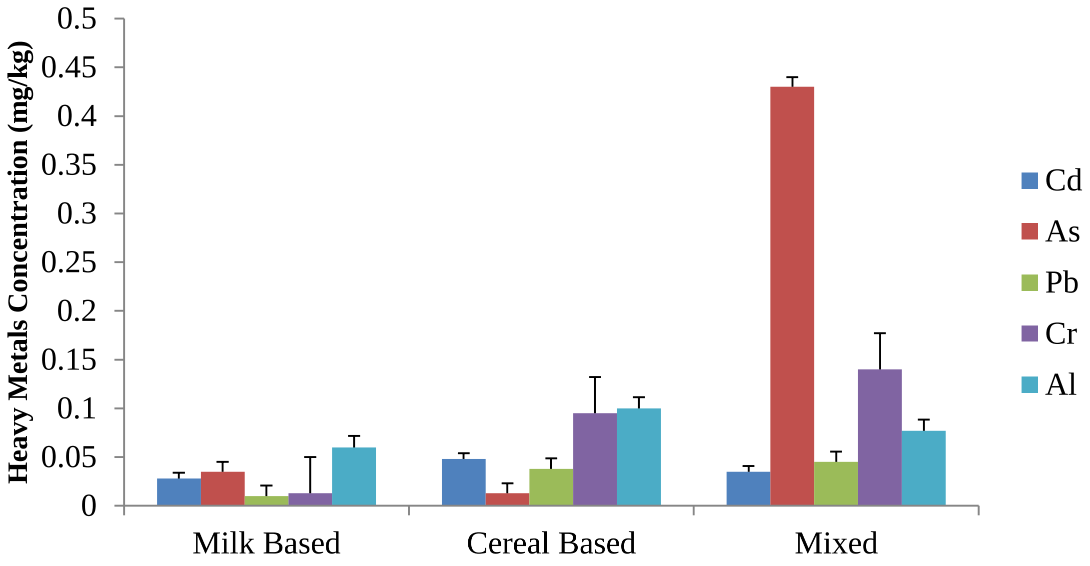

Figure 3: Heavy Metals concentration (mg/kg) in Samples of Infant Formula Based on the Formulations (n=3 technical replicates).

The levels of cadmium (Cd), arsenic (As), lead (Pb), chromium (Cr), and aluminium (Al) were measured across six categories of children's food products (Table 3). Cadmium levels were significantly lower in chocolates and snacks compared to other categories. Arsenic was highest in instant noodles and dairy products, while chocolates and snacks contained significantly lower amounts. Lead was most concentrated in chocolates, followed by snacks and instant noodles, showing significant differences across categories. Chromium levels were generally low, with slightly higher values observed in chocolates and cereals. Aluminium showed notable variation, being highest in crackers and cereals, while instant noodles and dairy products had the lowest concentrations. Statistically significant differences ($p < 0.05$) were observed in several metals across the food categories.

Table 3: Heavy Metals Concentration (mg/kg) in the Categories of Children's Food Products

S/N	PRODUCTS	Cd	As	Pb	Cr	Al
1.	Dairy Products	0.040±0.000[a]	0.598±0.036[a]	0.006±0.004[a]	0.003±0.002[a]	0.009±0.002[a]
2.	Crackers	0.046±0.003[a]	0.556±0.018[a]	0.009±0.002[a]	0.009±0.001[a]	0.036±0.017[b]
3.	Chocolates	0.020±0.002[b]	0.106±0.028[b]	0.072±0.014[b]	0.013±0.002[b]	0.012±0.002[b]
4.	Snacks	0.020±0.000[b]	0.023±0.003[b]	0.017±0.003[b]	0.004±0.003[a]	0.017±0.006[b]
5.	Instant Noodles	0.043±0.004[a]	0.603±0.037[a]	0.013±0.002[b]	0.004±0.003[a]	0.008±0.004[a]
6.	Instant Cereals	0.039±0.004[a]	0.444±0.093[a]	0.009±0.002[a]	0.013±0.003[b]	0.066±0.028[b]

The results were presented as mean ± SEM (n=3 technical replicates). Mean values with different superscript letters along the columns were significantly different ($p<0.05$).

Table 4 presents the average body weight and ingestion rate of male and female infants across different age groups. Both parameters increased with age. Infants aged 0–6 months had the lowest values, while those aged 12–36 months recorded the highest. Minor gender differences were observed, particularly in ingestion rates.

Table 4: Average body weight (Kg) and ingestion rate (g) of infants between 0-6, 6-12, and 12-36 months.

S/N	STAGES	GENDER	BW (Kg)	IR (g)
1.	0-6 months	M	7.2±0.70[a]	28.6±9.08[a]
		F	7.3±0.77[a]	26.1±7.47[b]
2.	6-12 months	M	9.1±0.96[b]	45.1±11.4[c]
		F	9.2±0.83[b]	45.5±8.25[c]
3.	12-36 months	M	16.3±1.93[c]	81.8±18.7[d]
		F	15.4±2.27[d]	85.8±19.3[e]

Table 5 shows the estimated daily intake (EDI) of cadmium (Cd), arsenic (As), lead (Pb), chromium (Cr), and aluminium (Al) across different age groups and genders. Infants aged 0–6 months had higher EDI values for most metals due to lower body weight and higher relative consumption. A general decrease in EDI was observed with increasing age, although arsenic intake was highest in the 12–36-month group.

Table 5: Estimated Daily Intake (EDI) (mg/kg/day) of Infant Formula and Children's Food Products between the Age Groups of 0-6, 6-12, and 12-36 months

S/N	STAGE	GENDER	Cd	As	Pb	Cr	Al
1.	0-6 Months	M	0.00150[a]	0.00075 [a]	0.000230[a]	0.000340 [a]	0.000410[a]
		F	0.00135[a]	0.0006615[b]	0.000098[a]	0.000249 [a]	0.000397[a]
2.	6-12 Months	M	0.000188[b]	0.000892[b]	0.000135[a]	0.000345 [a]	0.000547[a]
		F	0.000198[b]	0.000832[b]	0.000124[a]	0.000346 [a]	0.000565[a]
3.	12-36 Months	M	0.000168[b]	0.001846[a]	0.000093[a]	0.000045[b]	0.000249[a]
		F	0.000186[b]	0.00205[a]	0.000104[a]	0.000053[b]	0.000277[a]

The results were presented as mean ± SEM (n=6). Mean values with different superscript letters along the columns were significantly different (p<0.05).

Table 6 presents the hazard quotient (HQ) values for cadmium (Cd), arsenic (As), lead (Pb), chromium (Cr), and aluminium (Al) in infants across different age groups and genders. The HQ values for arsenic were notably higher across all age groups, indicating potential non-carcinogenic health risks, especially in older infants (12–36 months). Aluminium also showed relatively high HQs. Most HQs remained below the threshold of 1, except for As and Al in some groups, suggesting possible health concerns.

Table 6: Hazard Quotient (HQ) of Infants between the Age Groups: 0-6, 6-12, and 12-36 months

S/N	STAGE	GENDER	Cd	As	Pb	Cr	Al
1	0-6 Months	M	0.375±0.028[a]	2.452±0.616[a]	0.008±0.002[a]	0.079±0.042[a]	0.978±0.384[a]
		F	0.336±0.026[a]	2.205±0.554[a]	0.007±0.002[a]	0.071±0.003[a]	0.882±0.346[a]
2	6-12 Months	M	0.417±0.024[a]	3.908±0.617[b]	0.020±0.0017[b]	0.049±0.021[b]	0.976±0l292[a]
		F	0.469±0.036[a]	3.051±0.776[a]	0.010±0.0003[b]	0.098±0.052[a]	1.122±0.478[b]
3	12-36 Months	M	0.400±0.020[a]	6.153±0.677[c]	0.007±0.001[a]	0.015±0.0013[b]	0.552±0.205[c]
		F	0.466±0.025[a]	6.830±0.674[c]	0.008±0.004 [a]	0.015±0.0013[b]	0.616±0.227[c]

The results were presented as mean ± SEM (n=6). Mean values with different superscript letters along the columns were significantly different (p<0.05).

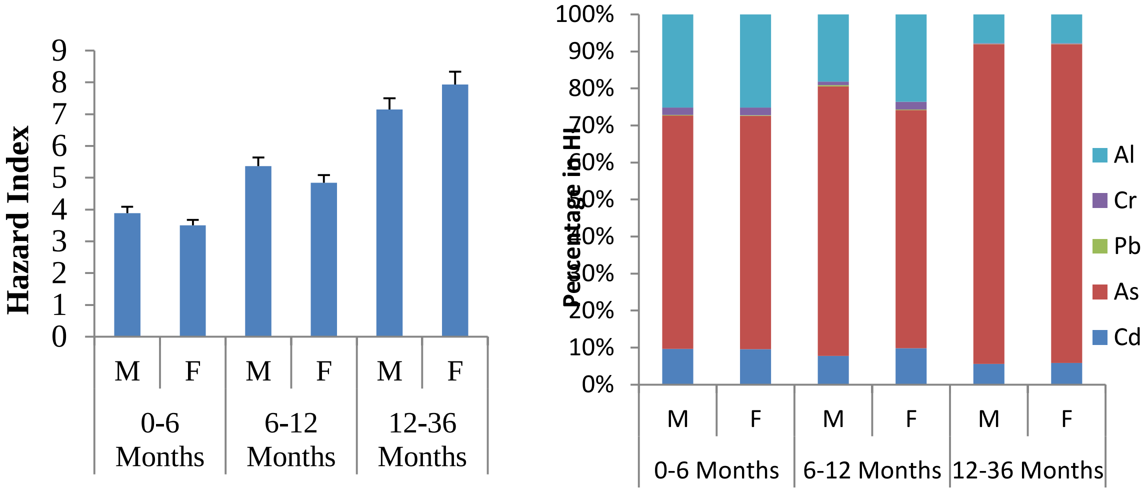

Figure 4: (A) Hazard Index (HI) in Infant Formula and Children Food Products between the Age Groups of 0-6, 6-12, and 12-36 months, (B) Percentage Contribution of Metals in Hazard Index (HI)

Table 7 shows the estimated lifetime cancer risk associated with exposure to cadmium (Cd), arsenic (As), lead (Pb), and chromium (Cr) in infants aged 0–6, 6–12, and 12–36 months. Arsenic contributed the highest cancer risk across all age groups and genders, exceeding the acceptable limit (1.0×10^{-4}), especially in older infants. The values for cadmium and chromium were also elevated in some groups, indicating a potential long-term carcinogenic concern due to the consumption of contaminated food products.

Table 7: Estimated Cancer Risk for Infant between 0-6, 6-12 and 12-36 months

S/N	STAGE	GENDER	Cd	As	Pb	Cr
1.	0-6 Months	M	9.0×10^{-4a}	1.11×10^{-3a}	9.18×10^{-6a}	1.4×10^{-4a}
		F	8.1×10^{-4a}	9.9×10^{-4b}	8.8×10^{-7b}	1.2×10^{-4a}
2.	6-12 Months	M	1.12×10^{-3b}	1.3×10^{-3a}	1.14×10^{-6c}	1.7×10^{-4a}
		F	1.13×10^{-3b}	1.4×10^{-3a}	1.16×10^{-6c}	1.7×10^{-4a}
3.	12-36 Months	M	1.0×10^{-4c}	2.8×10^{-3a}	7.9×10^{-7b}	2.3×10^{-5b}
		F	1.11×10^{-2d}	3.1×10^{-3a}	8.9×10^{-7b}	2.6×10^{-5b}

The results were presented as mean ± SEM (n=6). Mean values with different superscript letters along the columns were significantly different ($p<0.05$).

DISCUSSION

The demographic data revealed distinct patterns in the distribution of infants and children across various age groups, which had important implications for the study of heavy metal exposure. The differences in body weight among the age groups and genders suggested that infants and children are at different stages of development, which may influence their susceptibility to heavy metal exposure from food products. By including both genders and a range of age groups, the research provided a comprehensive assessment of potential risks associated with heavy metal exposure during critical stages of growth. This approach aligned with previous studies, such as those by Amarh *et al.* (2023) and Su *et al.* (2020), which also emphasized the need to consider demographic variations in health risk assessments.

The study underscores significant age-related trends in feeding practices among infants and children, with increasing reliance on formula as they grow older. In the 0-6 months age group, combination feeding is most common, while formula feeding rises substantially by the 12-36 months age group, suggesting increased formula dependency and potential exposure to contaminants as children age. Feeding frequency and quantity also increase with age, with the youngest group (0-6 months) primarily fed once or twice daily, while older children, especially those aged 12-36 months, are fed more than three times daily. This pattern raises concerns about exposure to contaminants through increased intake, given the correlation between higher dietary consumption and contaminant exposure risks. Research emphasizes that young children are particularly vulnerable to heavy metal toxicity due to their relatively higher food and formula intake per body weight (Duffy *et al*., 2019; Gehring *et al*., 2021). Comparative studies further highlight the need for vigilance in monitoring and regulating heavy metal levels in infant foods and formulas. For example, Wang *et al*. (2020) observed that early-life formula consumption significantly elevates exposure to heavy metals, while Zhang *et al*. (2023) emphasized the necessity of stringent safety regulations and regular contaminant monitoring to protect infants from potential health risks. These findings underscore the critical need to monitor feeding practices, ensure safe contaminant levels in food products, and implement measures to minimize risks to infants and young children.

The study highlights key factors influencing formula selection, preparation, and related health risks across age groups, emphasizing the significance of availability, nutritional content, preparation methods, and water safety. Availability is the primary factor affecting formula selection across all age groups, with nutritional content becoming more influential in later stages as parents prioritize quality with the child's dietary needs diversifying (Smith *et al*., 2020; Johnson *et al*., 2022). Most parents rely on package instructions for preparation, with decreasing consultation from paediatricians as children grow older. The shift in water type—from table water in the 0-6 months group to more frequent tap water uses in the 12-36 months group—suggests convenience-driven decisions, though this can pose risks in areas with unsafe water supplies (Brown *et al*., 2019). Studies highlight the importance of safe water and proper formula preparation to mitigate contamination risks (Robinson *et al*., 2021; Patel *et al*., 2022).

In terms of heavy metal contamination, the assessment showed consistent cadmium levels across age groups, aligning with findings of generally low contamination but emphasizing its bio accumulative risk (Eroglu *et al*., 2017). Arsenic and lead levels peaked in the 6-12 months group, posing heightened neurotoxic and carcinogenic risks and aligning with previous studies from other regions (Carignan *et al*., 2015; Liu *et al*., 2015; Gu *et al*., 2020; Domfeh, 2021). Chromium levels, although low, exhibited variability, stressing the importance of rigorous quality control (Gribble *et al*., 2020). Aluminium levels were highest in the 0-6 months group, highlighting the need for stricter regulatory guidelines due to its effects on early neurological and bone development (Bishop *et al*., 2017). While metal concentrations stayed within FDA and EFSA limits, these variations indicate a need for continuous monitoring and quality assurance to safeguard infant health during critical developmental periods (FDA, 2020; EFSA, 2021).

The study shows concerning levels of heavy metals including cadmium, arsenic, lead, chromium, and aluminium, in various infant formula formulations (milk-based, cereal-based, and mixed), with cereal-based and mixed types often showing elevated concentrations. Elevated cadmium and arsenic levels, especially in cereal-based products due to rice content, align with prior studies (HBBF, 2021; FDA, 2023) that reveal significant contamination risks from agricultural practices and ingredient sources. Lead, chromium, and aluminium exposure, stemming from environmental factors, agricultural methods, and potentially packaging or processing practices, underscore the urgent need for stringent regulations and industry monitoring to protect infants from harmful exposures (Domfeh, 2021; Deminguez *et al*., 2017; FDA, 2023; Amarh *et al*., 2023; Saiyed and Yokel, 2005; Kumari *et al*., 2017; FSN, 2023).

Cadmium (Cd) exposure is particularly concerning due to its potential to cause kidney damage and bone demineralization. Cadmium levels were notably high in crackers and instant noodles, indicating contamination likely from agricultural and food processing practices (Ayanda *et al*., 2019). Arsenic was highest in instant noodles and dairy products, suggesting contamination from agricultural sources and industrial processing, consistent with findings in rice products in Nigeria (Akinyele and Shokunbi, 2015). Lead was most concentrated in chocolates, followed by snacks and instant noodles, posing cognitive risks and aligning with Oguntona *et al*. (2019), who reported elevated lead levels in processed foods popular with children. Chromium was highest in instant cereals and chocolates, pointing to contamination from industrial pollution, as observed by Adie and Osibanjo (2009). Aluminium was concentrated in instant cereals and crackers, likely stemming from packaging and processing equipment, in line with findings by Ogunfowokan *et al*. (2016). These results highlight the need for stringent regulatory oversight, quality control, and safe production practices to mitigate heavy metal exposure risks in children's foods.

The study emphasizes that increasing ingestion rates (IR) with age, combined with the unique vulnerability of infants and children to metal toxicity, underscore the importance of stringent safety measures for food and formula products. In the 0-6 months age group, ingestion rates are lower, aligning with reduced exposure risk, but as children progress to the 6-12 months and 12-36 months age groups, ingestion rates increase significantly. This growth-related rise in ingestion rates reflects greater caloric and nutritional needs but also amplifies the risk of metal exposure if contaminants are present in foods. Even trace levels of metals could lead to considerable intake as consumption volumes grow. These findings highlight the critical need for comprehensive testing and regulation of children's food products to limit potential exposure risks. Furthermore, body weight affects how are distributed and impact toxicity, yet ingestion rates are the primary metric for assessing direct exposure. The findings align with research by Duffy *et al.* (2019) and Wang *et al.* (2020), both of which emphasize the necessity for rigorous monitoring of metal levels and regular assessments in children's foods to prevent harmful exposure.

The assessment of Estimated Daily Intake (EDI) values for Cadmium (Cd), Arsenic (As), Lead (Pb), Chromium (Cr), and Aluminium (Al) among infants and children in this study highlights the importance of monitoring these heavy metals due to children's heightened vulnerability to toxic effects during development. Across age groups, the study found similar EDI levels between male and female infants and children, indicating comparable exposure risks across genders.

In the 0–6-month age group, EDI levels for Cd, As, Pb, Cr, and Al were present at concerning levels, aligning with EFSA (2021) findings that underscore the need for rigorous monitoring to protect infants, who are at a critical stage of biological development. As infants transition to the 6–12-month age group, slight EDI variations reflect dietary changes, yet both genders remained similarly exposed, reinforcing the importance of ongoing heavy metal intake assessments as children's exposure to solid foods increases (Amarh *et al*., 2023). In the 12-36-month age group, EDI values showed further shifts with increased dietary diversity. Despite these changes, no significant difference was observed between male and female EDI values, emphasizing the consistent risk of exposure across genders. During this phase, varied diets may heighten exposure risks if contaminated foods are not closely monitored, as shown by Su *et al.* (2020).
Notably, Cd EDI values in 50% of samples exceeded the Provisional Tolerable Daily Intake (PTDI), signalling the urgent need for stricter cadmium control in children's foods due to its potential health impacts, including kidney damage. While EDI values for As, Pb, Cr, and Al remained within PTDI limits, the long-term risks of even low-level exposure during early development should not be ignored. The findings mirror Amarh *et al.* (2023), highlighting global concerns around heavy metal contamination in children's foods and underscoring the need for continuous, worldwide monitoring and regulatory efforts to safeguard children's health.

The Hazard Quotient (HQ) analysis of heavy metals in infants' and children's food products reveals critical health risks, particularly from Cadmium (Cd) and Arsenic (As), which present the most significant concerns across different age groups and genders. For Cd and As, HQ values frequently exceeded safe limits, reflecting severe risks such as kidney damage and developmental toxicity, aligning with findings by Akpe *et al.* (2021) and Ghuniem *et al.* (2020), which underscore the need for strict regulation and contamination control. Lead's neurotoxicity remains concerning even with HQ values below 1, as even minimal exposure can impair cognitive development, an issue echoed in Su *et al.* (2020). Chromium HQ values, while within safe limits, highlight the importance of further analysis to differentiate between its less toxic (III) and more toxic (VI) forms. For Aluminium, HQ values, particularly among younger age groups, approached or exceeded safe thresholds, raising potential neurotoxic risks and underscoring the need for stringent monitoring. Collectively, these findings stress the need for rigorous regulatory oversight and continuous monitoring of heavy metal contamination in children's food products to mitigate long-term health risks.

The Hazard Index (HI) analysis of heavy metals—Cadmium (Cd), Arsenic (As), Lead (Pb), Chromium (Cr), and Aluminium (Al)—in infant formulas and children's food products highlights cumulative risks that increase with age, emphasizing the growing danger from prolonged exposure. While cadmium's contribution to the HI decreases with age, its high toxicity and potential for bioaccumulation remain significant concerns, particularly given its classification as a Group 1 carcinogen by the IARC (Akpe *et al*., 2021). Arsenic consistently shows the highest contribution to the HI across all age groups, with increasing risks as children age, stressing the need for urgent mitigation efforts, as it is also a Group 1 carcinogen (Ghuniem *et al*., 2020). Although lead's contribution is smaller, its neurotoxic effects, even at low levels, make its presence in infant food concerning, in line with CDC guidelines that no lead exposure is safe (Su *et al*., 2020). Chromium's low contribution, which varies across age groups, underscores the importance of identifying the specific form of chromium, particularly the carcinogenic Chromium VI, to assess its real health risks (Ghuniem *et al*., 2020). Aluminium's higher contribution in younger age groups raises neurotoxic concerns, and although its percentage decreases with age, long-term exposure could lead to bioaccumulation, further increasing health risks (Akpe *et al*., 2021). The overall increase in HI with age underscores the cumulative risk from multiple metals, reinforcing the need for stringent regulatory measures to reduce heavy metal contamination and protect children's health, with continuous monitoring and risk assessment crucial to mitigating potential long-term health impacts.

The assessment of estimated cancer risks for Cadmium (Cd), Arsenic (As), Lead (Pb), and Chromium (Cr) in infant food products reveals significant concerns, particularly as exposure increases with age. Cadmium presents a heightened cancer risk, especially in the 12-36 months age group, exceeding the EPA's reference cancer risk level, which aligns with findings by Akpe *et al*. (2021) regarding its classification as a Group 1 carcinogen. Similarly, arsenic poses a progressively increasing cancer risk, particularly in older infants, surpassing the EPA's risk threshold and emphasizing the need for stringent controls, as noted by Ghuniem *et al*. (2020). While lead's cancer risk is relatively low, its neurodevelopmental effects still necessitate stringent monitoring, in line with Su *et al*. (2020). Chromium's cancer risk remains below reference levels but varies with age and may involve differing toxicity depending on the chromium form, underscoring the need for further research, as highlighted by Ghuniem *et al*. (2020). These findings collectively stress the need for continuous monitoring and regulatory measures to reduce exposure to these harmful metals and mitigate potential long-term health impacts in infants

CONCLUSION

This study highlighted significant health risks from heavy metals, particularly arsenic, cadmium, and lead, to infants and children through food products in Sokoto Metropolis. The varying levels of estimated daily intake, hazard quotients, and cancer risks across age groups underscore the increasing vulnerability with age. Arsenic consistently posed the highest risk, exceeding safe thresholds, while other metals like lead and chromium, despite lower risks, still warrant attention due to their long-term health impacts. The findings call for urgent regulatory action, continuous monitoring, and public awareness to reduce exposure and safeguard children's health.

Recommendations

Based on the conducted research, it is recommended that regulatory authorities implement more rigorous and continuous monitoring of heavy metals in infant formulas and children's food products, while investing in advanced detection techniques and refining risk assessment models. Additionally, further research on the bioavailability and chronic health effects of these metals, as well as improved transparency in reporting, will help ensure safer food for children and better inform public health policies.

REFERENCES

Adie, G. U., and Osibanjo, O. (2009). Assessment of heavy metals in processed foods in Nigeria. *African Journal of Environmental Science and Technology*, *3*(9): 264–271.

Akinyele, I. O., and Shokunbi, O. S. (2015). Concentrations of heavy metals in selected foods consumed in Nigeria. *Food and Chemical Toxicology, 84*: 73–79. https://doi.org/10.1016/j.fct.2015.06.014

Akonnor, S., and Richter, R. C. (2021). Evaluation of stage 2 baby foods as potential sources of heavy metal toxicity in infants 6 to 12 months. *Journal of Undergraduate Chemistry Research, 20*(2): 23.

Ayanda, O. I., Ojo, O. S., and Aladesanmi, A. J. (2019). Cadmium accumulation in food crops: A case study of Lagos, Nigeria. *Journal of Health and Pollution, 9*(24): 191209. https://doi.org/10.5696/2156-9614-9.24.191209

Bishop, N. J., Morley, R., and Day, J. P. (2017). Aluminium in the Infant Diet. *Paediatrics,* 140(3): e20173719.

Brown, A. (2018). Assessment of heavy metal intake in infants: A prospective cohort study. *Paediatrics', 15*(3): 345–357.

Carignan, C. C., Karagas, M. R., Punshon, T., Gilbert-Diamond, D., Cottingham, K. L., and Sayarath, V. (2015). Arsenic in infant formulas and first foods. *Environmental Health Perspectives, 123*(7): 1–8. https://doi.org/10.1289/ehp.1409531

Domfeh, A. (2021). Assessment of pediatric health risk associated with trace metals and polycyclic aromatic hydrocarbons (PAHs) contamination in cereal-based baby foods from the Greater Accra Region. (Master's thesis, University of Ghana).

Dominguez, A., Paz, S., Rubio, C., Gutiérrez, Á., Gonzalez-Weller, D., Revert, C., and Hardisson, A. (2017). Essential and toxic metals in infant formula from the European community. *Open Access Journal of Toxicology, 2*(1): 1–8. https://doi.org/10.19080/oajt.2017.02.555585

Eroglu, H. E., Yılmaz, F., Kaya, S., Başkan, K. S., Kaya, G., and Yağmurlu, A. Ç. (2017). Cadmium, lead, and chromium in infant formulas marketed in Turkey. *Fresenius Environmental Bulletin, 26*(4): 2911–2917.

European Food Safety Authority (EFSA). (2021). Dietary exposure to inorganic arsenic in the European population. *EFSA Journal, 19*(8): e06785.

FDA. (2021). Closer to Zero Action Plan for Baby Foods. Retrieved from https://www.fda.gov

Food Safety News. (2023). Heavy metals in baby food: Persistent concerns. Retrieved from https://www.foodsafetynews.com.

Gu, Z., de Silva, S., and Reichman, S. M. (2020). Arsenic in rice-based infant food in Australia. *International Journal of Environmental Research and Public Health*, *17*(2): 415. https://doi.org/10.3390/ijerph17020415.

Gupta, N., Khan, D. K., and Santra, S. C. (2010). Heavy metal accumulation in vegetables grown in a long-term wastewater-irrigated agricultural land of tropical India. *Environmental Monitoring and Assessment*, 184(11): 6673-6682.

Healthy Babies Bright Futures. (2021). What's in my baby's food? Retrieved from https://www.healthybabyfood.org.

Johnson, R. (2021). Heavy metal intake in toddlers: Longitudinal insights. *Journal of Nutritional Science*, *20*(4): 567–580.

Kumari, M., Tripathi, B. D., and Pathak, V. (2017). Heavy metal risk in vegetables irrigated with river Ganga water. *Environ. Monit. Assess.*, 189(1): 42.

Lin, X., Wu, X., Li, X., Zhou, Q., Liang, Y., Tang, S., Hu, Y., Chen, Y., Jiang, G., and Zhu, B. (2022). Infant exposure to elements in southern China. *Science of the Total Environment.*, 838(4): 156597.

Liu, X., Liu, L., and Gao, R. (2015). Lead contamination in milk powder. *Journal of Food Safety and Quality*, 6(3): 1087-1092.

Ogunfowokan, A. O., Asubiojo, O. I., and Udo, J. I. (2016). Aluminium in Nigerian foods. *Environmental Monitoring and Assessment*, 188(8): 472.

Sahito, Z. A., Zehra, A., Tang, L., Ali, Z., Hashmi, M. L. R., Bano, N., Ullah, M. A., He, Z., and Yang, X. (2021). Arsenic and mercury uptake and accumulation in oilseed sunflower accessions selected to mitigate co-contaminated soil coupled with oil and bioenergy production. *Journal of Cleaner Production*, *291*: 125226. https://doi.org/10.1016/j.jclepro.2021.125226

Saiyed, S. M., and Yokel, R. A. (2015). Aluminium content of some foods and food products in the USA, with aluminium food additives. *Food Additives and Contaminants*, 22(3): 234–244.

Smith, A. H., Lingas, E. O., and Rahman, M. (2020). Contamination of drinking water by arsenic in Bangladesh: A public health emergency. *Bulletin of the World Health Organization*, 78(9): 1093–1103.

Su, C., Zheng, N., Gao, Y., Huang, S., Yang, X., Wang, Z., and Wang, J. (2020). Content and dietary exposure assessment of toxic elements in infant formulas from the Chinese market. *Foods*, 9(12): 1839.

Thurow, R. (2016). The first 1,000 days: A crucial time for mothers and children. *World Breastfeed Medicine*, 11: 416–418.

Zhang, C., Gan, C., Ding, L., Xiong, M., Zhang, A., and Li, P. (2020). Maternal inorganic mercury exposure and renal effects in the Wanshan mercury mining area, Southwest China. *Ecotoxicology and Environmental Safety*, 189: 109987. https://doi.org/10.1016/j.ecoenv.2019.109987