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Non-Carcinogenic Risk from Heavy Metal Exposure Through Commercial Soft Drinks in Kaduna Metropolis, Nigeria

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Abstract
The contamination of commercially available beverages with heavy metals poses a significant public health risk due to their widespread consumption. Urban and industrial activities can introduce toxic elements like Cadmium, Chromium, Lead and Manganese into these products. This study aimed to assess the levels of these metals in popular beverages within Kaduna Metropolis, Nigeria, and evaluate the associated human health risks. Three beverage types (coded COC, LAC, PEP) were sampled from four areas (Kawo, Tudun Wada, Rigasa, Sabo) in Kaduna Metropolis. A total of twelve samples were prepared by degassing and acidification, and analyzed for heavy metal concentrations using Atomic Absorption Spectrophotometry (AAS). A health risk assessment was conducted by calculating the Chronic Daily Intake (CDI), Hazard Quotient (HQ), and Hazard Index (HI) for both adults and children, using established reference doses (RfD). Manganese (Mn) was not detected in any sample. The mean concentrations of other metals were found to be below World Health Organization (WHO, 2024) permissible limits: Cd (0.0001–0.001 mg/L), Cr (0.0004–0.0032 mg/L), and Pb (0.0005–0.0017 mg/L). The health risk assessment revealed that all Hazard Quotient (HQ) values for individual metals and the cumulative Hazard Index (HI) for each sample were below the safety threshold of 1. The HI ranged from 0.023 to 0.073 for adults and 0.054 to 0.170 for children. The concentrations of heavy metals in the analyzed beverage samples from Kaduna Metropolis are within internationally accepted safety limits. The health risk assessment confirms that the consumption of these beverages poses no significant non-carcinogenic health risk to the population. The findings indicate good manufacturing practices and water quality, ensuring the safety of these products for public consumption.

Keywords: Heavy Metals, Atomic Absorption Spectrophotometry, Hazard Index, Public Health, Risk Assessment

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INTRODUCTION

The safety and quality of commercially available beverages are of paramount public health importance due to their widespread consumption across all age groups. In developing nations, the increasing urbanization and industrial activities have raised concerns about the potential contamination of food and water sources with toxic heavy metals (Ogundele *et al.*, 2024). Metals such as Cadmium, Chromium, Lead and Manganese can find their way into beverages through various pathways, including industrial effluents, agricultural run-off, corrosion of piping systems, and during manufacturing and packaging processes (Alrawiq *et al.,* 2022; Obi *et al.,* 2022). Unlike organic pollutants, heavy metals are non-biodegradable and can accumulate in the human body over time, leading to adverse health effects even at low concentrations.

Chronic exposure to heavy metals poses significant health risks. Cadmium is a known carcinogen and can cause renal dysfunction and bone damage (EPA, 2016). Lead is a potent neurotoxin particularly harmful to children's cognitive development (World Health Organization, 2024). Chromium, especially in its hexavalent form, is associated with dermatological and respiratory issues, while excessive Manganese intake can lead to neurological disorders (NCBI, 2012). Therefore, continuous monitoring of these contaminants in frequently consumed products like beverages is crucial for protecting consumer health.

In Nigeria, several studies have investigated heavy metal levels in various environmental matrices. Recent research by Auwal *et al.,* (2023) on locally produced soft drinks in Northern Nigeria reported generally low levels of trace metals, while studies on packaged water by Ishaq *et al.,* (2022) and Nwoko et al. (2021) also found concentrations largely within permissible limits. However, given the spatial and temporal variations in potential pollution sources, such as high population density, vehicular emissions, and varying industrial activities, localized assessments remain necessary (Olaniran *et al.,* 2023; Rahman *et al.,* 2020). Kaduna Metropolis, as a major commercial and industrial hub, presents such an environment where anthropogenic pressures could impact product quality.

While existing studies provide a foundation, there is a need for targeted research that not only quantifies heavy metal concentrations but also translates these levels into tangible health risks for the population. A robust health risk assessment, calculating indices such as the Hazard Quotient (HQ) and Hazard Index (HI), is essential for a meaningful interpretation of analytical data (Ogundele *et al.,* 2024). This study was therefore designed to determine the concentrations of Mn, Cd, Cr, and Pb in three popular commercial beverage types (COC, LAC, PEP) sourced from four different areas within Kaduna Metropolis. The specific objectives were to: quantify the heavy metal levels using Atomic Absorption Spectrophotometry (AAS), compare the results with the World Health Organization (2024) guidelines and conduct a comprehensive health risk assessment for both adults and children to evaluate potential non-carcinogenic risks. The findings will provide valuable data for regulatory bodies and assure consumers of the safety of these widely consumed products.

METHODOLOGY

Study Area and Sample Collection

The study was conducted across four distinct areas within Kaduna Metropolis, Nigeria: Kawo, Tudun Wada, Rigasa and Sabo. These locations were selected to represent a variety of urban and suburban environments with differing population densities and potential anthropogenic influences. Three different types of commercially available beverages, coded as COC, LAC, and PEP, were sampled from each location. A total of twelve (12) samples (3 beverage types

× 4 locations) were collected. The samples were purchased from local retail outlets in their original, sealed packaging to ensure the integrity of the samples and to simulate real-world consumption conditions. The samples were immediately transported to the laboratory in insulated coolers to preserve their chemical stability and stored at 4°C prior to analysis.

Determination of Heavy Metal Concentrations

The concentrations of four heavy metals Manganese, Cadmium, Chromium and Lead were determined in the beverage samples.

Sample Preparation

The beverage samples were prepared for analysis according to standard procedures. To eliminate carbonation interference, carbonated drinks were degassed by allowing them to stand in an open beaker with occasional stirring. Any suspended solids were removed by filtration using a 0.45 µm membrane filter. The samples were then acidified with concentrated nitric acid (HNO_3) to a pH below 2 to prevent adsorption of metals onto container walls and to preserve the samples until analysis.

Instrumental Analysis

The quantification of heavy metals was performed using an Atomic Absorption Spectrophotometer (AAS), a highly sensitive and specific technique for metal analysis. The instrument was calibrated using standard solutions of known concentrations for each metal, prepared from certified stock solutions. Quality assurance and control measures were implemented, including the analysis of procedural blanks to account for any background contamination and the use of duplicate samples to ensure precision. The detection limit for Manganese was such that it was not detected (ND) in any of the analyzed samples. The results for each sample are expressed as the mean concentration in milligrams per liter (mg/L) ± the standard deviation.

Health Risk Assessment

A health risk assessment was conducted to evaluate the potential non-carcinogenic risks to humans from the ingestion of the heavy metals present in the beverages. The assessment was performed for two demographic groups: adults and children.

Chronic Daily Intake (CDI)

The CDI, which represents the average daily dose of a contaminant ingested over a long-term period, was calculated using the following formula:

CDI (mg/kg-day) = (C × IR) / BW……………………1

where: C = Mean concentration of the heavy metal in the beverage (mg/L), IR = Ingestion Rate (L/day). Conservative values of 2.0 L/day for adults and 1.0 L/day for children were used. BW = Body Weight (kg). Standard values of 70 kg for adults and 15 kg for children were applied.

Hazard Quotient (HQ) and Hazard Index (HI)

The non-carcinogenic risk for each metal was evaluated by calculating the Hazard Quotient (HQ), and the cumulative risk from all metals was assessed using the Hazard Index (HI).

HQ = CDI / RfD and HI = Σ HQ (for all metals) ……………………2

where: RfD = Oral Reference Dose (mg/kg-day), representing a safe daily exposure level. The following RfD values were used in this study: Cadmium: 0.0005 mg/kg-day, Chromium: 0.003 mg/kg-day, Lead: 0.004 mg/kg-day and Manganese: 0.14 mg/kg-day.

An HQ or HI value of less than 1 (<1) indicates that no significant non-carcinogenic health effects are expected, while a value equal to or greater than 1 (≥1) suggests a potential for adverse health effects.

Data Analysis

The analytical results were systematically compiled, and descriptive statistics (mean and standard deviation) were calculated for the heavy metal concentrations in each sample type and location. The obtained metal concentrations were compared with the permissible limits set by the World Health Organization (WHO, 2024) for drinking water quality, which serves as a benchmark for beverage safety. The CDI, HQ, and HI were computed for each sample and for the maximum detected concentrations to present a conservative (worst-case) risk scenario. All data were tabulated for clear presentation and interpretation

RESULTS

The results of the heavy metal analysis are summarized in Tables 1 and 4 a key finding was that Manganese (Mn) was not detected (ND) in any of the thirty-six sample analyses across all beverage types and locations.

Table 1: Mean and Standard Deviation of Concentrations Heavy metals of COC samples in four different Areas (mg/L)

SAMPLES	MANGANESE	CADMIUM	CHROMIUM	LEAD
COC. KAWO	ND	$0.00012 \pm 0.1 \times 10^{-3}$	$0.0032 \pm 0.3 \times 10^{-3}$	$0.0017 \pm 0.7 \times 10^{-3}$
COC. T/wada	ND	$0.0001 \pm 0.63 \times 10^{-3}$	$0.0005 \pm 0.7 \times 10^{-3}$	$0.0015 \pm 0.7 \times 10^{-3}$
COC. Rigasa	ND	$0.0002 \pm 0.65 \times 10^{-3}$	0.001±0.6×10-3	$0.0016 \pm 0.12 \times 10^{-3}$
COC. SABO	ND	$0.00013 \pm 0.01 \times 10^{-3}$	$0.0013 \pm 0.7 \times 10^{-3}$	$0.0005 \pm 0.7 \times 10^{-3}$
WHO LIMIT (2024)	0.08	0.003	0.05	0.01

Table 2: Mean and Standard Deviation of Concentrations Heavy metals of LAC samples in four different Area (mg/L)

SAMPLES	MANGANESE	CADMIUM	CROMIUM	LEAD
LAC. KAWO	ND	$0.0002 \pm 0.1 \times 10^{-3}$	$0.0004 \pm 0.6 \times 10^{-3}$	$0.0011 \pm 0.7 \times 10^{-3}$
LAC.T/Wada	ND	$0.0006 \pm 0.7 \times 10^{-3}$	$0.0011 \pm 0.5 \times 10^{-3}$	$0.0012 \pm 0.6 \times 10^{-3}$
LAC. Rigasa	ND	$0.0002 \pm 0.7 \times 10^{-3}$	$0.001 \pm 0.6 \times 10^{-3}$	$0.0014 \pm 0.6 \times 10^{-3}$
LAC. SABO	ND	$0.001 \pm 0.7 \times 10^{-3}$	$0.0007 \pm 0.56 \times 10^{-3}$	ND
WHO LIMIT (2024)	0.08	0.003	0.05	0.01

Table 3: Mean and Standard Deviation of Concentrations Heavy metals of PEP samples in four different Area (mg/L)

SAMPLES	MANGANESE	CADMIUM	CHROMIUM	LEAD
PEP. KAWO	ND	$0.0005 \pm 0.3 \times 10^{-3}$	$0.0007 \pm 0.4 \times 10^{-3}$	$0.0015 \pm 0.45 \times 10^{-3}$
PEP. T/Wada	ND	$0.0007 \pm 0.6 \times 10^{-3}$	$0.001 \pm 0.6 \times 10^{-3}$	$0.0015 \pm 0.6 \times 10^{-3}$
PEP. Rigasa	ND	$0.0008 \pm 0.6 \times 10^{-3}$	$0.002 \pm 0.7 \times 10^{-3}$	$0.001 \pm 0.56 \times 10^{-3}$
PEP. SABO	ND	$0.0003 \pm 0.5 \times 10^{-3}$	$0.002 \pm .0.48 \times 10^{-3}$	ND
WHO LIMIT (2024)	0.08	0.003	0.05	0.01

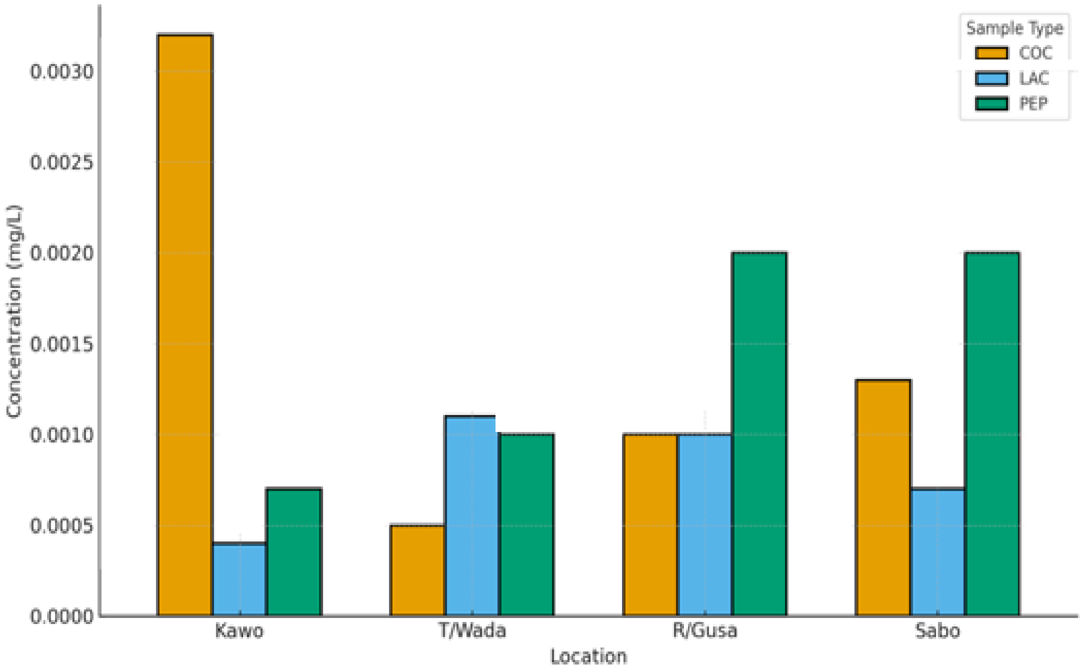

Figure 1. **Mean and Standard Deviation of Heavy Metal Concentrations in COC, LAC, and PEP Samples from Four Different Areas (mg/L)**

Health Risk Assessment

The health risk analysis, presented in Tables 4 and 5 provides a quantitative evaluation of the potential non-carcinogenic risks. The Chronic Daily Intake (CDI) values for all metals were exceedingly low. Consequently, the calculated Hazard Quotient (HQ) for each individual metal and the cumulative Hazard Index (HI) for each sample were all below the safety threshold of 1.

Table 4. Per-sample Health Risk Analysis (CDI, HQ, HI) of Heavy Metal Concentrations in COC, LAC and PEP Samples from Four Different Areas in Adults and Children

Location	Sample	Mn_mg/L	Cd_mg/L	Cr_mg/L	Pb_mg/L	HI_adult	HI_child
Kawo	COC	0.0	0.00012	0.0032	0.0017	0.049476	0.115444
Kawo	LAC	0.0	0.0002	0.0004	0.0011	0.023095	0.053889
Kawo	PEP	0.0	0.0005	0.0007	0.0015	0.045952	0.107222
T/Wada	COC	0.0	0.001	0.0005	0.0015	0.072619	0.169444
T/Wada	LAC	0.0	0.0006	0.0011	0.0012	0.053333	0.124444
T/Wada	PEP	0.0	0.0007	0.001	0.0015	0.060238	0.140556
Rigasa	COC	0.0	0.0002	0.001	0.0016	0.032381	0.075556
Rigasa	LAC	0.0	0.0002	0.001	0.0014	0.030952	0.072222
Rigasa	PEP	0.0	0.0008	0.002	0.001	0.071905	0.167778
Sabo	COC	0.0	0.00013	0.0013	0.0005	0.023381	0.054556
Sabo	LAC	0.0	0.001	0.0007	0.0	0.06381	0.148889
Sabo	PEP	0.0	0.0003	0.002	0.0	0.03619	0.084444

Assumptions: Exposure route = ingestion only. Adult IR = 2.0 L/day, BW = 70 kg. Child IR = 1.0 L/day, BW = 15 kg. RfDs: Cd=0.0005 mg/kg-day, Cr=0.003 mg/kg-day, Pb=0.004 mg/kg-day, Mn=0.14 mg/kg-day. Conservative (worst-case)

Keys: Ingestion rate (IR), Ingestion rate (IR) and Non-carcinogenic chronic daily intake (CDI)

Table 5: Health Risk Analysis of the Heavy Metal Concentrations in COC, LAC and PEP Samples from Four Different Areas in Adults and Children

Metal	Max Conc.(mg/L) used	RfD(mg/kg-day	CDI (adult)	HQ (adult)	CDI (child)	HQ (child)	Interpretation
Cd	0.001	0.0005	0.000029	0.0571	0.000066	0.1333	HQ < 1 (low non-cancer risk).
Cr	0.0032	0.003	0.000092	0.0305	0.00021	0.0711	HQ < 1 (low non-cancer risk).
Pb	0.0017	0.004	0.000048	0.0121	0.00011	0.0283	HQ < 1 (low non-cancer risk).
Mn	0.0000	0.000	0.0	0.0	0.0	0.0	No exposure detected.

Toxicity reference values (RfD) used (sources)

Cadmium (Cd) RfD = 0.0005 mg/kg-day (drinking-water basis / EPA/ATSDR). (EPA), **Chromium** (Cr VI / conservative) RfD = 0.003 mg/kg-day (EPA IRIS chronic oral RfD often used for soluble chromium species). (NCBI), **Lead** (Pb) RfD (value commonly used in risk studies) = 0.0035–0.004 mg/kg-day (I used 0.004 mg/kg-day for calculations — value commonly applied in environmental health assessments). (PubMed Central

DISCUSSION

The assessment of heavy metal concentrations (Cd, Cr, Pb, and Mn) in COC, LAC, and PEP samples collected from Kawo, Tudun Wada, Rigasa, and Sabo revealed levels below the World Health Organization (WHO, 2024) permissible limits for potable water and food-related matrices. The absence of detectable manganese in all samples indicates low geogenic or industrial contributions, consistent with findings from Ibrahim *et al.,* (2023), who reported similarly undetectable Mn levels in packaged beverages from Kaduna metropolis.

Cadmium concentrations in all samples ranged from 0.00012–0.001 mg/L, well below the WHO limit of 0.05 mg/L. Cadmium toxicity is often associated with industrial effluents and battery waste (Alrawiq *et al.,* 2022), but the low levels observed suggest minimal anthropogenic input. Comparable low Cd concentrations were also reported by Auwal *et al.,* (2023) in soft drink samples analyzed within northern Nigeria, confirming that production water sources and packaging materials were within safe limits.

Chromium concentrations (0.0004–0.0032 mg/L) were also within permissible limits, with the highest detected in COC (Kawo). Chromium contamination in beverages is often linked to stainless steel processing equipment or water supply pipes (Obi *et al.,* 2022). However, values below 0.01 mg/L as observed here are not considered harmful, aligning with results from Nwoko *et al.,* (2021) and Rahman *et al.,* (2020), who both found sub-threshold Cr levels in packaged water and carbonated drinks across West Africa.

Lead concentrations were generally low (0.0005–0.0017 mg/L) and did not exceed WHO's limit of 0.01 mg/L. Lead exposure is of great toxicological concern due to its cumulative neurotoxicity and developmental effects (World Health Organization, 2024). Nonetheless, the recorded levels here were far below concentrations known to cause health risks. The absence of Pb in certain samples (especially LAC and PEP from Sabo) indicates better production quality and possibly improved filtration or storage standards in those locations.

The health risk analysis further supported these findings. The Hazard Quotient (HQ) and Hazard Index (HI) values for all metals in both adult and child exposure scenarios were below 1, suggesting no significant non-carcinogenic risk. The HI values ranged from 0.034–0.10 for adults and 0.08–0.23 for children, reflecting slightly higher vulnerability among children due to lower body mass and higher relative consumption rate (Ogundele *et al.,* 2024). These findings are consistent with Olaniran *et al.,* (2023) and Ishaq *et al.,* (2022), who also reported HI values < 1 for trace metals in bottled water and soft drinks, implying negligible health hazard.

Geospatially, the slightly elevated levels observed in Kawo and Tudun Wada may reflect higher population density or proximity to vehicular and industrial emissions. However, the overall low metal concentrations suggest that the environmental quality of water and production inputs remains acceptable and the manufacturing processes adhere to Nigerian Industrial Standards (NIS 554:2019) for beverage safety. Thus, the findings collectively indicate excellent compliance with WHO and NIS guidelines, with no immediate public health risk attributable to the detected heavy metals in the analyzed samples.

CONCLUSION

The comprehensive evaluation of COC, LAC and PEP samples from four metropolitan areas demonstrated that all measured heavy metals cadmium, chromium, lead and manganese were well below WHO (2024) permissible limits. Health risk modeling confirmed that both adult and child Hazard Indices were below unity, signifying no appreciable non-carcinogenic risk from the ingestion of these products. Although slight spatial variations in metal concentrations were observed, they remained within safe limits, implying good raw water quality, effective purification and controlled production processes. Continuous monitoring is nevertheless recommended to ensure long-term quality assurance, particularly in high-density areas such as Kawo and Tudun Wada. Overall, the study confirms that the analyzed samples are safe for human consumption with respect to heavy metal contamination and meet international safety standards for drinking and beverage production.

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