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Biochemical and Health Risk Assessment of Heavy Metals in Traditional Nigerian Beverages

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Abstract

Background

Traditional beverages such as Zobo, Agbo, Kunu, and Tigernut are widely consumed in Nigeria, but their safety is not routinely assessed beyond basic composition. This study examined the levels of selected heavy metals in these drinks and considered their possible health and biochemical implications.

Methods

Samples were collected from three major markets—Akim, Marian, and Watt. The concentrations of Chromium (Cr), Nickel (Ni), Cadmium (Cd), Copper (Cu), Zinc (Zn), Iron (Fe), and Manganese (Mn) were determined using atomic absorption spectrophotometry. Health risk was assessed using USEPA models, including Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Carcinogenic Risk (CR).

Results

Higher concentrations of Cr, Cd, and Ni were observed in some samples, especially Tigernut and Zobo from Akim and Marian markets. In these samples, THQ and HI values were above 1, while CR values for Cr and Ni were above acceptable limits. This suggests a pattern of repeated exposure rather than isolated contamination.

Conclusion

The findings raise concerns about the safety of these commonly consumed beverages. From a biochemical point of view, continued exposure to these metals may affect normal cellular processes over time. There is a need for better monitoring and improved handling practices in the production of local drinks.

Key Message

Heavy metal contamination of locally prepared beverages has been reported in Nigeria, but data comparing multiple beverage types across locations with quantified risk indices remain limited. This study shows that chromium, cadmium, and nickel occur at higher levels in selected beverages, particularly in samples from Akim and Marian markets, and are associated with elevated THQ, HI, and CR values. By linking these results with established biochemical effects of these metals, the study provides context for how repeated exposure may affect cellular processes over time. The findings support the need for improved monitoring of beverage production practices and more integrated approaches that combine exposure assessment with biological relevance.

1.0 Introduction

The consumption of locally prepared beverages remains widespread across many parts of Nigeria, where drinks such as zobo, agbo, kunu, and tigernut milk are commonly consumed for their nutritional value and cultural relevance. These beverages are typically produced using plant-derived ingredients and traditional processing methods, making them accessible and affordable to a large segment of the population. In addition to their sensory appeal, they are often regarded as sources of energy, micronutrients, and bioactive compounds [1–3].

Tigernut milk (commonly referred to as *kunun aya* in the Northern part of Nigeria), for instance, is prepared from *Cyperus esculentus(*combined with coconut milk, dates and ginger*)* and is valued for its carbohydrate content, dietary fiber, and presence of vitamins such as vitamin E. Zobo, derived from *Hibiscus sabdariffa*, is known for its antioxidant properties, while kunu (a cereal-based beverage) and agbo (a herbal mixture) are traditionally consumed for both nutritional and medicinal purposes [2–5]. Despite these perceived benefits, the methods of preparation and handling of these beverages are often informal and lack standardized quality control.

One of the major concerns associated with such production systems is the potential contamination of beverages with heavy metals. Heavy metals such as chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) may enter food products through contaminated water, raw materials, processing equipment, or environmental exposure during production and storage [6–8]. Unlike many organic contaminants, heavy metals are not biodegradable and may accumulate in biological systems over time, leading to adverse health effects.

Chronic exposure to heavy metals has been associated with a range of toxicological outcomes, including oxidative stress, disruption of enzymatic processes, and interference with essential metal homeostasis [9–11]. Chromium and cadmium, in particular, have been widely studied for their roles in inducing oxidative damage and cellular dysfunction, while nickel has been linked to carcinogenic processes through mechanisms involving DNA damage and epigenetic alterations [12–14].

Given the frequency of consumption of these beverages, there is a need to evaluate not only the concentration of heavy metals present but also the potential health risks associated with their intake. Risk assessment models such as estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), and carcinogenic risk (CR) provide useful tools for assessing both non-carcinogenic and carcinogenic risks associated with dietary exposure [15–17].

Although several studies have reported heavy metal contamination in food and beverages, there is limited information on the comparative risk associated with different types of locally produced beverages within the same geographical area. In addition, few studies have examined these risks from a biochemical perspective, particularly in relation to oxidative stress and enzyme disruption pathways.

Therefore, this study was designed to determine the concentrations of selected heavy metals in commonly consumed locally prepared beverages (zobo, agbo, kunu, and tigernut milk) obtained from major markets in Calabar metropolis, Nigeria, and to evaluate the associated health risks using established toxicological models. The findings are intended to provide insight into potential exposure pathways and contribute to ongoing efforts aimed at improving food safety and public health.

2.0 Materials and Methods

2.1 Study Area

The study was conducted in Calabar Metropolis, Cross River State, Nigeria (see figure 1). Samples were obtained from three major markets (Akim, Marian, and Watt), which serve as key commercial centers supplying locally produced traditional beverages to a large population. The study area is located within the tropical rainforest zone, characterized by high humidity, significant rainfall, and elevated ambient temperatures. These environmental conditions may influence beverage production, storage, and susceptibility to contamination.

2.2 Sample Collection

Four commonly consumed locally prepared beverages- zobo, agbo, kunu, and tigernut milk- were randomly purchased from vendors across the three selected markets. A total of thirty-six (36) samples were collected, comprising four beverage types from three markets (4 × 3 × 3).

Samples were collected in clean, sterilized plastic containers, appropriately labeled, and transported immediately in ice-packed coolers to the Biochemistry Laboratory for analysis.

The inclusion of multiple beverage types and sampling locations was intended to provide a representative assessment of potential consumer exposure within the study area.

2.3 Sample Preparation and Digestion

Samples were subjected to wet acid digestion prior to analysis. Briefly, 5 mL of each sample was transferred into a digestion tube, followed by the addition of 20 mL of an acid mixture (HNO_3:H_2SO_4:HCl:$HClO_4$; 1:3:1:1 v/v).

Digestion was carried out using a FOSS Tecator™ digestion system at 250 °C for approximately 1 hour, or until a clear solution was obtained. The digested samples were then filtered into 100 mL volumetric flasks and diluted to volume with deionized water.

2.4 Heavy Metal Determination

The concentrations of chromium (Cr), cadmium (Cd), nickel (Ni), copper (Cu), zinc (Zn), iron (Fe), and manganese (Mn) were determined using Atomic Absorption Spectrophotometry (AAS) (Buck Scientific Model 210VGP).

Instrument calibration was performed using certified standard solutions for each metal. Metal concentrations were determined following standard analytical procedures, and results were expressed in mg/L.

2.5 Quality Assurance and Quality Control

All glassware and sample containers were acid-washed and thoroughly rinsed with deionized water prior to use. Analytical grade reagents were used throughout the study.

Method accuracy was evaluated through recovery analysis using spiked samples, with percentage recoveries ranging from 95% to 105%. Procedural blanks and reference standards were included to monitor potential contamination and ensure analytical reliability. **Data were expressed as mean values of the samples analyzed.**

2.6 Statistical Analysis

Descriptive statistical methods were used to evaluate variations in heavy metal concentrations across beverage types and sampling locations.

2.7 Ethical Consideration

This study did not involve human or animal subjects. The analysis was limited to commercially available beverages; therefore, ethical approval was not required.

2.8 Health Risk Assessment Models

Potential human health risks associated with the consumption of heavy metal-contaminated beverages were evaluated using United States Environmental Protection Agency (USEPA) risk assessment models. The models applied included Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI), and Carcinogenic Risk (CR), assuming chronic exposure via ingestion.

2.8.1 Estimated Daily Intake (EDI)

The estimated daily intake (EDI) of each metal was calculated using the equation:

EDI = (C × IR) / BW

Where:

C = concentration of heavy metal in beverage (mg/L)

IR = ingestion rate (0.24 L/day)

BW = body weight (60 kg)

2.8.2 Target Hazard Quotient (THQ)

The target hazard quotient (THQ) was used to assess non-carcinogenic risk:

THQ = (EF × ED × IR × C) / (RfD × BW × AT)

Where:

EF = exposure frequency (365 days/year)

ED = exposure duration (30 years)

IR = ingestion rate (0.24 L/day)

C = concentration of heavy metal (mg/L)

RfD = oral reference dose (mg/kg/day)

BW = body weight (60 kg)

AT = averaging time (10,950 days)

THQ < 1 indicates no significant health risk, while THQ ≥ 1 indicates potential risk.

2.8.3 Hazard Index (HI)

The hazard index (HI) represents the cumulative non-carcinogenic risk of multiple metals and was calculated as:

$HI = THQ_1 + THQ_2 + \ldots + THQ_n$

Where:

THQ_1, THQ_2 … THQ_n represent the individual target hazard quotients of the metals.

HI ≥ 1 indicates potential health concern.

2.8.4 Carcinogenic Risk (CR)

Carcinogenic risk (CR) was calculated using the equation:

CR = EDI × CSF

Where:

EDI = estimated daily intake (mg/kg/day)

CSF = cancer slope factor ($mg/kg/day^{-1}$)

Acceptable risk range: 1×10^{-6} to 1×10^{-4}

CR > 10^{-4} indicates significant carcinogenic risk.

3.0 Results

3.1 Heavy Metal Concentrations in Beverage Samples

Table 3 presents the concentrations of Cr, Ni, Cu, Zn, Fe, Mn, and Cd in beverage samples from Akim Market. Tigernut milk recorded the highest concentrations of Cr (1.255 mg/L), Cu (0.161 mg/L), and Cd (0.459 mg/L), while Agbo recorded the lowest Cr concentration (0.276 mg/L). Nickel concentration was highest in Kunu (0.142 mg/L) and lowest in Zobo (0.041 mg/L). Copper ranged from 0.021 mg/L in Kunu to 0.161 mg/L in Tigernut milk. Zinc, iron, and manganese concentrations were generally low across all samples. Cadmium ranged from 0.184 mg/L in Kunu to 0.459 mg/L in Tigernut milk.

Table 4 shows the concentrations of heavy metals in beverages from Marian Market. Tigernut milk recorded the highest concentrations of Cr (0.430 mg/L), Ni (0.270 mg/L), Cu (0.310 mg/L), and Mn (0.150 mg/L). Kunu recorded the highest Fe concentration (0.220 mg/L), while Agbo recorded the highest Zn concentration (0.130 mg/L). Zobo showed moderate values across most metals. Cadmium concentrations ranged from 0.050 mg/L in Zobo and Kunu to 0.070 mg/L in Tigernut milk.

Table 5 presents the concentrations of heavy metals in beverages from Watt Market. Tigernut milk recorded the highest concentrations of Ni (0.270 mg/L), Cu (0.320 mg/L), Zn (0.170 mg/L), and Fe (0.230 mg/L). Zobo recorded the highest Cr concentration (0.230 mg/L), while Kunu recorded the lowest Cr value (0.040 mg/L). Manganese concentrations were highest in Zobo (0.120 mg/L), while cadmium ranged from 0.050 mg/L in Kunu to 0.170 mg/L in Zobo.

Overall, the variations in selected heavy metals (Cr, Cd, and Ni) across the study locations are illustrated in Figure 2 below.

3.2 Estimated Daily Intake (EDI)

Table 6 presents the estimated daily intake (EDI) values of heavy metals corresponding to the concentrations observed in Table 3. Tigernut milk recorded the highest EDI values for Cr (0.0050

mg/kg/day), Cu (0.0006 mg/kg/day), and Cd (0.0018 mg/kg/day), while Agbo recorded the lowest Cr intake (0.0011 mg/kg/day). Nickel intake was highest in Kunu (0.0006 mg/kg/day) and lowest in Zobo and Agbo (0.0002 mg/kg/day). Copper intake ranged from 0.0001 mg/kg/day in Kunu to 0.0006 mg/kg/day in Tigernut milk. Zinc, iron, and manganese intake values were generally low across all samples.

Table 7 shows the estimated daily intake values of heavy metals in beverages from Marian Market. Tigernut milk recorded the highest EDI values for Cr (0.0017 mg/kg/day), Ni (0.0011 mg/kg/day), and Cu (0.0012 mg/kg/day). Kunu recorded the highest Fe intake (0.0009 mg/kg/day), while Agbo recorded the highest Zn intake (0.0005 mg/kg/day). Zobo showed moderate intake values across most metals. Cadmium intake ranged from 0.0002 mg/kg/day in Zobo, Agbo, and Kunu to 0.0003 mg/kg/day in Tigernut milk.

Table 8 presents the estimated daily intake values for beverages from Watt Market. Tigernut milk recorded the highest intake values for Ni (0.0011 mg/kg/day), Cu (0.0013 mg/kg/day), Zn (0.0007 mg/kg/day), and Fe (0.0009 mg/kg/day). Zobo recorded the highest Cr intake (0.0009 mg/kg/day), while Kunu recorded the lowest Cr intake (0.0002 mg/kg/day). Cadmium intake ranged from 0.0002 mg/kg/day to 0.0007 mg/kg/day across samples.

3.3 Target Hazard Quotient (THQ) and Hazard Index (HI)

Table 9 presents the THQ and HI values for beverages from Akim Market. Tigernut milk recorded the highest THQ values for Cr (1.667) and Cd (1.800), as well as the highest HI value (3.507). Zobo recorded the next highest HI value (2.516), followed by Kunu (1.800), while Agbo recorded the lowest HI value (1.882). THQ values for Zn, Fe, and Mn were low across all samples.

Table 10 shows the THQ and HI values for beverages from Marian Market. Tigernut milk recorded the highest HI value (0.958), followed by Kunu (0.620), Zobo (0.529), and Agbo (0.420). Tigernut milk also recorded the highest THQ values for Cr (0.567), Ni (0.055), Cu (0.030), and Cd (0.300). THQ values for Zn, Fe, and Mn remained low across all samples.

Table 11 presents the THQ and HI values for beverages from Watt Market. Zobo recorded the highest HI value (1.034), followed by Tigernut milk (0.459), Agbo (0.385), and Kunu (0.287). Tigernut milk recorded the highest THQ values for Ni (0.055) and Cu (0.033), while Zobo recorded the highest Cd THQ value (0.700). THQ values for Zn, Fe, and Mn were low across all samples.

Overall, the distribution of THQ and HI values across the study locations is illustrated in Figure 3.

3.4 Carcinogenic Risk (CR)

Table 12 presents the carcinogenic risk (CR) values for chromium and nickel in beverages from Akim Market. Tigernut milk recorded the highest chromium CR value (0.0025), followed by Zobo (0.0021),

Kunu (0.0016), and Agbo (0.0006). Nickel CR values were highest in Kunu and Tigernut milk (0.0005) and lowest in Zobo and Agbo (0.0002).

Table 13 shows the carcinogenic risk (CR) values for beverages from Marian Market. Tigernut milk recorded the highest CR values for chromium (0.0009) and nickel (0.0010). Kunu recorded a chromium CR value of 0.0006, while Zobo and Agbo recorded lower values. Nickel CR values ranged from 0.0001 in Kunu to 0.0010 in Tigernut milk.

Table 14 presents the carcinogenic risk (CR) values for beverages from Watt Market. Zobo recorded the highest chromium CR value (0.0005), followed by Agbo (0.0003), while Kunu and Tigernut milk recorded the lowest values (0.0001). Nickel CR values were highest in Tigernut milk (0.0010), followed by Zobo (0.0004), while Agbo and Kunu recorded lower values (0.0002).

4.0 Discussion

The present study evaluated heavy metal contamination in commonly consumed traditional beverages and assessed associated health risks using established USEPA models. Across the sampled locations, a consistent pattern emerged in which Chromium (Cr), Cadmium (Cd), and Nickel (Ni) were present at comparatively higher concentrations than other metals, particularly in samples obtained from Akim and Marian markets. While all analyzed metals are presented in the dataset, chromium, cadmium, and nickel are highlighted in the figures due to their relatively higher concentrations and associated risk indices.

A closer look at the data suggests that certain beverages, especially Tigernut milk and Zobo, tend to accumulate higher levels of these metals. This pattern may not be incidental. Tigernut milk, for instance, undergoes multiple handling and processing steps, which could increase the likelihood of contamination through water sources, processing equipment, or environmental exposure. In contrast, the relatively lower values observed in Watt market samples may reflect differences in sourcing, preparation practices, or environmental conditions. Similar influences of environmental conditions, raw material sourcing, and handling practices on heavy metal contamination have been reported in previous studies [1–4,5,20,21].

From a biochemical standpoint, the implications of these findings are noteworthy. Chromium, particularly in its hexavalent form, is known to undergo intracellular reduction, generating reactive intermediates in the process. This reduction cycle can lead to the formation of reactive oxygen species, thereby disturbing cellular redox balance. Over time, such disturbances may affect lipid membranes, proteins, and nucleic acids, ultimately compromising cellular integrity [11,12].

Cadmium presents a different but equally concerning profile. Its strong affinity for sulfhydryl groups allows it to interact with and inhibit a range of enzymes, including those involved in antioxidant defense. Additionally, its tendency to accumulate in tissues, especially the liver and kidneys, suggests that even low-level but repeated exposure could gradually disrupt metabolic processes [13–15]. The observed values in this study, therefore, raise questions about long-term biochemical burden rather than immediate toxicity.

Nickel, on the other hand, appears to exert its effects more subtly. By interacting with metal-binding sites in proteins and influencing gene expression pathways, it may alter cellular signaling and regulatory mechanisms. Its involvement in epigenetic modifications and interference with DNA repair processes has been documented, which aligns with the elevated carcinogenic risk values obtained in some samples [16–19].

When considered collectively, the metals do not act in isolation. The Hazard Index (HI) values exceeding unity in several samples suggest a combined exposure scenario. Biochemically, such co-exposure is important because multiple metals may compete for detoxification pathways, including glutathione utilization and metallothionein binding. This can amplify oxidative stress and reduce the efficiency of cellular defense systems.

Interestingly, the relatively low risk indices observed in Watt market samples indicate that contamination is not uniform across locations. This variation reinforces the idea that environmental and processing factors play a significant role in determining metal levels in these beverages, as also observed in related studies [5,20,21].

Overall, the findings point toward a pattern of chronic, low-to-moderate exposure with potential cumulative biochemical effects. While acute toxicity may not be immediately evident, the long-term implications, particularly at the level of cellular metabolism and genomic stability- warrant closer attention [11,13,22–24].

Abbreviations

• AAS
Atomic Absorption Spectrophotometry
• AT
Averaging Time
• BW
Body Weight
• Cd
Cadmium
• CR
Carcinogenic Risk
• Cr
Chromium
• CSF
Cancer Slope Factor
• Cu
Copper
• EDI

Estimated Daily Intake
• ED
Exposure Duration
• EF
Exposure Frequency
• Fe
Iron
• HI
Hazard Index
• IR
Ingestion Rate
• Mn
Manganese
• Ni
Nickel
• RfD
Reference Dose
• THQ
Target Hazard Quotient
• USEPA
United States Environmental Protection Agency
• WHO
World Health Organization
• Zn
Zinc

Declarations

Authors' Contributions

Favor Akpakpan Udoeyop conceptualized the study, designed the methodology, performed data analysis, and drafted the manuscript. Uwem Okon Edet contributed to sample collection, laboratory analysis, and data validation. Claribel Okorie, Precious Adejoh Idakwoji, Fintan Ekochin C. and Nnyenime Chikwado Nwodo contributed to data interpretation, manuscript revision, and critical review of the final draft. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets generated during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Data sharing statement

The datasets generated and analysed during this study are available from the corresponding author on reasonable request.

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Tables

Table 1

Standard exposure parameters used in risk Assessment

Parameter	Symbol	Value	Unit
Exposure frequency	EF	365	days/year
Exposure duration	ED	30	Years
Ingestion rate	IR	0.24	L/day
Body weight	BW	60	Kg
Averaging time (non-cancer)	AT	10,950	Days
Averaging time (cancer)	AT	25,550	Days

Table 2

Toxicological reference values (Oral Reference Dose (RfD) and Cancer Slope Factors (CSF)

Metal	RfD (mg/kg/day)	CSF (mg/kg/day^{-1})	Source
Cr (VI)	0.003	0.5	USEPA IRIS
Ni	0.02	0.91	USEPA IRIS
Cd	0.001	—	USEPA
Cu	0.04	—	WHO
Zn	0.3	—	WHO
Fe	0.7	—	WHO
Mn	0.14	—	WHO

Note: Carcinogenic risk was evaluated only for chromium and nickel due to the availability of oral cancer slope factors.

Table 3
Toxic metal concentrations (mg/L) of locally produced beverages purchased from Akim Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	1.041	0.041	0.043	0.004	0.003	0.014	0.276
Agbo	0.276	0.055	0.059	0.006	0.005	0.008	0.367
Kunu	0.796	0.142	0.021	0.009	0.006	0.009	0.184
Tigernut milk	1.255	0.133	0.161	0.014	0.006	0.006	0.459

Table 4
Toxic metal concentrations (mg/L) of locally produced beverages purchased from Marian Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	0.220	0.070	0.090	0.030	0.170	0.110	0.050
Agbo	0.130	0.140	0.180	0.130	0.190	0.070	0.060
Kunu	0.290	0.030	0.090	0.150	0.220	0.080	0.050
Tigernut milk	0.430	0.270	0.310	0.070	0.120	0.150	0.070

Table 5
Toxic metal concentrations (mg/L) of locally produced beverages purchased from Watt Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	0.230	0.110	0.070	0.040	0.160	0.120	0.170
Agbo	0.130	0.040	0.060	0.030	0.130	0.080	0.060
Kunu	0.040	0.060	0.050	0.150	0.180	0.070	0.050
Tigernut milk	0.050	0.270	0.320	0.170	0.230	0.050	0.080

Table 6
Estimated daily intake (EDI) of heavy metals (mg/kg/day) for beverages from Akim Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	0.0042	0.0002	0.0002	0.0000	0.0000	0.0001	0.0011
Agbo	0.0011	0.0002	0.0002	0.0000	0.0000	0.0000	0.0015
Kunu	0.0032	0.0006	0.0001	0.0000	0.0000	0.0000	0.0007
Tigernut	0.0050	0.0005	0.0006	0.0001	0.0000	0.0000	0.0018

Table 7
Estimated daily intake (EDI) of heavy metals (mg/kg/day) for beverages from Marian Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	0.0009	0.0003	0.0004	0.0001	0.0007	0.0004	0.0002
Agbo	0.0005	0.0006	0.0007	0.0005	0.0008	0.0003	0.0002
Kunu	0.0012	0.0001	0.0004	0.0006	0.0009	0.0003	0.0002
Tigernut milk	0.0017	0.0011	0.0012	0.0003	0.0005	0.0006	0.0003

Table 8
Estimated daily intake (EDI) of heavy metals (mg/kg/day) for beverages from Watt Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd
Zobo	0.0009	0.0004	0.0003	0.0002	0.0006	0.0005	0.0007
Agbo	0.0005	0.0002	0.0002	0.0001	0.0005	0.0003	0.0002
Kunu	0.0002	0.0002	0.0002	0.0006	0.0007	0.0003	0.0002
Tigernut milk	0.0002	0.0011	0.0013	0.0007	0.0009	0.0002	0.0003

Table 9
Target hazard quotient (THQ) and hazard index (HI) for beverages from Akim Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd	HI
Zobo	1.400	0.010	0.005	0.000	0.000	0.001	1.100	2.516
Agbo	0.367	0.010	0.005	0.000	0.000	0.000	1.500	1.882
Kunu	1.067	0.030	0.003	0.000	0.000	0.000	0.700	1.800
Tigernut	1.667	0.025	0.015	0.000	0.000	0.000	1.800	3.507

Table 10
Target hazard quotient (THQ) and hazard index (HI) for beverages from Marian Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd	HI
Zobo	0.300	0.015	0.010	0.000	0.001	0.003	0.200	0.529
Agbo	0.167	0.030	0.018	0.002	0.001	0.002	0.200	0.420
Kunu	0.400	0.005	0.010	0.002	0.001	0.002	0.200	0.620
Tigernut	0.567	0.055	0.030	0.001	0.001	0.004	0.300	0.958

Table 11
Target hazard quotient (THQ) and hazard index (HI) for beverages from Watt Market

Sample	Cr	Ni	Cu	Zn	Fe	Mn	Cd	HI
Zobo	0.300	0.020	0.008	0.001	0.001	0.004	0.700	1.034
Agbo	0.167	0.010	0.005	0.000	0.001	0.002	0.200	0.385
Kunu	0.067	0.010	0.005	0.002	0.001	0.002	0.200	0.287
Tigernut	0.067	0.055	0.033	0.002	0.001	0.001	0.300	0.459

Table 12
Carcinogenic risk (CR) of selected metals for beverages from Akim Market

Sample	Cr	Ni
Zobo	0.0021	0.0002
Agbo	0.0006	0.0002
Kunu	0.0016	0.0005
Tigernut	0.0025	0.0005

Table 13
Carcinogenic risk (CR) of selected metals for beverages from Marian Market

Sample	Cr	Ni
Zobo	0.0005	0.0003
Agbo	0.0003	0.0005
Kunu	0.0006	0.0001
Tigernut	0.0009	0.0010

Table 14
Carcinogenic risk (CR) of selected metals for beverages from Watt Market

Sample	Cr	Ni
Zobo	0.0005	0.0004
Agbo	0.0003	0.0002
Kunu	0.0001	0.0002
Tigernut	0.0001	0.0010

Figures

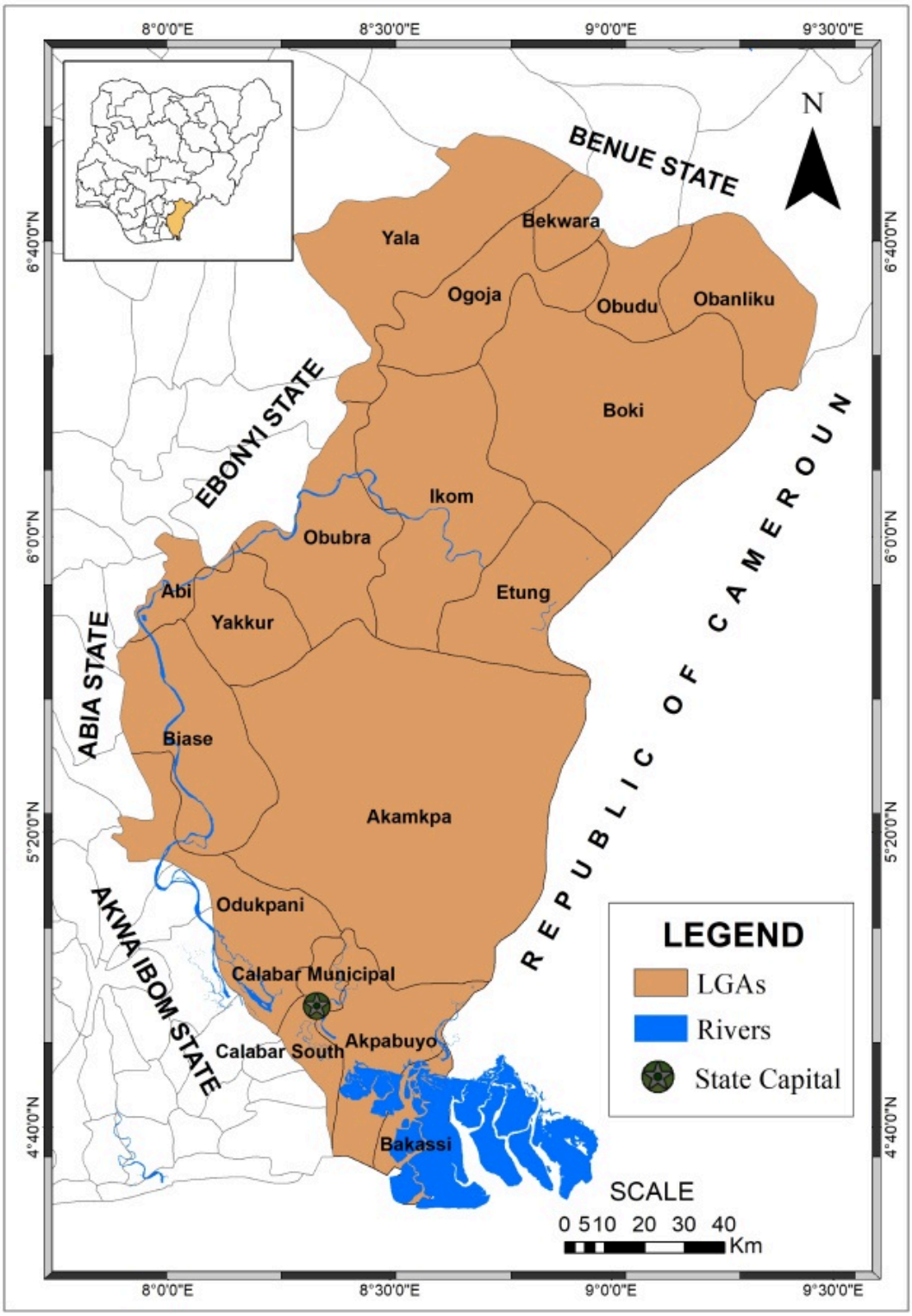


Figure 1

Map of the study area (Calabar Metropolis, Cross River State, Nigeria).Source: Cross River State Government (*https://www.crossriverstate.gov.ng/history*)

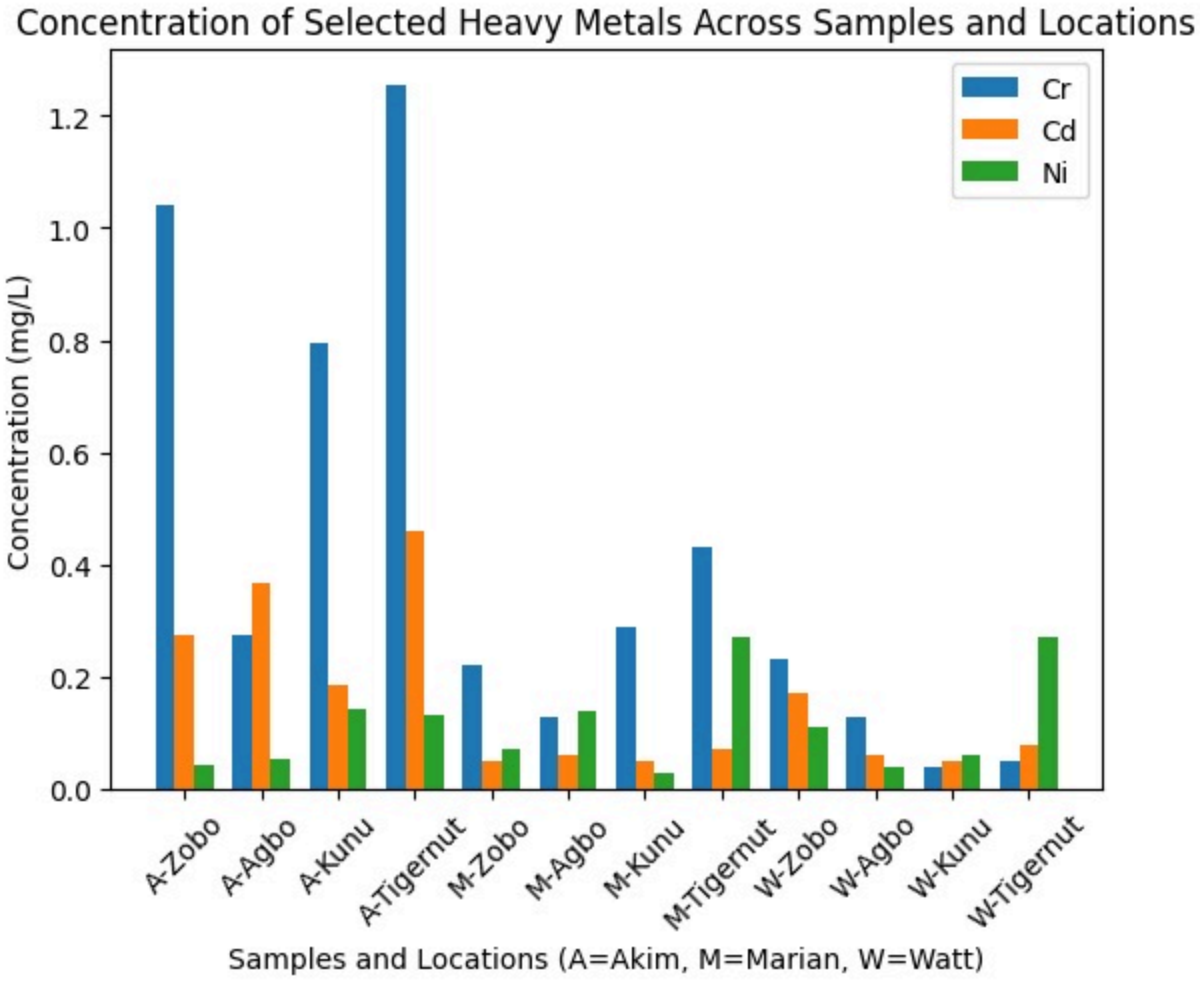


Figure 2

Concentration of selected heavy metals (Cr, Cd, Ni) in beverage samples from Akim (A), Marian (M), and Watt (W) markets.

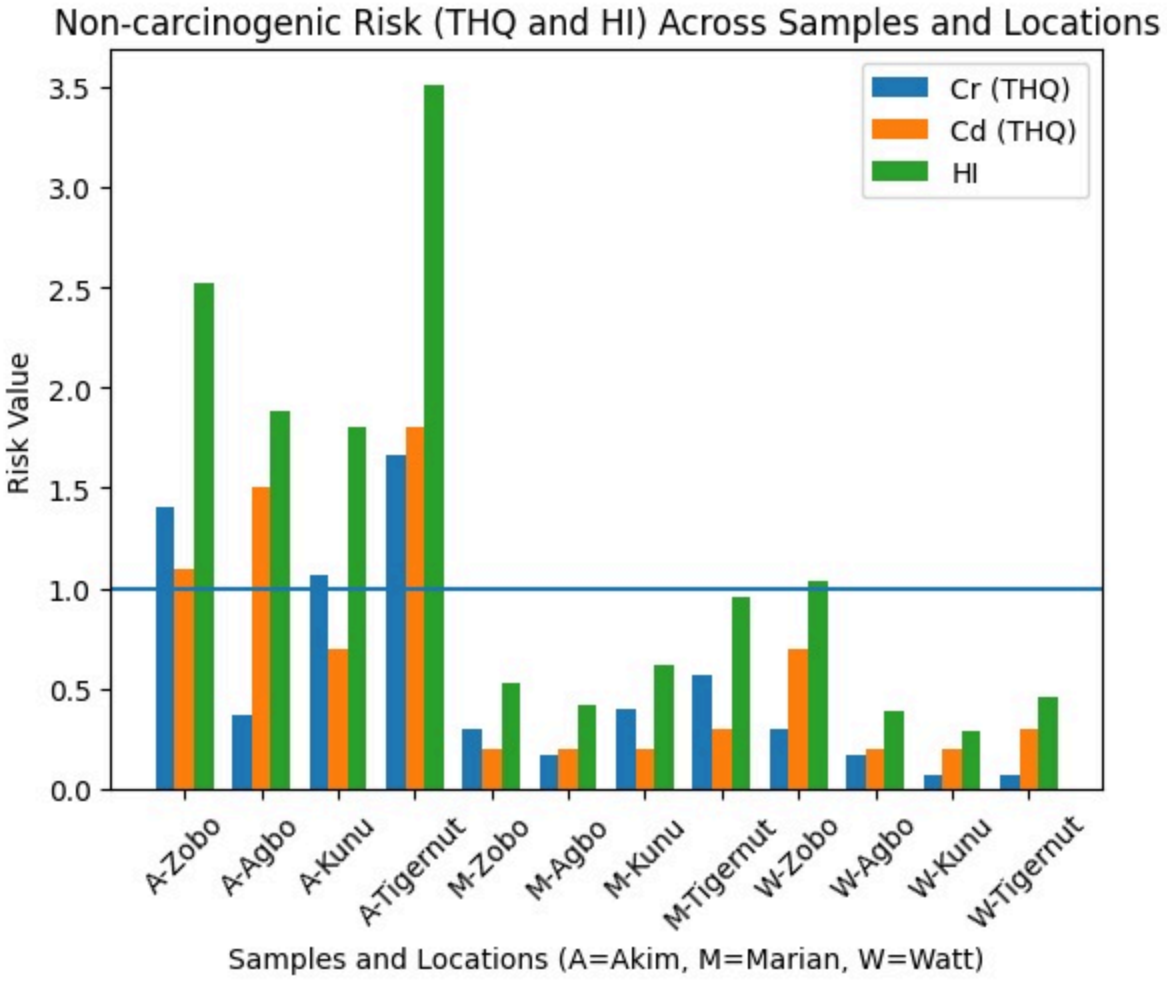


Figure 3

Non-carcinogenic risk (THQ) of chromium (Cr) and cadmium (Cd), and hazard index (HI) across beverage samples from Akim (A), Marian (M), and Watt (W) markets. The horizontal line represents the safety threshold (THQ = 1).