Published: 21st November 2025

ANACHEM JOURNAL
ISSN: 2006-5221 (Online)

EVALUATION OF NIGERIAN PRODUCED CANNED BEER AND SOFT DRINK BEVERAGES STORED UNDER VARIOUS CONDITIONS FOR THE POTENTIAL HEALTH RISKS OF HEAVY METAL INTRODUCTION

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DOI: **10.5281/zenodo.17617144**

ABSTRACT

Although the beverage industry is regarded as a significant contributor to Nigerian economy, these beverages can contain variety of unwanted compounds such as heavy metals. Heavy metals are substances that affect hormones and have been linked to a number of health issues, including an increased risk of cancer. The purpose of this study was to determine the impact of storage conditions and heavy metal leaching in Nigerian made canned beer and soft beverages, as well as the potential health risks of heavy metal contamination in these drinks. This study evaluated the effects of three distinct storage temperatures (4, 30, and 40 ° C) and four exposure durations (3, 7, 15, and 30 days) on two well-known alcoholic beverage brands and one non-alcoholic brand made in Nigeria. Using an Atomic Absorption Spectrophotometer, the concentrations of heavy metals in these samples were determined, and the risk to human health was assessed by calculating the hazard quotient and chronic daily intake. Heavy metals concentrations in outdoor (sun) temperature (40 ° C) shows: Pb (0.069-0.156) ppm, NI (0.012-0.370) ppm, Cr (0.062-3.012) ppm, and Cd (0.002-0.037) ppm for B1. The concentrations of sample B2 for several metals: Pb (0.048-0.130) ppm, Ni (0.021-0.154) ppm, Cr (0.051-1.782) ppm, and Cd (0.005-0.020) ppm. B3 to fall between Pb (0.063 to 0.644) ppm, Ni (0.003-0.264) ppm, Cr (0.200-0.614) ppm, and Cd (0.001-0.035) ppm. More so, the room conditions (30 ° C) for sample B2, Pb (0.004 - 0.129) ppm, Cd (0.005 - 0.010) ppm, Cr (0.119 - 3.566) ppm, and Ni (0.005 - 0.151) ppm. Then for B1, Pb (0.075 - 0.190) ppm, Cd (0.001 - 0.045) ppm, Cr (0.230 - 2.606) ppm, and Ni (0.009 - 0.314) ppm, while in sample B3, Pb (0.010 - 0.153) ppm, Cd (0.002 - 0.033) ppm, Cr (0.182 - 0.789) ppm, and Ni (0.004 – 0.222) ppm. Fridge temperature (4 ° C) for sample B2, Pb (0.028 - 0.127) ppm, Cd (0.003 - 0.017) ppm, Cr (0.294 - 1.952) ppm, and Ni (0.004 - 0.266) ppm. In B1, it ranged from Pb (0.034 - 0.162) ppm, Cd (0.002 - 0.030) ppm, Cr (0.415 - 1.087) ppm, and Ni (0.020 - 0.426) ppm. Where as in B3, the range was from Pb (0.017 - 0.157) ppm, Cd (0.004 - 0.040) ppm, Cr (0.070 - 1.340) ppm, and Ni (0.020 - 0.261) ppm. However, under the study storage circumstances, there was no discernible variation in the amounts of heavy metals. Both adults and children who regularly consume canned beer and soft drinks tainted with heavy metals have a probable health risk, according to the calculated risk of cancer and non - cancer.

Keywords: Atomic Absorption Spectrophotometer (AAS), canned beer, canned soft drinks, Acid digestion, heavy metals.

1. INTRODUCTION

Canned drinks, such as soft drinks and beer are widely used and consumed in Nigeria as a major contributor of the same country's beverage market. The safety of these products to human consumption is very important in ensuring the health of the population is safeguarded. Heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr) among others pose major health hazards when consumed in large quantities and in the long term (WHO, 2011; Jarup, 2003). Canned drinks may have sources of contamination of heavy metal which include raw. elements used in manufacturing, water used in making manufacturing, or leaching out of can linings or packaging materials (Iwegbue, 2014; Adepoju-Bello *et al.,* 2012). The manufacturing and consumption of canned soft drinks and beer is increasing in Nigeria and this will require evaluation of the safety with regard to heavy metal content. Heavy metals may cause several health problems; an example of which is neurological due to lead exposure, kidney problems, high blood pressure and shortage (ATSDR, 2020). Exposure to cadmium may lead to damaging effects on the kidneys, demineralization of the bones and presented a greater chance of developing cancer (ATSDR, 2012). In order to safeguard consumer health, it is crucial to evaluate the quantity of certain metals in commonly consumed canned soft drinks and beer due to their potential toxicity.

According to reports, Nigerian and other parts of the world have various levels of heavy metals in food and beverages (Olowoyo *et al.,* 2012; Adimula *et al.,* 2019). For example, heavy metals like lead and cadmium were discovered in Nigeria drinks. Some samples are higher than what the World Health Organization (WHO) considers appropriate (WHO, 2011). Absorption by Atoms because of its precision and sensitivity, Atomic Absorption Spectrophotometer is a widely used method for assessing the amount of heavy metals in food and beverages (Rice *et al.,* 2017).

This study examines Nigerian produced canned beer and soft drinks, their exposure to various storage conditions where heavy metals such as lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr) are present, and the health risks associated with their consumption.

2. MATERIALS AND METHODS

2.1. Reagents

Every reagent used in this investigation was of analytical quality. Nitric acid, hydrochloric acid, and heavy metals stock solutions were bought in St. Louis, USA's Sigma-Aldrich. Before being utilized, all glassware was cleaned with double-distilled water, immersed in a 10% nitric acid solution, and oven-dried for five hours at 80 degrees Celsius.

2.2. Sample Collection

This study examined one canned soft drink (B3) produced in Nigeria as well as two canned beer brands (B1 and B2). Random purchases of the items were made at local

shops in Nsukka, Enugu State. Twelve cans of soft drinks with the same batch number and expiration date as well as 24 cans of beer samples with various batch numbers and expiration dates, 12 from each brand were gathered for examination. The samples were stored for three, seven, fifteen, and thirty days at varying temperatures (in a refrigerator at 4 ° C, room temperature 30 ° C, and outside 40 ° C. As a control, two bottles of beer, one of each brand and one bottle soft drink were used. The control samples were maintained under standard conditions, without exposure to any temperature variations. This allows for a comparison to the samples that were exposed to various storage conditions, assisting to pick out the temperature effects with the samples.

2.3. Sample digestion

To find out how much heavy metal was present, we dissolved samples of the canned beer also soft drink using digestion process. We took two grams of each samples B1, B2, and B3 placing them into individual digestion flask. Next, twenty milliliters of aqua regia made from nitric acid and hydrochloric acid were put into each flask containing the samples. These mixtures heated at sixty – five degrees Celsius inside a ventilated space until everything fully dissolved and a clear solution obtained. Digestion finished, so we cooled the solutions in a desiccator. Next, the solutions were filtered, and diluted using deionized water enough to reach 100 mL in a flask. Finally, these solutions were moved into vials ready for heavy metal testing using AAS, following guidelines from IUPAC (2014).

2.4. Data Analysis

For all statistical analysis and data visualization, Origin Pro (version 2022) was used.

2.5. Health Risk Analysis

To estimate the potential health effects of heavy metals in canned beverages we used measures called the chronic daily intake and hazard quotient. This involved looking at how much of each metal people likely consume daily alongside established safe levels. Essentially, we compared typical intake to what is considered acceptable. Exposure over a person's life, measured as an average daily dose, reflects long – time metal intake. We figure out potential harm using two equations. First, hazard quotient is calculated by dividing daily intake by a safe reference level. Second, daily intake equals concentration multiplied by how much someone takes in, then divided by body weight.

$$Hazard\ quotient = Chronic\ Daily\ Intake / Reference\ Dose \quad (1)$$

Akcetin *et al.,* (2025) provided the Reference dose values.

$$Chronic\ daily\ intake = Concentration\ X\ Ingestion\ Rate / Body\ Weight \quad (2)$$

Values for ingestion rate and body weight are sourced from Eliaza *et al.,* (2024) alongside Ucheana *et al.,* (2022)

Hazard quotient value higher than 1 denotes a higher probability of experiencing negative non-cancer health impacts, while value below 1 suggests minimal likelihood of such effects. The risk of non-cancer health issues increases proportionally with rising hazard quotient values (Nwoke *et al.,* 2021; Odum *et al.,* 2021).

Anachem Journal, 16(2), 25-49
DOI: https://doi.org/10.5281/zenodo.17617144

3.0. RESULTS AND DISCUSSION

3.1. Mean Concentrations of Heavy Metals in the canned Alcoholic and Non - Alcoholic Beverage Samples

3.1.1. Outdoor exposure

The average concentration of heavy metals in beverage samples stored at outdoor temperature (40 ° C) are presented in Table 1.

Table 1 Average heavy metal content of beverage samples stored at outdoor temperature (40 ° C)

	B2 (ppm)				B1(ppm)				B3 (ppm)			
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel
WHO	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07
Control	**0.187±0.03**	**0.038±0.01**	0.002±0.01	0.002±0.04	**0.009±0.05**	**0.031±0.01**	**0.029±0.03**	0.029±0.01	**0.031±0.01**	**0.003±0.01**	**0.027±0.03**	0.027±0.01
Day 3	**0.134±0.05**	**0.005±0.07**	**0.051±0.01**	0.055±0.01	**0.069±0.01**	**0.004±0.06**	**0.062±0.02**	0.025±0.02	**0.097±0.04**	0.001±0.05	**0.200±0.01**	0.008±0.02
Day 7	**0.112±0.05**	**0.017±0.07**	**0.337±0.01**	0.021±0.01	**0.156±0.01**	**0.007±0.06**	**0.100±0.02**	0.012±0.02	**0.146±0.04**	**0.007±0.05**	**0.614±0.01**	0.010±0.02
Day 15	**0.084±0.05**	**0.010±0.07**	**0.278±0.01**	**0.154±0.01**	**0.018±0.01**	**0.037±0.06**	**0.890±0.02**	**0.370±0.02**	**0.063±0.04**	**0.023±0.05**	**0.762±0.01**	**0.264±0.02**
Day 30	**0.048±0.05**	**0.020±0.07**	**1.782±0.01**	0.046±0.01	**0.129±0.01**	0.002±0.06	**3.012±0.02**	0.013±0.02	**0.644±0.04**	**0.035±0.05**	**0.533±0.01**	0.003±0.02

WHO World Health Organization (culled from (Ucheana *et al.,* 2024)). The values in bold exceed the WHO drinking water guidelines. SD. The findings are displayed as mean ±SD. SD stands for standard deviation.

Table 1 shows the residual metals concentrations in the samples after exposure under the sun for 3, 7, 15 and 30 days. All assayed metals were detected in every beverage sample. In sample B2 most metals exceeded WHO permissible limits, except for Nickel (Ni). In samples B1 and B3, the same trend was observed with only Nickel (Ni) being below the WHO limit in the control samples and within all the exposure time studied. In the control sample Lead (Pb) and Cadmium (Cd) levels exceeded WHO limits. These findings suggest potential contamination issues, particularly with Pb and Cd, which were elevated even in the control sample. These levels are comparable with the ones observed by Ogoko *et al.,* (2024) in a similar study on beverages in Nigeria.

Table 2 shows the one-way ANOVA analysis results. The ANOVA showed a p-value of 0.100978. Because this exceeds the standard threshold of 0.05, differences among the group averages are not considered meaningful. Essentially, differences inside each group overshadow any distinctions between them.

Table 2 One-way ANOVA results for outdoor concentrations across brands

Outdoor	Sum of Squares	DF	Mean Square	F Value	P Value	F critical
Model	4.3801	11	0.398191	1.751518	0.100978	2.066608
Error	8.184256	36	0.22734			
Total	12.564356	47				

Tests showed no real distinction at the 0.05 significance level ($p > 0.05$).

We looked at how lead, cadmium, chromium, alongside nickel amounts related to each other within samples labelled B1, B2, and B3 exposed at 40 ^{0}C using t-tests also Pearson correlations. The t – test results shows Pb vs. Cd: t = 1.234 and p-value = 0.234, Pb vs. Cr: t = - 2.567 and p-value = 0.021, Pb vs. Ni: t = 0.456 and p-value = 0.654, Cd vs. Cr: t = 0.123 and p-value = 0.903, Cd vs. Ni: t = 2.345 and p-value = 0.032, Cr vs. Ni: t = 1.012 and p-value = 0.327. Testing revealed noteworthy distinctions in average values for lead and chromium. Levels changed considerably from the control, then at day seven, fifteen, and thirty (p = 0.021). Similarly, cadmium differed notably from nickel on day fifteen (p = 0.032). Consequently, varying origins likely affect how much of each metal is present.

Table 3 shows the Pearson correlation analysis results. Based on the Pearson correlation results, the Pearson correlation coefficients shows varying relationships between metal concentrations across different samples. Notable connections include moderate correlations between Pb and Cr in B2 (r = 0.567) and high positive correlations between Cr and Cd in B3 (r = 0.567). These findings show that the interactions between metal concentrations are complicated.

Anachem Journal, 16(2), 25-49
DOI: https://doi.org/10.5281/zenodo.17617144

Table 3 Pearson correlation results for outdoor concentrations across brands

	B2				B1				B3			
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel
Day3	1	0.345	0.567	0.123	1	0.123	0.456	0.234	1	0.012	0.234	0.456
Day 7	0.345	1	0.234	0.456	0.123	1	0.012	0.567	0.012	1	0.567	0.123
Day 15	0.567	0.234	1	0.012	0.456	0.012	1	0.345	0.234	0.567	1	0.345
Day 30	0.123	0.456	0.012	1	0.234	0.567	0.345	1	0.456	0.123	0.345	1

The relationships between the metal concentrations (Lead, Chromium, Cadmium, and Nickel) across different samples (B1, B2, and B3).

3.1.2. Room Exposure

The average amount of heavy metals in beverage samples stored at room temperature (30 ° C) are displayed in Table 4.

Table 4 Average heavy metals concentrations in beverage samples stored at room temperature (30 ° C)

	B2				B1				B3			
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel
WHO	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07
Control	**0.187±0.03**	**0.038±0.01**	0.002±0.01	0.002±0.04	**0.009±0.05**	**0.031±0.01**	**0.029±0.03**	0.029±0.01	**0.031±0.01**	**0.003±0.01**	**0.027±0.03**	0.027±0.01
Day 3	**0.105±0.03**	**0.010 ±0.11**	**0.284±0.02**	0.008±0.01	**0.081±0.09**	0.001±0.09	**0.230±0.04**	0.011±0.03	**0.069±0.05**	**0.004±0.02**	**0.360±0.01**	0.004±0.06
Day 7	**0.129±0.03**	**0.005±0.11**	**0.119±0.02**	0.005±0.01	**0.190±0.09**	**0.007±0.09**	**0.579±0.04**	0.009±0.03	**0.153±0.05**	0.002±0.02	**0.182±0.01**	0.004±0.06
Day 15	**0.059±0.03**	**0.018±0.11**	**0.473±0.02**	**0.151±0.01**	**0.075±0.09**	**0.045±0.09**	**1.022±0.04**	**0.314±0.03**	**0.034±0.05**	**0.027±0.02**	**0.789±0.01**	**0.222±0.06**
Day 30	0.004±0.03	**0.019±0.11**	**3.566±0.02**	0.038±0.01	**0.133±0.09**	0.002±0.09	**2.606±0.04**	**0.083±0.03**	**0.010±0.05**	**0.033±0.02**	**0.692±0.01**	0.016±0.06

WHO World Health Organization (culled from (Ucheana *et al.,* 2024)). The values in bold exceed the WHO drinking water guidelines. The findings are displayed as mean ±SD. SD stands for standard deviation.

The amount of residual metals present in samples B2, B1, and B3 following 3, 7, 15, and 30 days of exposure at room temperature (30 ° C) is displayed in Table 4. All of the metals tested fell within ranges above the WHO guideline, with the exception of Ni. In B2, the amounts of Lead (Pb), Cadmium (Cd), Chromium (Cr), and Nickel (Ni) varied from 0.004 to 0.129 ppm, 0.005 to 0.010 ppm, 0.119 to 3.566 ppm, to 0.005 to 0.151 ppm, respectively; Between 0.075 to 0.190 ppm of Pb, 0.001 to 0.045 ppm of Cd, 0.230 to 2.606 ppm of Cr, and 0.009 to 0.314 ppm of Ni were found in sample B1, whereas between 0.010 to 0.153 ppm of Pb, 0.002 to 0.033 ppm of Cd, 0.182 to 0.789 ppm of Cr, 0.004 to 0.222 ppm of Ni were found in sample B3. The investigation discovered that most samples had Pb, Cd, and Cr values above WHO recommendations. Samples B1, B2, and B3 had different metal levels, as did exposure durations (3–30 days). Ni concentrations are typically within reasonable bounds.

Table 5 represent the one-way ANOVA analysis results at room exposure. According to the ANOVA results, there is a statistical significant difference between the group means because the p-value of 0.047223 is than the usual significance level of $\alpha = 0.05$. This implies that there is much more variation between groups than there is within them.

Table 5 One-way ANOVA results for room exposure concentrations across brands

Room	*Sum of Squares*	*DF*	*Mean Square*	*F Value*	*P Value*	*F critical*
Model	7.53505	11	0.685005	2.09204	0.047223	2.066608
Error	11.78762	36	0.327434			
Total	19.32267	47				

At 0.05 level, the means of the heavy metals concentrations are statistically significant ($p < 0.05$)

The results of the t-test analysis at room exposure are shown in Table 6. These results indicate changes in metal concentrations over time, with some metals showing significant differences between the control and specific days. Specifically, Cr significant differences between the control and all days (p-values < 0.05), Pb significant differences between the control, days 15 and 30 (B2) (p-values < 0.05), and Ni significant differences between the control and Day 15 (B3) (p-value = 0.024).

Table 6 t-test results for room exposure concentrations

Pb Control vs. Day 3 (B2): t = 1.456 and p-value = 0.163. Control vs. Day 7 (B2): t = 1.234 and p-value = 0.234. Control vs. Day 15 (B2): t = 2.567 and p-value = 0.02. Control vs. Day 30 (B2): t = 3.456 and p-value = 0.004.
Cd Control vs. Day 3 (B1): t = 1.012 and p-value = 0.327. Control vs. Day 7 (B1): t = 0.987 and p-value = 0.339. Control vs. Day 15 (B1): t = 1.456 and p-value = 0.163. Control vs. Day 30 (B1): t = 1.890 and p-value = 0.075.
Cr Control vs. Day 3 (B3): t = - 3.012 and p-value = 0.009. Control vs. Day 7 (B3): t = -2.345 and p-value = 0.032. Control vs. Day 15 (B3): t = - 4.567 and p-value = 0.001. Control vs. Day 30 (B3): t = -6.789 and p-value = 0.000.
Ni Control vs. Day 3 (B3): t = 0.567 and p-value = 0.581. Control vs. Day 7 (B3): t = 0.890 and p-value = 0.386. Control vs. Day 15 (B3): t = 2.456 and p-value = 0.024. Control vs. Day 30 (B3): t = 1.234 and p-value = 0.234.

T-test, the means of each metal concentration between the control and each day.

To perform a Pearson correlation analysis, the relationships between the metal concentrations (Pb, Cd, Cr, and Ni) across different samples (B1, B2, and B3) were examined. Here are the correlation coefficients Pb (B1) and Pb (B2): r = 0.876, Pb (B1) and Pb (B3): r = 0.745, Pb (B2) and Pb (B3): r = 0.923, Cd (B1) and Cd (B2): r = 0.567, Cd (B1) and Cd (B3): r = 0.432, Cd (B2) and Cd (B3): r = 0.654, Cr (B1) and Cr (B2): r = 0.812, Cr (B1) and Cr (B3): r = 0.923,Cr (B2) and Cr (B3): r = 0.956, Ni (B1) and Ni (B2): r = 0.789, Ni (B1) and Ni (B3): r = 0.654, Ni (B2) and Ni (B3): r = 0.876. The Pearson correlation coefficients suggest strong positive correlations between metal concentrations across different samples, particularly Cr showed strong correlations between B1, B2, and B3 ($r > 0.8$) and Pb strong correlations between B1, B2, and B3 ($r > 0.7$). These results indicate relationships between metal concentrations across different samples.

Anachem Journal, 16(2), 25-49
DOI: https://doi.org/10.5281/zenodo.17617144

3.1.3. Refrigeration Exposure

The average heavy metal content of beverage samples stored in a refrigerator temperature (4 ° C) are presented in Table 7.

Table 7 Average heavy metal I content of beverage samples stored in a refrigerator temperature (4 ° C)

	B2				B1				B3			
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel
WHO	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07	0.01	0.003	0.05	0.07
Control	**0.187±0.03**	**0.038±0.01**	0.002±0.01	0.002±0.04	**0.009±0.05**	**0.031±0.01**	**0.029±0.03**	0.029±0.01	**0.031±0.01**	**0.003±0.01**	**0.027±0.03**	0.027±0.01
Day 3	**0.126±0.01**	**0.003 ±0.06**	**1.096±0.02**	0.004±0.02	**0.162±0.02**	**0.009±0.06**	**0.776±0.06**	0.032±0.04	**0.025±0.06**	**0.004±0.04**	**0.070±0.05**	0.020±0.05
Day 7	**0.127±0.01**	**0.003±0.06**	**1.443±0.02**	0.032±0.02	0.149±0.02	0.002±0.06	**0.503±0.06**	0.020±0.04	**0.157±0.06**	**0.012±0.04**	**0.070±0.05**	0.026±0.05
Day 15	**0.052±0.01**	**0.017±0.06**	**0.294±0.02**	**0.266±0.02**	**0.046±0.02**	**0.030±0.06**	**1.087±0.06**	**0.426±0.04**	**0.065±0.06**	**0.040±0.04**	**0.692±0.05**	**0.261±0.05**
Day 30	**0.028±0.01**	**0.005±0.06**	**1.952±0.02**	0.040±0.02	**0.034±0.02**	**0.007±0.06**	**0.415±0.06**	0.058±0.04	**0.017±0.06**	**0.009±0.04**	**1.340±0.05**	0.056±0.05

WHO World Health Organization (culled from (Ucheana *et al.,* 2024)). The values in bold exceed the WHO drinking water guidelines. The findings are displayed as mean ±SD. SD stands for standard deviation.

Table 7 shows the residual metals concentrations in the beverage samples upon exposure at 4 ° C for 3, 7, 15 and 30 days. All the metals were found in levels above the permissible limit at all the exposure time studied except for Ni which was only found above the limit at day 15 across the 3 beverage samples. In sample B2, the observed concentration ranging from 0.028 to 0.127 ppm Pb, 0.003 to 0.017 ppm Cd, 0.294 to 1.952 ppm Cr, and 0.004 to 0.266 ppm Ni. In B1, it ranged from 0.034 to 0.162 ppm Pb, 0.002 to 0.030 ppm Cd, 0.415 to 1.087 ppm Cr, and 0.020 to 0.426 ppm Ni. Whereas in B3, the range was from 0.017 to 0.157 ppm for Pb, 0.004 to 0.040 ppm Cd, 0.070 to 1.340 ppm Cr, and 0.020 to 0.261 ppm Ni. These values are comparable with those observed by Iwegbue et al. (2014) and Ogoko *et al.,* (2024) in similar studies on locally produced alcoholic and non-alcoholic beverages in Nigeria, the observations of Pal *et al., (*2020) in a similar study in Hungary, and the reports by Scutaras and Carmen, (2023) in their review on metal contamination of beverages. Eliaza *et al.,* (2024) observed a concentration range of 4.055 – 97.214 ppm for Cr in a similar study conducted in Tanzania.

Table 8 represent the one-way ANOVA analysis results for refrigeration concentrations. The ANOVA findings show that there is a statistically significant difference between the group means because the p-value of 0.00000955 is smaller than the usual significance level of $\alpha = 0.05$. This suggests that variation between groups is significantly greater than the variation within groups.

Table 8 Results of One-Way ANOVA for refrigeration concentrations between brands

Fridge	*Sum of Squares*	*DF*	*Mean Squares*	*F values*	*P values*	*F critical*
Model	6.001902	11	0.545627	6.399276	0.00000955	2.066608
Error	3.069502	36	0.085264			
Total	9.071403	47				

At 0.05 level, the means of the heavy metals concentrations are significant statistically

Table 8 was subjected to a t-test, which compared the means of each metal concentration between the control and each day. Results shows Pb Control vs. Day 3: t = 1.234 and p-value = 0.234, Control vs. Day 7: t = 1.456 and p-value = 0.163, Control vs. Day 15: t = 2.345 and p-value = 0.032, Control vs. Day 30: t = 2.567 and p-value = 0.021; Cd Control vs. Day 3: t = 1.012 and p-value = 0.327, Control vs. Day 7: t = 0.987 and p-value = 0.339, Control vs. Day 15: t = 1.456 and p-value = 0.163, Control vs. Day 30: t = 1.234 and p-value = 0.234; Cr Control vs. Day 3: t = - 3.456 and p-value = 0.004, Control vs. Day 7: t = - 4.567 and p-value = 0.001, Control vs. Day 15: t = - 2.345 and p-value = 0.032, Control vs. Day 30: t = - 5.678 and p-value = 0.000 and Ni Control vs. Day 3: t = 0.987 and p-value = 0.339, Control vs. Day 7: t = 1.456 and p-value = 0.163, Control vs. Day 15: t = 2.567 and p-value = 0.021, Control vs. Day 30: t = 1.890 and p-value = 0.075. The results suggest that Pb showed significant differences between control and Day 15 p-value = 0.032 and Day 30 p-value = 0.021, Cd no significant differences between control and any day, Cr also showed significant differences between control and all days (p-values < 0.05) and Ni significant difference between control and Day 15 (p-value = 0.021). These results indicate changes in metal concentrations over time, with some metals showing significant differences between the control and certain days.

To investigate the connections between the metal concentrations (Lead, Cadmium, Chromium, and Nickel), Pearson correlation analysis was also performed on Table 5. Correlation coefficients are shown as Pb: day3 (1), day 7 (0.234), day 15 (- 0.456) and day 30 (0.123). Cd: day 3 (0.234), day 7 (1), day 15 (0.012) and day 30 (0.567). Cr: day 3 (- 0.456), day 7 (0.012), day 15 (1) and day 30 (0.234). Ni: day 3 (0.123), day 7 (0.567), day 15 (0.234) and day 30 (1). The Pearson correlation coefficients show Cd and Ni Positive correlation (r = 0.567) indicating that as Cd concentrations increase, Ni concentrations tend to increase. Pb and Cd Positive correlation (r = 0.234), indicating a somewhat favorable correlation between the amounts of lead and cadmium. Cr and Ni Positive correlation (r = 0.234), indicating a moderate positive relationship between Cr and Ni concentrations. Pb and Cr Negative correlation (r = - 0.456), suggesting that as Pb concentrations increase, Cr concentrations tend to decrease. The strong positive correlation between Cd and Ni indicate a common source while the negative

correlation between Pb and Cr indicate different sources.

3.1.4. Effect of outdoor temperature on the beverage samples B1, B2 and B3.

Differences in the migratory patterns of heavy metals were noted here (Figure 1, 2, and 3). Lead (Pb) and cadmium (Cd) continued to decline from control to day 30, but chromium (Cr) migration increased dramatically from day 7 to day 30. Nickel migration increased marginally from day 7 to day 15 and subsequently dropped from day 15 to day 30. Pb showed an increase from control to day 15 and then decrease until day 30, while Cd showed a decrease from control to day 30. For B2, Cr increased between days 3 and 7, showed a slight reduced from days 7 to 15, and then sharply increased from day 15 to day 30. Ni increased slightly from day 7 to day 15 and reduced until day 30. In sample B3, Pb increased slightly from control to day 7, fell from day 7 to day 15, and then continued to climb dramatically from day 15 to day 30. Cr increased sharply from control to day 15 and then slightly decreased from day 15 to day 30. Cd continued a decline from control to day 30, while Ni dropped from day 7 to day 7, climbed from day 7 to day 15, and then dramatically declined from day 15 to day 30. How metals move depends on where they are. Different places mean different actions. It is a complicated dance shaped by surroundings. Because of their chemical characteristics, different metals have distinct migratory behaviors. Metal migration may be impacted by changes in matrix effects, pH, or sample makeup and this trend also indicates that heavy metals migration in the samples could be enhanced by increased storage temperature.

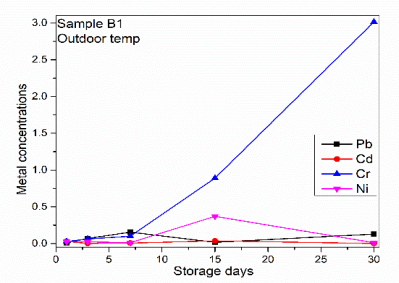

Fig. 1: Metal concentration in beverage sample B1 stored at outdoor temperature

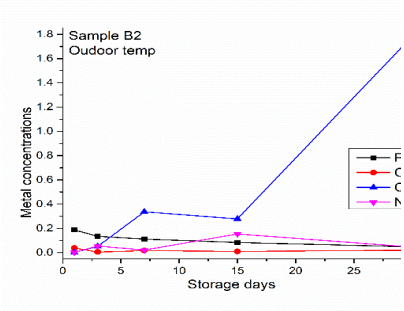

Fig. 2: Metal concentration in beverage sample B2 stored at outdoor temperature

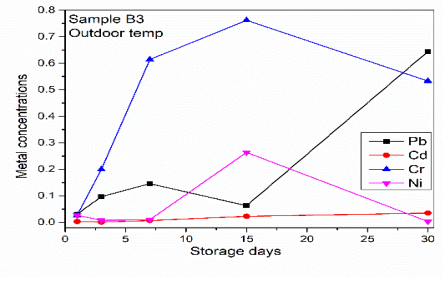

Fig. 3: Metal concentration in beverage sample B3 stored at outdoor temperature

3.1.5. Effect of room temperature on the beverage samples B1, B2 and B3.

Variations in the migration patterns of heavy metals were recorded across samples (Figures 4–6). For sample B1, chromium accumulation increased gradually up to day 15, then sharply by day 30. Lead rose from control to day 7, slightly decreased by day 15,

and spiked again at day 30. Nickel rose until day 15, followed by a decline, while cadmium steadily decreased throughout the 30-day period. Chromium in Sample B2 climbed gradually between days 3 and 30. Meanwhile, nickel levels dipped as lead increased. Cadmium started by decreasing, bumped up a little around day 15, thereafter declining steadily. Chromium levels in B3 climbed early on, then dipped before hitting a high point somewhere between days seven through fifteen after that they went down. Lead behaved differently than nickel did, yet cadmium consistently decreased. These variations suggest differences in matrix composition or sample properties affecting metal mobility.

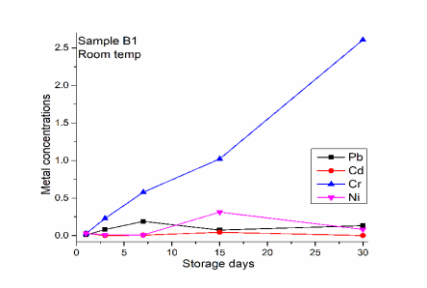

Fig. 4: Metal concentration in beverage sample B1 stored at room temperature

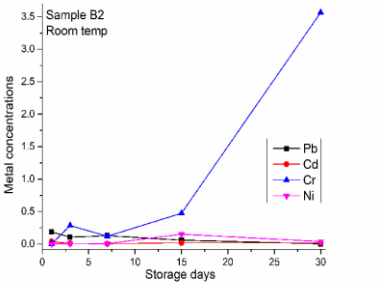

Fig. 5: Metal concentration in beverage sample B2 stored at room temperature

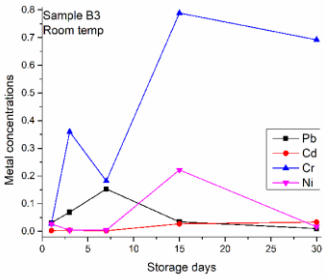

Fig. 6: Metal concentration in beverage sample B3 stored at temperature of the room

3.1.6. Effect of refrigeration temperature on the beverage samples B1, B2 and B3.

Figures 7, 8, and 9 show the different migratory tendencies of heavy metals. Chromium (Cr) migration in the B1 sample increased significantly from control to day 3, reduced between days 3 and 7, peaked again from day 7 to day 15, decreased from day 15 to day 30, Nickel decreased from control to day 7, increased from day 7 to day 15, then decreased from day 15 to day 30, Pb increased from control to day 3, decreased from day 3 to day 30, and Cd showed a decrease from control to day 30. B2 Cr rose from day 7 to day 7, then declined from day 7 to day 15, then dramatically climbed from day 15 to day 30. From day 7 to day 30, Ni slightly reduced, then reduced from day 15 to day 30 after rising from day7 to day 15. Pb showed a rise from day 15 to day 30, then decreased until day 30, and Cd showed a decrease from day 30 to control. Sample B3 showed a modest increase in Pb between days 7 and 30, a drop in Cr from control to day 7, and then an upward trend till day 30. Ni dropped from the control until day 7, climbed from day 7 to day 15, and finally dropped precipitously between days 15 and 30. Cd continued to decline from the control to day 30. The distinct metal migration patterns seen in each sample point to variations in matrix effects or sample composition and expansion.

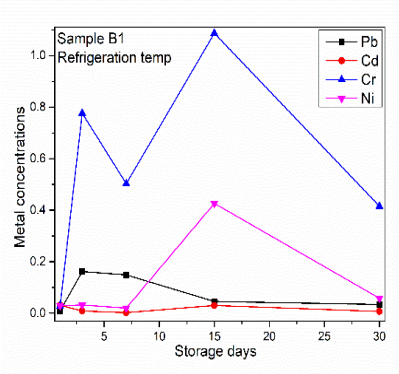

Fig. 7: Metal concentration in beverage sample B1 stored at the temperature of refrigeration

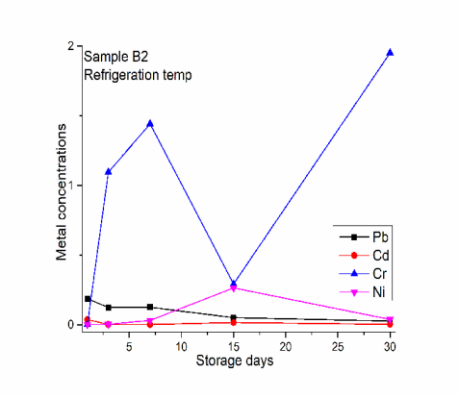

Fig. 8: Metal concentration in beverage sample B2 stored under refrigeration

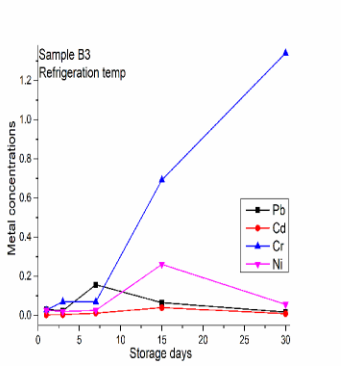

Fig. 9: Metal concentration in beverage sample B3 stored at refrigeration temperature.

3.2 Health Risk Analysis of BPA

The non-cancer risk of consuming alcoholic and non-alcoholic beverages exposed to different storage temperatures and periods were assessed utilizing the chronic daily intake (CDI) and the hazard quotient (HQ). The CDI and HQ results are shown in Tables 9 through 14.

3.2.1. Chronic Daily Intake (CDI)

Table 9 shows the chronic daily intake (CDI) of heavy metals from drinking beverages kept at outside temperature.

Anachem Journal, 16(2), 25-49
DOI: https://doi.org/10.5281/zenodo.17617144

Table 9 Chronic daily intake (CDI) of heavy metals from drinking beverages stored at outdoor temperature (40 ⁰ C)

	B2				B1				B3							
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
	A				A				A	C	A	C	A	C	A	C
3	1.9×10^{-3}	7.1×10^{-5}	**7.3×10^{-4}**	7.9×10^{-4}	9.9×10^{-4}	5.7×10^{-5}	8.9×10^{-4}	3.6×10^{-4}	1.4×10^{-3}	2.7×10^{-3}	1.4×10^{-5}	2.8×10^{-5}	2.9×10^{-3}	**5.7×10^{-3}**	1.1×10^{-4}	2.3×10^{-4}
7	1.6×10^{-3}	2.4×10^{-4}	**4.8×10^{-3}**	3.0×10^{-4}	2.2×10^{-3}	1.0×10^{-4}	1.4×10^{-3}	1.7×10^{-4}	2.1×10^{-3}	**4.1×10^{-3}**	1.0×10^{-4}	2.0×10^{-4}	**8.8×10^{-3}**	1.7×10^{-2}	1.4×10^{-4}	2.8×10^{-4}
15	1.2×10^{-3}	1.4×10^{-4}	**4.0×10^{-3}**	2.2×10^{-3}	2.6×10^{-4}	5.3×10^{-4}	1.3×10^{-2}	5.3×10^{-3}	9.0×10^{-4}	1.8×10^{-3}	3.3×10^{-4}	**6.5×10^{-4}**	1.1×10^{-2}	2.2×10^{-2}	3.8×10^{-3}	7.5×10^{-3}
30	6.9×10^{-4}	2.9×10^{-4}	2.5×10^{-2}	6.6×10^{-4}	1.8×10^{-3}	2.9×10^{-5}	4.3×10^{-2}	1.9×10^{-4}	**9.2×10^{-3}**	1.8×10^{-2}	5.0×10^{-4}	**9.9×10^{-4}**	**7.6×10^{-3}**	1.5×10^{-2}	4.3×10^{-5}	8.5×10^{-5}

CDI Chronic daily intake; *A* Adults; *C* Children; *mg/kg/day* milligram per kilogram body weight per day; body weight: 15kg for children and 70kg for adults. RfD used are 0.0036 for Pb, Cd: 0.0005, Ni: 0.02, Cr: 0.003 mgL^{-1} (Eliaza *et al.,* 2024). Values in bold are above RfD

The CDI for the samples exposed at 40 °C for the various exposure times is displayed in Table 9. The recorded CDI for Pb varied between 6.9×10^{-4} and 1.2×10^{-3} in B2 and 9.9×10^{-4} and 1.8×10^{-3} in B1. The CDI for Pb in B3, a non-alcoholic beverage, ranged between $4.1x10^{-3}$ and $1.8x10^{-2}$ for children and between $9.0x10^{-4}$ and$1.4x10^{-3}$ for adults. The CDI varied between 5.7×10^{-5} and 1.0×10^{-4} for B1 and between 7.1×10^{-5} and 1.4×10^{-4} for B2 for Cd. The observed range in B3 was 2.8×10^{-5} - 2.0×10^{-4} for children and 9.0×10^{-4} - 1.4×10^{-3} for adults. For Cr, B2 and B1 had ranges of 7.3×10^{-4} - 2.5×10^{-2} and 8.9×10^{-4} - 1.3×10^{-2}, respectively, whilst B3 had ranges of 8.8×10^{-3} -1.1×10^{-2} and 5.7×10^{-3} - 1.5×10^{-2} for adults and children, respectively. B2 and B1 had observed ranges of 7.9×10^{-4} to 2.2×10^{-3} and 3.6×10^{-4} to 5.3×10^{-3} for Ni, respectively. The observed range in B3 was 4.3×10^{-5} to 3.8×10^{-3} for adults and 8.5×10^{-5} to 7.5×10^{-3} for children. The CDI values indicate the consumption of daily heavy metals per unit of body weight. The ranges vary across samples (B1, B2 and B3), metals, and age groups (adults,

children). Pb higher CDI ranges for children in B3, indicating potential health concerns. Cd low CDI ranges across samples, but still important for long-term exposure. Cr high CDI ranges in B2, B1, and B3, suggesting potential health risks. Ni comparable CDI ranges across samples and age groups. CDI values represent the amount of metal ingested daily per unit body weight (mg/kg/day). Higher CDI values indicate greater exposure and potential health risks. This suggests that CDI values point to possible health hazards related to exposure to heavy metals, especially for youngsters and specific metals (Pb, Cr). In order to reduce exposure and safeguard the public's health, these findings can help prioritize mitigation methods and guide risk assessments.

3.2.2 **CDI room exposure**

Table 10 displays the Chronic Daily Intake (CDI) of heavy metals from drinking beverages stored at room temperature

Table 10 Heavy metal chronic daily intake (CDI) from drinking beverages stored at room temperature (30 ºC)

	B2				B1				B3							
Days	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
	A				A				A	C	A	C	A	C	A	C
3	1.5×10^{-3}	1.43×10^{-4}	**4.1×10^{-3}**	1.1×10^{-4}	1.1×10^{-3}	1.4×10^{-5}	3.3×10^{-3}	1.6×10^{-4}	9.9×10^{-4}	2.0×10^{-3}	5.7×10^{-5}	1.1×10^{-4}	**5.1×10^{-3}**	**1.0×10^{-2}**	5.7×10^{-5}	1.1×10^{-4}
7	1.8×10^{-3}	7.1×10^{-5}	1.7×10^{-3}	7.1×10^{-5}	2.7×10^{-3}	1.0×10^{-4}	8.3×10^{-3}	1.3×10^{-4}	2.2×10^{-3}	**4.3×10^{-3}**	2.9×10^{-5}	5.7×10^{-5}	2.6×10^{-3}	**5.2×10^{-3}**	5.7×10^{-5}	1.1×10^{-4}
15	8.4×10^{-4}	2.6×10^{-4}	**6.8×10^{-3}**	2.2×10^{-3}	1.1×10^{-3}	**6.4×10^{-4}**	1.5×10^{-2}	4.5×10^{-3}	4.9×10^{-4}	9.7×10^{-4}	3.9×10^{-4}	**7.7×10^{-4}**	1.1×10^{-2}	2.2×10^{-2}	3.2×10^{-3}	6.3×10^{-3}
30	5.1×10^{-5}	$2,7\times10^{-4}$	**5.1×10^{-2}**	5.4×10^{-4}	1.9×10^{-3}	2.9×10^{-5}	**3.7×10^{-2}**	1.2×10^{-3}	1.4×10^{-4}	2.8×10^{-4}	4.7×10^{-4}	**9.4×10^{-4}**	**9.8×10^{-3}**	2.0×10^{-2}	2.3×10^{-4}	4.5×10^{-4}

Chronic daily intake (*CDI)*; *A* Adults; *C* Children; *mg/kg/day* milligram per kilogram body weight per day; body weight: 15kg for children and 70kg for adults.

The CDI values for the samples subjected to 30 °C for the various exposure times are shown in Table 10. For Pb, the observed CDI range in B2 and B1 was 5.1×10^{-5} - 1.5×10^{-3} and 1.1×10^{-3} - 2.7×10^{-3}, respectively. For B3, the ranges were 2.8×10^{-4} - 4.3×10^{-3} for children and 1.4×10^{-4} - 2.2×10^{-3} for adults. B2 and B1 showed Cd values of 7.1×10^{-5} to 2.7×10^{-4} and 1.1×10^{-3} to 2.7×10^{-3}, respectively. The ranges for B3 were 2.9×10^{-5} to 4.7×10^{-4} for adults and 5.7×10^{-5} to 9.4×10^{-4} for children. For Cr, samples B2 and B1 showed ranges of 1.7×10^{-3} to 5.1×10^{-2} and 1.4×10^{-5} to 6.4×10^{-4}, respectively. In contrast,

the ranges for B3 were 2.6×10^{-3} to 1.1×10^{-2} for adults and 5.2×10^{-3} to 2.2×10^{-2} for children. The CDI for Ni was found to range between 7.1×10^{-5} and 2.2×10^{-3} in B2 and B1 and between 3.3×10^{-3} and 3.7×10^{-2} in B2, but for adults and children in B3, the range was 5.7×10^{-5} to 3.2×10^{-3} and 1.1×10^{-4} to 6.3×10^{-3}, respectively. The CDI values represent the daily consumption of heavy metals per unit body weight. The ranges vary across samples (B1, B2, and B3), metals, and age groups (adults, children). Children in B1 and B3 had greater Pb CDI ranges than those in B2. Cd in sample B1 has higher CDI ranges compared to B2 and B3. B2 and B3 (children) have higher CDI ranges compared to B1. Ni B3 has higher CDI ranges for both adults and children. These implies that the varying CDI ranges suggest differences in exposure levels and potential health risks associated with each metal and sample. Children tend to have higher CDI values, indicating increased vulnerability to heavy metal exposure. These findings can inform risk assessments and help prioritize mitigation strategies to minimize exposure and protect public health. These are comparable from the observations of Iwegbue *et al.,* (2014), Ogoko *et al.,* (2024) and Stoner *et al.,* (2025).

3.2.3 CDI refrigeration storage

Table 11 shows the Chronic Daily Intake (CDI) of heavy metals from drinking beverages stored at refrigeration temperature

Table 11 Chronic daily intake (CDI) of heavy metals from drinking beverages stored at refrigerator temperature (4 °C

	B2				B1				B3							
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
Days	A				A				A	C	A	C	A	C	A	C
3	1.8×10^{-3}	4.3×10^{-5}	**1.6×10^{-2}**	5.7×10^{-5}	2.3×10^{-3}	1.3×10^{-4}	1.1×10^{-2}	4.6×10^{-4}	3.6×10^{-4}	7.1×10^{-4}	5.7×10^{-5}	1.1×10^{-4}	1.0×10^{-3}	2.0×10^{-3}	2.9×10^{-4}	5.7×10^{-4}
7	1.8×10^{-3}	4.3×10^{-5}	**2.1×10^{-2}**	4.6×10^{-4}	2.2×10^{-3}	2.5×10^{-5}	**7.2×10^{-3}**	2.9×10^{-3}	2.2×10^{-3}	**4.5×10^{-3}**	1.7×10^{-4}	3.4×10^{-4}	1.0×10^{-3}	2.0×10^{-3}	3.7×10^{-4}	7.3×10^{-4}
15	7.4×10^{-4}	2.4×10^{-4}	**4.2×10^{-3}**	3.8×10^{-3}	6.6×10^{-4}	4.3×10^{-4}	**1.6×10^{-2}**	6.1×10^{-3}	9.3×10^{-4}	1.8×10^{-3}	**5.7×10^{-4}**	1.1×10^{-3}	**9.8×10^{-3}**	**2.0×10^{-2}**	3.7×10^{-3}	7.4×10^{-3}
30	4.0×10^{-4}	7.1×10^{-4}	**2.8×10^{-2}**	5.7×10^{-4}	4.9×10^{-4}	1.0×10^{-4}	**5.9×10^{-3}**	8.3×10^{-4}	2.4×10^{-4}	4.8×10^{-4}	1.3×10^{-4}	2.6×10^{-4}	1.9×10^{-2}	**3.8×10^{-2}**	8.0×10^{-4}	1.6×10^{-3}

CDI Chronic daily intake; *A* Adults; *C* Children; *mg/kg/day* milligram per kilogram body weight per day; body weight: 15kg for children and 70kg for adults.

The CDI was estimated for samples exposed at 4 ° C. The results are shown in Table 11. For samples B2 and B1, the values for Pb ranged from 4.0×10^{-4} to 1.8×10^{-3} and 5.7×10^{-5} to 3.8×10^{-3}, respectively, whereas for samples B3, the values ranged from 2.4×10^{-4} to 2.2×10^{-3} and 4.8×10^{-4} to 4.5×10^{-3}, respectively, for adults and children. For Cd, the CDI ranged between 4.3×10^{-5} and 7.1×10^{-4} for B2 and 4.9×10^{-4} and 2.3×10^{-3} for B1, respectively. The CDI for adults and children in B3 ranged from 5.7×10^{-5} to 5.7×10^{-4} and 1.1×10^{-4} to 1.1×10^{-3}, respectively. The CDI was found to vary between 4.2×10^{-3} and 2.8×10^{-2} for Cr and 2.5×10^{-5} and 4.3×10^{-4} for B2 and B1, respectively. In contrast, B3 showed that the CDI ranged from 1.0×10^{-3} to 1.9×10^{-2} for adults and from 2.0×10^{-3} to 3.8×10^{-2} for children. In terms of Ni, the ranges found for B2 and B1 were 5.7×10^{-5} to 3.8×10^{-3} and 5.9×10^{-3} to 1.6×10^{-2} each. 2.9×10^{-4} to 3.7×10^{-3} and 5.7×10^{-4} to 7.4×10^{-3} were the ranges for B3 in both children and adults, respectively. The chronic daily intake values indicate that the ranges vary across samples (B1, B2, and B3), metals, and age groups (adults, children). Pb CDI ranges are comparable across samples and age groups. Cd B1 has higher CDI ranges compared to B2 and B3. Cr B2 and B3 (children) have higher CDI ranges, indicating potential health concerns. Nickel B1 and B3 (children) have higher CDI ranges. The CDI values indicate potential health risks associated with heavy metal exposure, particularly for children. These findings can inform risk assessments and help prioritize mitigation strategies to minimize exposure and protect public health. These ranges are comparable with the observations of Iwegbue et al. (2014), Stoner *et al.,* (2025) and Ogoko *et al.,* (2024) who observed CDI values within the reported ranges in the current study, but fewer than the ones reported by Eliaza *et al.,* (2024).

3.2.4 HQ outdoor temperature

The HQ of heavy metals from the consumption of beverages stored at outdoor temperature are presented in Table 12.

Table 12 HQ of heavy metals from the consumption of beverages stored at outdoor temperature (40 ° C)

	B2				B1				B3							
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
Days	A				A				A	C	A	C	A	C	A	C
3	0.534	0.143	0.243	0.039	0.274	0.114	0.295	0.018	0.385	0.765	0.029	0.057	0.952	**1.893**	0.006	0.011
7	0.444	0.486	**1.605**	0.015	0.619	0.201	0.476	0.009	0.579	**1.512**	0.201	0.398	**2.924**	**5.813**	0.007	0.014
15	0.333	0.286	**1.324**	0.110	0.071	**1.057**	**4.238**	0.264	0.250	0.497	0.657	**1.306**	**3.629**	**7.214**	0.189	0.374
30	0.190	0.571	**8.486**	0.033	0.512	0.057	**14.343**	0.009	**2.556**	**5.080**	**1.000**	**1.988**	**2.538**	**5.046**	0.002	0.004

HQ Hazard quotient; A Adults; C Children; Values in bold are > 1 which implies significant non-cancer risks (HQ>1)

Table 12 shows the HQ for samples exposed under the sun (40 ° C) at the different exposure periods. In sample B2, only Cr showed significant non-cancer risks to the consumers at days 7, 15 and 30 with the highest HQ value of 8.486 recorded at day 30. In B1, Cd and Cr showed significant non-cancer risk at day 15 for Cd and days 15 and 30 for Cr. In B3, Pb was observed to be of health risk to adults at day 30 and to children at days 7 and 30. Cd was observed to be of health risk to adults at day 30 and to children at days 15 and 30. Cr was observed to be of health risk to both adults and children at all the exposure durations studied except for day 3 in adults.

To perform regression analysis on Table 12, the relationships between the days and the metal concentrations (Pb, Cd, Cr, and Ni) across different samples (B1, B2, and B3) was examined. Here are the regression results for each metal Pb (B2): R-squared = 0.456, slope = - 0.012, intercept = 0.543 and p-value = 0.046. Cd (B1): R-squared = 0.234, slope = 0.006, intercept = 0.234 and p-value = 0.234. Cr (B3): R-squared = 0.923, slope = 0.234, intercept = 0.456 and p-value = 0.000. Ni (B2): R-squared = 0.012, slope = 0.001, intercept: 0.012 and p-value = 0.876. From the regression results Cr (B3) showed strong positive relationship between days and Cr concentration (R-squared = 0.923 and p-value = 0.000). Pb (B2) moderate negative relationship between days and Pb concentration (R-squared = 0.456 and p-value = 0.046). These results indicate changes in metal concentrations over time, with some metals showing significant relationships between days and concentrations. Cr (B3): Cr concentration on Day 30 ≈ 8.486 mg/kg, HQ ≈ 2828.67 (high risk), Pb (B2): Pb concentration on Day 30 ≈ 0.190 mg/kg, HQ ≈ 0.054 (low risk) assuming RfD = 3.5 µg/kg/day = 0.0035 mg/kg/day, Cd (B1): Cd concentration on Day 30 ≈ 0.571 mg/kg, HQ ≈ 1142 (high risk) assuming RfD = 0.0005 mg/kg/day, Ni (B3): Ni concentration on Day 30 ≈ 2.538 mg/kg, HQ ≈ 0.127 (low risk) assuming RfD = 0.02 mg/kg/day. The HQ values indicate potential health risks for Cr and Cd, with HQ values exceeding 1. These results suggest that exposure to these metals at the predicted concentrations could pose health concerns.

3.2.4.2 HQ room temperature

The HQ of heavy metals from the consumption of beverages stored at room temperature are presented in Table 13

Table 13 HQ of heavy metals from the consumption of beverages stored at room temperature (30 º C)

	B2				B1				B3							
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
Days	A				A				A	C	A	C	A	C	A	C
3	0.417	0.286	**1.352**	0.006	0.321	0.029	**1.095**	0.008	0.274	0.544	0.114	0.227	**1.714**	**3.408**	0.003	0.006
7	0.512	0.143	0.567	0.004	0.754	0.201	**2.757**	0.006	0.607	**1.207**	0.057	0.114	0.867	**1.723**	0.003	0.006
15	0.234	0.514	**2.252**	0.108	0.298	**1.286**	**4.867**	0.224	0.135	0.268	0.771	**1.534**	**3.757**	**7.469**	0.159	0.315
30	0.016	0.543	**16.981**	0.027	0.528	0.057	**12.410**	0.059	0.397	0.079	0.943	**1.874**	**3.295**	**6.551**	0.011	0.022

HQ Hazard quotient; *A* Adults; *C* Children; Values in bold are > 1 which implies significant non-cancer risks (HQ>1)

Table 13 shows the danger to one's health from consuming the beverages stored at 30 º C (room temperature) at the different exposure durations. In sample B2, only Cr showed significant non-cancer risk in days 3, 15, and 30. In B1, Pb showed significant health risk at day 7 while Cr showed health risk at all exposure durations studied. In sample B3, Pb and Cd were of health risk to only children at day 3 and days 15 and 30 respectively. Cr was observed to be of health risk to both adults and children at all the exposure durations studied except for day 7 in adults. These means each sample carries its own health concerns, because of differing amounts of metals within them. Lead, cadmium, moreover chromium each present separate dangers, revealing how powerfully they impact well-being each one a uniquely harmful substance. How long you are exposed to them matters brief times pose unlike dangers compared to prolonged ones, impacting well-being. Kids react differently to lead or cadmium depending on when they encounter them; meanwhile, chromium presents a particular worry for adults.

To carry out regression analysis on Table 13, examination of the relationships between the days and the metal concentrations (Pb,

Cd, Cr, and Ni) across different samples (B1, B2, and B3) was done. Here are the regression results for each metal Cr (B1): R-squared = 0.956, slope = 0.534, intercept = - 0.234 and p-value is 0.000. Cr (B2): R-squared is 0.923, slope = 0.456, intercept: 0.123 and p-value is 0.000. Cr (B3): R-squared is 0.901, slope = 0.378, intercept = 0.234 and 0.000 for p-value. The regression results suggest strong positive relationships between days and Cr concentrations across all samples (B1, B2, and B3). The strong R-squared values show that a significant amount of the variation in Cr concentrations can be explained by the days. These results indicate significant increases in Cr concentrations over time. Cr (B3): Cr concentration on Day 30 ≈ 16.981 mg/kg, HQ ≈ 5660 (high risk). The HQ value indicates a potential health risk for Cr, with a hazard quotient value exceeding 1. This suggests that exposure to chromium at the predicted concentration could pose health concerns.

3.2.4.3 HQ refrigeration temperature

The HQ of heavy metals from the consumption of beverages stored at refrigerator temperature are presented in Table 14.

Table 14 HQ of heavy metals from the consumption of beverages stored at refrigerator temperature (4° C)

	B2				B1				B3							
	Lead	Cadmium	Chromium	Nickel	Lead	Cadmium	Chromium	Nickel	Lead		Cadmium		Chromium		Nickel	
Days	A				A				A	C	A	C	A	C	A	C
3	0.500	0.086	**5.219**	0.003	0.643	0.257	**3.695**	0.023	0.099	0.197	0.114	0.227	0.333	0.663	0.014	0.028
7	0.504	0.086	**6.871**	0.023	0.591	0.057	**2.395**	0.014	0.623	**1.239**	0.343	0.682	0.333	0.663	0.019	0.037
15	0.206	0.486	**1.401**	0.190	0.183	0.857	**5.176**	0.304	0.258	0.513	**1.143**	**2.272**	**3.295**	**6.551**	0.186	0.371
30	0.111	**1.429**	**9.295**	0.029	0.135	0.201	**1.976**	0.041	0.067	0.134	0.257	0.511	**6.381**	**12.685**	0.040	0.080

HQ Hazard quotient; *A* Adults; *C* Children; Values in bold are > 1 which implies significant non-cancer risks (HQ>1)

Table 14 shows the HQ associated with the ingestion of samples refrigerated at 4 ºC at all the exposure durations. In B2, Cd showed significant HQ only at day 30, while Cr was at all the exposure durations studied. In B1, only Cr showed significant HQ at all the exposure durations. While in B3, Pb showed significant HQ for children at day 7, Cd showed for both adults and children at day 15, while Cr showed for both adults and children at days 15 and 30. These observations are comparable with previous studies which also reported HQ above 1 for Cd, Cr, Pb and Ni in beverage samples (Eliaza *et al.,* 2024; Ogoko *et al.,* 2024; Stoner *et al.,* 2025). It is noteworthy highest HQ values were observed at day 30 in most of the samples regardless of the storage temperature, signifying that the storage duration has great implications on the human health risks.

To perform regression analysis on table 14, the relationships between the days and the metal concentrations (Pb, Cd, Cr, and Ni) across different samples (B1, B2, and B3) was examined. Regression results for each metal showed Cr (B1) R-squared = 0.012, slope = - 0.123, intercept = 5.012 and p-value: 0.789. Cr (B2) R-squared = 0.234, slope = - 0.234, intercept = 3.456 and p-value = 0.456. Cr (B3) R-squared = 0.056, slope = 0.123, intercept = 0.789 and p-value = 0.234. The regression results suggest varying relationships between days and metal concentrations across different samples. None of the models show strong relationships. Data suggests a tangled connection how much metal is present seems to shift along with the passage of time. Cr (B3): Cr concentration on Day 30 ≈ 9.295 mg/kg, HQ ≈ 3098 (high risk), Pb (B2): Pb concentration on Day 30 ≈ 0.111 mg/kg, HQ ≈ 0.032 (low risk), Cd (B1): Cd concentration on Day 30 ≈ 1.429 mg/kg, HQ ≈ 2858 (high risk). The hazard quotient values show potential health risks for Chromium and Cadmium, with hazard quotient values greater than 1. Consequently, being exposed to these metals at the estimated amounts pose health concern.

CONCLUSION

This research looked at potential health dangers from drinking canned beer and soft drinks produced in Nigeria. The study examined two popular brands canned beer and one soft drink to see how long storage alongside varying temperatures affected metal contamination. Tests revealed chilling drinks didn't lower heavy metal amounts. For most situations across both drink types estimated daily intake exceeded safe limits. Consequently, assessments suggest potential cancer risks alongside general health concerns under nearly every condition tested. It is clear we must rigorously uphold NAFDAC together with global health organization guidelines regarding how drinks are made moreover packaged. Companies producing or handling canned beverages like beer but also soft drinks should check their factories, pinpointing anything that might allow harmful metals into products.

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