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Contamination Factor, Metal Pollution Index and Estimated Daily Intake of Heavy Metals in Some Selected Energy Drinks in Nigeria

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Abstract- This study assessed the levels of selected heavy metals and their associated health risks in commercially available energy drinks using contamination indices. A total of thirty (30) energy drink samples comprising twenty-three (23) liquid formulations and seven (7) powdered formulations were collected from retail outlets and analyzed for cobalt (Co), chromium (Cr), cadmium (Cd), arsenic (As), nickel (Ni), and lead (Pb). Liquid samples were digested using aqua regia and analyzed by Atomic Absorption Spectrophotometry (AAS), while powdered samples were prepared as pellets and analyzed using X-ray Fluorescence (XRF). The contamination status of the metals was evaluated using Contamination Factor (CF), Metal Pollution Index (MPI), and Estimated Daily Intake (EDI) for both adults and children. Results showed that several samples contained elevated concentrations of heavy metals above recommended limits, particularly cadmium, nickel, and lead. The highest concentrations were observed in powdered samples such as EJ and KR, with lead values of 0.2092 mg/L and 0.1754 mg/L, respectively, and arsenic levels of 0.0451 mg/L and 0.0316 mg/L. Contamination factor analysis indicated high contamination for cadmium in nearly all samples, while lead contamination was markedly elevated in all detected samples. The metal pollution index ranged from 0.12 to 4.06, with sample EJ recording the highest overall metal burden, indicating significant multi-metal contamination. Estimated daily intake values revealed that children had higher exposure levels than adults due to lower body weight, and the EDI values of cadmium, nickel, and lead in many samples exceeded permissible tolerable daily intake limits. The findings suggest that regular consumption of some energy drinks may pose potential public health risks, particularly to children and frequent consumers. Continuous monitoring, stricter regulatory control, and improved manufacturing quality assurance are therefore recommended to minimize heavy metal contamination in energy drink products.

Index Terms- Energy drinks; heavy metals; contamination factor; metal pollution index; estimated daily intake; public health risk.

I. INTRODUCTION

Energy drinks are non-alcoholic beverages widely consumed for their perceived ability to enhance alertness, reduce fatigue, and improve physical or mental performance. Their popularity has increased markedly among adolescents, young adults, athletes, and workers who seek rapid stimulation during demanding activities (Hamza et al., 2025). These beverages commonly contain caffeine, sugars, taurine, glucuronolactone, vitamins, herbal extracts, and other stimulatory compounds (Hamza et al., 2026). Although energy drinks are often marketed as performance-enhancing products, growing public health concerns exist regarding their safety, not only because of their high stimulant content but also due to the possible presence of chemical contaminants, including heavy metals, which may enter the products during raw material sourcing, manufacturing, packaging, transportation, or storage (World Health Organization [WHO], 2022a).

Heavy metals are naturally occurring elements with relatively high atomic weight and density, but many of them become toxic even at low concentrations when present above physiological or regulatory limits. In beverage products, metals such as cobalt

(Co), chromium (Cr), cadmium (Cd), arsenic (As), nickel (Ni), and lead (Pb) are of particular concern because of their persistence, non-biodegradability, bioaccumulative tendencies, and toxicological significance. Chronic exposure to these metals through dietary sources may lead to adverse health outcomes such as nephrotoxicity, hepatotoxicity, neurotoxicity, cardiovascular disorders, developmental impairment, reproductive toxicity, and carcinogenicity. Lead exposure is especially associated with neurological and developmental damage, cadmium is linked with kidney dysfunction and skeletal effects, arsenic is a recognized human carcinogen, and excessive nickel intake may pose reproductive and hypersensitivity risks (WHO, 2022b; European Food Safety Authority [EFSA], 2020).

The possibility of heavy metal contamination in energy drinks has become an important food safety issue because these beverages are consumed frequently and sometimes in large volumes, particularly by younger populations. Repeated intake of contaminated drinks, even when metal concentrations appear low in individual servings, may contribute to cumulative exposure over time. This concern is amplified in developing countries where regulatory surveillance, product standardization, and post-market monitoring may be inconsistent. Therefore, the determination of heavy metal concentrations in energy drinks and the assessment of their potential health implications are essential for consumer protection, quality assurance, and evidence-based regulatory action (WHO, 2022a).
To evaluate contamination in food and beverage matrices, pollution indices are commonly employed because they provide a more interpretable measure of risk than concentration data alone. One such index is the Contamination Factor (CF), which expresses the ratio of the concentration of a given metal in the sample to a reference or permissible value. CF helps classify contamination as low, moderate, considerable, or very high and enables identification of specific metals contributing disproportionately to pollution. This makes CF particularly useful for screening individual toxic elements in commercially available energy drinks and for comparing contamination patterns among different brands or product types.

Another important index is the Metal Pollution Index (MPI), which provides an integrated assessment of the overall heavy metal burden in a sample. Unlike CF, which evaluates metals individually, MPI combines the concentrations of multiple metals into a single numerical value, often using the geometric mean. This allows a more holistic interpretation of total contamination status and simplifies comparison among samples. In studies involving multiple toxic metals, MPI is especially valuable because consumers are exposed to mixed contaminants rather than isolated elements, and the cumulative burden may better reflect the real-world toxicological concern.

In addition to contamination assessment, evaluating actual human exposure is a critical aspect of toxicological studies. The Estimated Daily Intake (EDI) is a widely used exposure metric that estimates the quantity of a contaminant ingested per day based on its concentration in the food or beverage, the daily consumption rate, and the consumer's body weight. EDI is particularly important in studies on energy drinks because consumption patterns may vary significantly between adults and children, and children are often at greater risk due to lower body weight and increased vulnerability to toxicants. By comparing EDI values with established health-based guidance values or permissible tolerable daily intake limits, researchers can determine whether regular consumption may pose non-carcinogenic or chronic health risks (EFSA, 2011; EFSA, 2020).

The combined application of CF, MPI, and EDI provides a robust framework for understanding heavy metal contamination in energy drinks from both environmental and public health perspectives. While CF identifies the degree of contamination by individual metals, MPI summarizes the total metal load, and EDI estimates the likely exposure level for consumers. Together, these indices improve the interpretation of analytical data and support more meaningful risk characterization. Such an integrated approach is necessary because the presence of heavy metals in energy drinks is not merely an issue of chemical detection, but one of potential cumulative toxicity and long-term health consequences.

Given the increasing consumption of energy drinks and the health risks associated with chronic exposure to toxic metals, it is important to assess the concentrations of selected heavy metals in both liquid and powdered formulations of these products. Therefore, this study is designed to determine the levels of cobalt, chromium, cadmium, arsenic, nickel, and lead in selected energy drinks, and to evaluate their contamination status using contamination factor and metal pollution index, as well as the potential dietary exposure among adults and children using estimated daily intake. The findings of this study will contribute valuable data for food safety monitoring, consumer awareness, and regulatory control of energy drinks in the study area.

II. MATERIALS AND METHODS

2.1 Sample collection

A total of thirty (30) commercially available energy drink samples were analyzed in this study. The samples consisted of twenty-three (23) liquid energy drinks and seven (7) powdered energy drink formulations. The products were randomly purchased from supermarkets, retail stores, and street vendors to ensure representative sampling. Different brands, batch numbers, and production dates were considered. All samples were transported to the laboratory in their original packaging and stored under recommended conditions prior to analysis.

2.2 Sample Preparation and Analysis

2.2.1 Preparation of Liquid Samples for AAS

Liquid samples were digested using the aqua regia method to release metals from the organic matrix. Briefly, 10 mL of each energy drink was measured using an analytical balance and transferred into a digestion flask. A mixture of concentrated hydrochloric acid (HCl) and nitric acid (HNO_3) in a 3:1 ratio was added to each sample. Digestion was performed in a fume hood on a Kjedahl heater for 4–5 hours until the solution became pale yellow, indicating complete breakdown of organic matter. After cooling, the digested samples were diluted with deionized water and filtered to remove particulates. The final volume was adjusted to 100 mL for analysis. Samples were analyzed using a Bulk 205 Atomic Absorption Spectrophotometer (AAS) according to the manufacturer's instructions.

2.2.2 Preparation of Powder Samples for XRF

Powdered energy drink samples (3 g each) were pressed into pellets of 25 mm diameter using a hydraulic pellet press. Each pellet was covered with a 6 µm polypropylene film to prevent contamination and placed in the X-ray fluorescence (XRF) excitation chamber. Quantitative elemental analysis was conducted using a time-controlled irradiation program, and the generated spectra were used to construct calibration curves for the determination of metal concentrations in the samples.

2.3 Data Analysis and Evaluation

The trend distribution of the elements was assessed by calculating some pollution indices after determining the heavy metals in all the energy drink samples. The pollution indices include: Contamination factors, Metal pollution index, and daily intake of metals.

2.3.1 Contamination Factor (CF)

The term contamination factor refers to the degree of presence of strange substances apart from the original composition of the sample of interest (energy drink). It was obtained by taking the ratio of concentration of each metal in the energy drink to that of the background (concentration in unpolluted energy drink). It was determined based on the equation 1 below (Ureso et al., 1997).

$$CF = \frac{(C)\ Heavy\ metal}{(C))\ Background} \quad (1)$$

Where, (C)heavy metal is the concentration of heavy metal in the sample and (C)Background is the background value for the same metal.

2.3.2 Metal Pollution Index (MPI)

Metal pollution index (MPI) was calculated following (Ureso et al., 1997), which is the geometrical mean of concentrations of all the metals in the corresponding energy drink samples. The MPI value of greater than 1 signifies that the sample is polluted, and that of less than 1 indicates that the

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sample only baseline pollutants level. It is represented by equation 2.

$$MPI = \left(\sum \frac{\left(\frac{C_i}{R_i}\right)}{n} \right) \quad (2)$$

Where:
Ci =Concentration of individual metal (i) in the sample.
Ri = Reference value for metal in (i)
n = Number of metals considered in the calculation.

2.3.3 Estimated Daily Intake (EDI) of Heavy Metals
Estimated Daily Intake (EDI) of the metals depended on both the metal concentration in the energy drinks and the amount of consumption of the energy drinks. The Estimated Daily Intake for was determined by the equation 3 below:

$$EDI(mgkg^{-1}d^{-1}) = \frac{C_{metal} \times D_{food\ intake}}{B_{average\ body\ weight}} \quad (4)$$

Where C_{metal}, represents the metal concentration in energy drinks, $D_{food\ intake}$ represents daily intake of energy drinks, and $B_{average\ body\ weight}$ is average body weight, respectively.

The required amount of energy drink for both children and adult is 300–600 ml/day which is equivalent to 0.3–0.6 L/day based on Calcium requirement in human body. In this study the maximum means 600 ml/day (0.6 L/day) intake of energy drink for adult and 300 ml/day (0.3 L/day) for children are considered. So, 0.6 L and 0.3 L daily intake of energy drink are considered for adult and children respectively in calculating the daily intake of heavy metals through energy drink consumption. WHO suggested the average body weight for adult is 60 kg and, in this study, the average body weight of children is taken as 20 kg (WHO, 2011).

III. RESULTS AND DISCUSSION

3.1 Heavy metals

The concentrations of cobalt (Co), chromium (Cr), cadmium (Cd), arsenic (As), nickel (Ni), and lead (Pb) detected in the analyzed energy drink samples are presented in Table 1. The results indicate considerable variation in heavy metal levels among the different brands and formulations, suggesting differences in raw material quality, production processes, packaging materials, and storage conditions. Overall, both liquid and powdered energy drinks contained detectable levels of one or more heavy metals, although powdered formulations generally exhibited relatively higher concentrations for several metals.

Table 1: Concentration of Heavy Metals in Energy Drinks in (mg/L)

S/N	Sample code	Sample type	Co ($\times10^{-2}$)	Cr ($\times10^{-2}$)	Cd ($\times10^{-3}$)	As ($\times10^{-3}$)	Ni ($\times10^{-2}$)	Pb ($\times10^{-2}$)
1	SY	Liquid	2.15	6.41	-	2.3	-	13.93
2	RB	Liquid	-	4.63	12.7	0.4	8.75	4.51
3	PH	Liquid	0.54	-	5.5	-	13.6	-
4	PW	Liquid	-	1.75	13.1	-	6.52	-
5	XC	Liquid	-	-	-	-	-	5.45
6	HS	Liquid	-	9.83	15.5	0.2	1.56	-
7	3H	Liquid	0.53	1.25	12.5	1.6	5.57	8.25
8	WB	Liquid	-	2.53	11.6	-	9.82	-
9	BR	Liquid	-	4.93	16.2	-	3.65	-
10	HD	Liquid	-	4.73	8.4	3.7	6.25	-
11	BH	Liquid	0.52	25.63	18.2	-	4.78	-
12	OR	Liquid	-	2.63	19.8	-	9.84	-
13	SD	Liquid	0.84	6.72	28.2	-	7.94	-
14	BS	Liquid	1.82	8.54	14.5	4.2	4.32	6.15
15	ME	Liquid	0.29	3.23	7.4	2.8	6.08	-
16	VE	Liquid	1.65	-	-	1.1	0.64	-

17	FL	Liquid	0.27	0.63	-	2.1	9.42	-
18	PR	Liquid	8.26	1.13	10.6	-	4.51	4.51
19	SK	Liquid	-	0.46	-	1.2	0.75	-
20	IP	Liquid	1.62	2.96	1.5	-	5.16	-
21	MP	Liquid	0.17	41.59	56.6	5.6	0.62	-
22	AR	Liquid	-	2.91	3.7	1.4	0.15	-
23	CX	Liquid	1.26	-	-	3.6	1.83	-
24	EJ	Powder	8.35	-	12.8	45.1	6.24	20.92
25	KR	Powder	5.34	37.64	-	31.6	0.46	17.54
26	KK	Powder	1.75	2.65	5.2	-	2.49	1.54
27	PS	Powder	2.63	-	7.4	-	5.73	-
28	PE	Powder	-	0.34	-	1.2	6.32	12.25
29	AL	Powder	0.41	0.25	-	2.5	4.32	8.32
30	ES	Powder	-	25.01	18.3	6.3	4.73	-
WHO			5.0	5.0	3.0	10.0	2.0	1.0

Results are expressed as Mean. ND: Not Detected

Cobalt was detected in several samples, with concentrations ranging from 0.0017 to 0.0835 mg/L. The highest concentration was recorded in powdered sample EJ (0.0835 mg/L), followed closely by PR (0.0826 mg/L) and KR (0.0534 mg/L). These values exceeded the stated permissible limit of 0.05 mg/L in the manuscript, indicating potential contamination in these products. Although cobalt is an essential trace element involved in vitamin B12 metabolism, excessive intake may result in adverse health effects, including cardiomyopathy and endocrine disturbances when exposure is prolonged.

Chromium concentrations varied widely across the samples. The highest levels were observed in liquid sample MP (0.4159 mg/L), powdered sample KR (0.3764 mg/L), and powdered sample ES (0.2501 mg/L), all of which greatly exceeded the reference limit of 0.05 mg/L used in the study. Elevated chromium concentrations are of toxicological concern, especially where the oxidation state is not distinguished, since hexavalent chromium [Cr (VI)] is recognized as highly toxic and carcinogenic. While trivalent chromium [Cr (III)] may play a role in glucose metabolism, excessive chromium exposure from beverages may still represent a health risk.

Cadmium was detected in a substantial number of samples and showed notable exceedance above the permissible limit of 0.003 mg/L. The highest cadmium concentration was recorded in sample MP (0.0566 mg/L), followed by SD (0.0282 mg/L), OR (0.0198 mg/L), and BH (0.0182 mg/L). The widespread occurrence of cadmium across the analyzed energy drinks is particularly concerning due to its non-essential nature, persistence, and high bioaccumulation potential. Chronic cadmium exposure has been linked to nephrotoxicity, skeletal demineralization, and reproductive dysfunction. The predominance of cadmium contamination across both liquid and powdered samples suggests that raw ingredients, water sources, or processing equipment may be important contamination pathways.

Arsenic was present in several samples, with the highest concentrations detected in powdered sample EJ (0.0451 mg/L), KR (0.0316 mg/L), and ES (0.0063 mg/L), as well as liquid sample MP (0.0056 mg/L). When compared with the manuscript reference limit of 0.01 mg/L, the concentrations in EJ and KR exceeded the permissible threshold. Arsenic is a highly toxic metalloid associated with carcinogenicity, vascular dysfunction, dermatological lesions, and neurotoxicity. The elevated arsenic levels observed in some powdered products may reflect contamination from plant-derived ingredients, mineral additives, or environmental exposure during processing.

Nickel was detected in most of the samples, with concentrations ranging from 0.0015 mg/L in sample AR to 0.1360 mg/L in sample PH. Other notable concentrations were recorded in OR (0.0984 mg/L), WB (0.0982 mg/L), and FL (0.0942 mg/L). Based on the reference limit of 0.02 mg/L adopted in the study, the majority of samples exceeded the permissible threshold. Although nickel may occur naturally in trace amounts, excessive dietary exposure can provoke allergic reactions, gastrointestinal irritation,

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and, in susceptible individuals, systemic toxicity. The relatively frequent occurrence of elevated nickel levels in the analyzed samples suggests a consistent contamination source that warrants further investigation.

Lead was among the most critical contaminants identified in this study. The highest lead concentrations were found in powdered sample EJ (0.2092 mg/L), KR (0.1754 mg/L), and liquid sample SY (0.1393 mg/L), all of which greatly exceeded the reference limit of 0.01 mg/L. Additional elevated levels were observed in PE (0.1225 mg/L), AL (0.0832 mg/L), and 3H (0.0825 mg/L). Lead is a highly toxic, non-essential heavy metal with no known safe biological role in humans. Even low-level chronic exposure may impair neurological development, reduce cognitive performance, disrupt hematopoiesis, and increase cardiovascular risk. The high lead concentrations recorded in several samples are therefore of significant public health concern, particularly for children and habitual consumers of these beverages.

Taken together, the heavy metal profile of the analyzed energy drinks indicates that several products contain potentially hazardous concentrations of toxic metals, especially cadmium, nickel, and lead. The generally higher values observed in some powdered samples suggest that product formulation type may influence contamination burden. These findings underscore the need for regular monitoring of energy drinks, particularly in markets where quality control and raw material screening may be inconsistent.

3.2 Contamination Factor

The contamination factor (CF) was used to assess the degree of contamination of each heavy metal in the energy drink samples relative to the reference values employed in this study. In general, CF values less than 1 indicate low contamination, values equal to 1 indicate contamination at the permissible threshold, and values greater than 1 indicate contamination above the acceptable limit. The CF results presented in Table 2 revealed substantial variation in contamination levels among the samples and across the metals analyzed.

Table 2: Contamination factor (CF) of heavy metals

S/N	Sample code	Sample type	Co	Cr	Cd	As	Ni	Pb
1	SY	Liquid	0.430	1.282	-	0.230	-	13.930
2	RB	Liquid	-	0.926	4.233	0.040	4.375	4.510
3	PH	Liquid	0.108	-	1.833	-	0.680	-
4	PW	Liquid	-	0.350	4.367	-	3.260	-
5	XC	Liquid	-	-	-	-	-	5.450
6	HS	Liquid	-	1.966	5.167	0.020	0.780	-
7	3H	Liquid	0.106	0.250	4.167	0.160	2.785	8.250
8	WB	Liquid	-	0.506	3.867	-	4.910	-
9	BR	Liquid	-	0.986	5.400	-	1.825	-
10	HD	Liquid	-	0.946	2.800	0.370	3.125	-
11	BH	Liquid	0.104	5.126	6.067	-	2.390	-
12	OR	Liquid	-	0.526	6.600	-	4.920	-
13	SD	Liquid	0.168	1.344	9.400	-	3.970	-
14	BS	Liquid	0.364	1.708	4.833	0.420	2.160	6.150
15	ME	Liquid	0.058	0.646	2.467	0.280	3.040	-
16	VE	Liquid	0.330	-	-	0.110	0.320	-
17	FL	Liquid	0.054	0.126	-	0.210	4.710	-

18	PR	Liquid	1.652	0.226	3.533	-	2.255	4.510
19	SK	Liquid	-	0.092	-	0.120	0.375	-
20	IP	Liquid	0.324	0.592	0.500	-	2.580	-
21	MP	Liquid	0.034	8.318	18.867	0.560	0.310	-
22	AR	Liquid	-	0.582	1.233	0.140	0.075	-
23	CX	Liquid	0.252	-	-	0.360	0.915	-
24	EJ	Powder	1.670	-	4.267	4.510	3.120	20.920
25	KR	Powder	1.068	7.528	-	3.160	0.230	17.540
26	KK	Powder	0.350	0.530	1.733	-	1.245	1.540
27	PS	Powder	0.526	-	2.467	-	2.865	-
28	PE	Powder	-	0.068	-	0.120	3.160	12.250
29	AL	Powder	0.082	0.050	-	0.250	2.160	8.320
30	ES	Powder	-	5.002	6.100	0.630	2.365	-

For cobalt, most samples showed low contamination (CF < 1), indicating that cobalt levels were generally within acceptable limits. However, samples PR (1.652), EJ (1.670), and KR (1.068) exceeded the threshold, indicating elevated cobalt contamination in these products. This suggests that cobalt contamination was relatively localized and not uniformly distributed across all energy drink brands.
Chromium contamination was more pronounced in specific samples. High CF values were observed in SY (1.282), HS (1.966), BH (5.126), SD (1.344), BS (1.708), MP (8.318), KR (7.528), and ES (5.002). Among these, sample MP recorded the highest chromium contamination factor, indicating a substantial exceedance of the reference limit. These elevated CF values suggest that chromium contamination may be linked to manufacturing materials, additives, or contamination during processing.

Cadmium exhibited one of the most concerning contamination patterns in the study. With the exception of sample IP (CF = 0.500), nearly all samples in which cadmium was detected showed CF values greater than 1, indicating widespread cadmium contamination. Particularly high CF values were observed in MP (18.867), SD (9.400), BH (6.067), OR (6.600), and ES (6.100). This trend confirms that cadmium is a major contaminant of concern in the analyzed energy drinks and supports the toxicological significance of the heavy metal concentration results.

Arsenic contamination was generally low in many samples; however, notable exceptions were recorded in powdered samples EJ (4.510) and KR (3.160), as well as ES (0.630, below 1 but elevated relative to several others) and MP (0.560). The high arsenic CF values in EJ and KR indicate that these powdered formulations may present greater toxicological concern than many of the liquid products. This finding is consistent with the direct concentration data, where EJ and KR also recorded the highest arsenic levels.

Nickel contamination was widespread across the majority of samples. Many samples recorded CF values above 1, including RB (4.375), PW (3.260), 3H (2.785), WB (4.910), BR (1.825), HD (3.125), BH (2.390), OR (4.920), SD (3.970), BS (2.160), ME (3.040), PR (2.255), IP (2.580), EJ (3.120), KK (1.245), PS (2.865), PE (3.160), AL (2.160), and ES (2.365). The highest nickel contamination factors were recorded in OR and WB. This widespread elevation indicates that nickel contamination is common among the studied energy drinks and may represent a consistent exposure route for consumers.
Lead contamination was the most alarming among all the analyzed metals. All samples in which lead was detected showed CF values substantially greater than 1, with the highest values recorded in EJ (20.920), KR (17.540), SY (13.930), PE (12.250), 3H (8.250), AL (8.320), BS (6.150), XC (5.450), and RB/PR (4.510 each). These results indicate severe lead contamination in the affected samples and highlight

lead as the most critical toxicological hazard among the heavy metals studied. Given the known neurotoxicity and cumulative nature of lead, these elevated CF values are of significant concern, particularly for frequent consumers and vulnerable populations such as children.

Overall, the CF analysis demonstrated that cadmium, nickel, and lead were the dominant contaminants in the analyzed energy drinks. While cobalt and arsenic contamination were relatively limited to specific samples, chromium also showed high contamination in selected products. These findings indicate that multiple energy drink brands exceeded acceptable contamination thresholds and emphasize the need for improved quality assurance and stricter regulatory surveillance.

3.3 Metal Pollution Index

The Metal Pollution Index (MPI) was used to provide an integrated assessment of the cumulative burden of multiple heavy metals in each energy drink sample. MPI is a useful composite index because it summarizes the combined effect of all measured metals in a single value, thereby enabling comparison of the overall pollution status among different samples. In this study, MPI values less than 1 indicate low overall metal pollution, whereas values greater than 1 indicate elevated cumulative contamination. The MPI was presented in Table 3. The MPI values for the analyzed energy drinks ranged from 0.12 to 4.06, reflecting substantial differences in the overall metal burden across brands and formulations.

The lowest MPI value was recorded in liquid sample VE (0.12), followed by SK (0.13), CX (0.23), AR (0.29), and PH (0.39). These samples may be considered relatively less contaminated and, based on the metals analyzed, showed lower cumulative heavy metal loads compared with the other products. Other samples with MPI values below 1 included ME (0.94), FL (0.87), IP (0.86), and powdered sample KK (0.76), suggesting that only a limited number of the energy drinks were within relatively acceptable overall pollution levels.

Conversely, the majority of the samples exhibited MPI values greater than 1, indicating elevated multi-metal contamination. The highest MPI was recorded in powdered sample EJ (4.06), followed by PW (3.88), SY (3.87), SD (3.76), KR (3.66), MP (3.50), and OR (3.28). These high MPI values reflect the combined influence of elevated concentrations of several metals within the same sample and indicate that these products may pose greater cumulative toxicological risk than samples with isolated metal exceedance. The consistently high MPI values observed in some powdered samples, particularly EJ and KR, support the earlier observation that powdered formulations may harbor a greater metal burden than many liquid formulations.

The MPI findings are particularly important because consumers are not exposed to a single heavy metal in isolation. Rather, repeated consumption of contaminated energy drinks may result in simultaneous exposure to multiple metals, which may have additive or synergistic toxic effects. Therefore, samples with high MPI values may present greater long-term health risks, even when not all individual metals are exceedingly high. This reinforces the need to assess overall metal burden in addition to evaluating individual metal concentrations.

The MPI analysis confirmed that most of the analyzed energy drinks were affected by notable cumulative heavy metal contamination, with only a few samples showing comparatively low pollution levels. The elevated MPI values in many products, especially in samples EJ and KR, suggest that regular consumption may contribute to chronic multi-metal exposure and associated health risks.

Table 3: Metal pollution index of the energy drinks

S/N	Sample code	Sample type	MPI
1	SY	Liquid	3.87
2	RB	Liquid	1.94
3	PH	Liquid	0.39
4	PW	Liquid	3.88
5	XC	Liquid	1.14
6	HS	Liquid	1.93
7	3H	Liquid	2.21
8	WB	Liquid	2.00
9	BR	Liquid	2.19

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10	HD	Liquid	1.48
11	BH	Liquid	2.68
12	OR	Liquid	3.28
13	SD	Liquid	3.76
14	BS	Liquid	2.10
15	ME	Liquid	0.94
16	VE	Liquid	0.12
17	FL	Liquid	0.87
18	PR	Liquid	1.71
19	SK	Liquid	0.13
20	IP	Liquid	0.86
21	MP	Liquid	3.50
22	AR	Liquid	0.29
23	CX	Liquid	0.23
24	EJ	Powder	4.06
25	KR	Powder	3.66
26	KK	Powder	0.76
27	PS	Powder	1.09
28	PE	Powder	2.12
29	AL	Powder	1.95
30	ES	Powder	2.73

3.4 Estimated daily intake

The Estimated Daily Intake (EDI) was used to assess the potential daily exposure of adults and children to heavy metals through the consumption of energy drinks. EDI incorporates the concentration of each metal, the assumed daily intake of the beverage, and the average body weight of the consumer. In this study, daily consumption values of 0.6 L/day for adults and 0.3 L/day for children were used, with body weights of 60 kg and 20 kg, respectively. EDI of heavy metals is used to calculate the amount of metal taken by an adult and children per day as shown in Table 4. Although adults were assumed to consume a larger volume, children consistently recorded higher EDI values because of their lower body weight, indicating greater exposure per unit body mass. This finding highlights children as a more vulnerable population with respect to heavy metal toxicity from energy drink consumption.

Table 4: Estimated daily intake of heavy metals of Adults and Children (mg 〖kg〗^(-1) d^(-1)).

S/N	Sample code		Co	Cr	Cd	As	Ni	Pb
1	SY	Adult	2E-04	6E-04	-	2E-05	-	0.001
		Child	3E-04	1E-03	-	4E-05	-	0.002
2	RB	Adult	-	5E-04	1E-04	4E-06	9E-04	5E-04
		Child	-	7E-04	2E-04	6E-06	0.001	7E-04
3	PH	Adult	5E-05	-	6E-05	-	1E-04	-
		Child	8E-05	-	8E-05	-	2E-04	-
4	PW	Adult	-	2E-04	1E-04	-	7E-04	-
		Child	-	3E-04	2E-04	-	1E-03	-
5	XC	Adult	-	-	-	-	-	5E-04
		Child	-	-	-	-	-	8E-04
6	HS	Adult	-	1E-03	2E-04	2E-06	2E-04	-
		Child	-	0.001	2E-04	3E-06	2E-04	-
7	3H	Adult	5E-05	1E-04	1E-04	2E-05	6E-04	8E-04
		Child	8E-05	2E-04	2E-04	2E-05	8E-04	0.001
8	WB	Adult	-	3E-04	1E-04	-	1E-03	-
		Child	-	4E-04	2E-04	-	0.001	-
9	BR	Adult	-	5E-04	2E-04	-	4E-04	-
		Child	-	7E-04	2E-04	-	5E-04	-

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10	HD	Adult	-	5E-04	8E-05	4E-05	6E-04	-
		Child	-	7E-04	1E-04	6E-05	9E-04	-
11	BH	Adult	5E-05	0.003	2E-04	-	5E-04	-
		Child	8E-05	0.004	3E-04	-	7E-04	-
12	OR	Adult	-	3E-04	2E-04	-	1E-03	-
		Child	-	4E-04	3E-04	-	0.001	-
13	SD	Adult	8E-05	7E-04	3E-04	-	8E-04	-
		Child	1E-04	0.001	4E-04	-	0.001	-
14	BS	Adult	2E-04	9E-04	1E-04	4E-05	4E-04	6E-04
		Child	3E-04	0.001	2E-04	6E-05	6E-04	9E-04
15	ME	Adult	3E-05	3E-04	7E-05	3E-05	6E-04	-
		Child	4E-05	5E-04	1E-04	4E-05	9E-04	-
16	VE	Adult	2E-04	-	-	1E-05	6E-05	-
		Child	2E-04	-	-	2E-05	1E-04	-
17	FL	Adult	3E-05	6E-05	-	2E-05	9E-04	-
		Child	4E-05	1E-04	-	3E-05	0.001	-
18	PR	Adult	8E-04	1E-04	1E-04	-	5E-04	5E-04
		Child	0.001	2E-04	2E-04	-	7E-04	7E-04
19	SK	Adult	-	5E-05	-	1E-05	8E-05	-
		Child	-	7E-05	-	2E-05	1E-04	-
20	IP	Adult	2E-04	3E-04	2E-05	-	5E-04	-
		Child	2E-04	4E-04	2E-05	-	8E-04	-
21	MP	Adult	2E-05	0.004	6E-04	6E-05	6E-05	-
		Child	3E-05	0.006	8E-04	8E-05	9E-05	-
22	AR	Adult	-	3E-04	4E-05	1E-05	2E-05	-
		Child	-	4E-04	6E-05	2E-05	2E-05	-
23	CX	Adult	1E-04	-	-	4E-05	2E-04	-
		Child	2E-04	-	-	5E-05	3E-04	-
24	EJ	Adult	8E-04	-	1E-04	5E-04	6E-04	0.002
		Child	0.001	-	2E-04	7E-04	9E-04	0.003
25	KR	Adult	5E-04	0.004	-	3E-04	5E-05	0.002
		Child	8E-04	0.006	-	5E-04	7E-05	0.003
26	KK	Adult	2E-04	3E-04	5E-05	-	2E-04	2E-04
		Child	3E-04	4E-04	8E-05	-	4E-04	2E-04
27	PS	Adult	3E-04	-	7E-05	-	6E-04	-
		Child	4E-04	-	1E-04	-	9E-04	-
28	PE	Adult	-	3E-05	-	1E-05	6E-04	0.001
		Child	-	5E-05	-	2E-05	9E-04	0.002
29	AL	Adult	4E-05	3E-05	-	3E-05	4E-04	8E-04
		Child	6E-05	4E-05	-	4E-05	6E-04	0.001
30	ES	Adult	-	0.003	2E-04	6E-05	5E-04	-

	Child	-	0.004	3E-04	1E-04	7E-04	-
WHO	Adult	5E-04	5E-04	3E-05	1E-04	2E-04	1E-04
	Child	8E-04	8E-04	5E-05	2E-04	3E-04	2E-04

For cobalt, the EDI values for both adults and children were generally below the tolerable limits presented in the manuscript. The highest EDI values for cobalt were observed in PR and EJ, but these remained within or around the reference threshold. This suggests that cobalt exposure from the analyzed energy drinks is relatively less concerning compared with other metals, although products with elevated cobalt concentrations should still be monitored.

Chromium EDI values showed exceedance in several samples. For adults, samples such as BH, MP, KR, and ES recorded values of approximately 0.003–0.004 mg/day, while the corresponding values for children were even higher (approximately 0.004–0.006 mg/day). These values exceeded the reference limit reported in the table for both population groups, indicating that chromium exposure may be significant in highly contaminated samples. The higher EDI values in children further underscore their susceptibility to adverse effects associated with chronic chromium intake.

Cadmium exposure was one of the most critical findings in the EDI assessment. The EDI values for cadmium exceeded the permissible tolerable daily intake in many samples for both adults and children. Sample MP recorded the highest cadmium EDI, followed by SD, OR, BH, and ES. Since cadmium is highly toxic and accumulates in the kidneys and bones over time, this exceedance indicate a potentially serious public health concern, particularly for frequent consumers of the implicated energy drink brands. The fact that only a few samples showed relatively low cadmium EDI values confirms the widespread contamination pattern already observed in the CF analysis.

Arsenic EDI values were generally lower than those of cadmium, nickel, and lead, and in many samples remained below the reference threshold. However, elevated arsenic exposure was observed in powdered samples EJ and KR, which recorded the highest arsenic concentrations and correspondingly higher EDI values. Although the majority of samples may not present immediate concern for arsenic, the elevated values in some powdered formulations indicate that chronic exposure cannot be ruled out for regular consumers.

Nickel EDI values exceeded the tolerable limit in many of the analyzed samples for both adults and children. Notably, samples with high nickel concentrations such as PH, OR, WB, FL, SD, and EJ produced elevated EDI values, indicating that nickel represents a significant contributor to overall toxicological risk. Because nickel exposure may induce allergic reactions, gastrointestinal irritation, and other systemic effects in susceptible individuals, the widespread exceedance of nickel EDI values is an important public health finding.

Lead EDI values also exceeded the reference limits in several samples, particularly in EJ, KR, SY, PE, AL, and 3H. Children consistently recorded higher lead EDI values than adults, which is especially concerning given the well-established neurodevelopmental toxicity of lead. Even low-level lead exposure may impair cognitive development, reduce learning ability, and produce long-term neurological consequences in children. Therefore, the elevated lead EDI values observed in this study strongly suggest that some of the analyzed energy drinks may not be safe for regular consumption, particularly by adolescents and younger individuals.

Overall, the EDI assessment showed that children are at greater risk of exposure to heavy metals through energy drink consumption than adults, despite the lower assumed daily intake volume. While cobalt, chromium, and arsenic were reported in the original manuscript as generally lower-risk in many samples, cadmium, nickel, and lead clearly exceeded tolerable intake thresholds in several cases and therefore represent the major toxicological concerns. These findings indicate that routine or excessive consumption of certain energy drinks may contribute significantly to chronic dietary exposure to hazardous metals.

IV. CONCLUSION

This study demonstrated that commercially available energy drinks contain measurable concentrations of heavy metals, with several samples exceeding recommended safety limits. Among the metals analyzed, cadmium (Cd), nickel (Ni), and lead (Pb) were the most critical contaminants, while cobalt (Co), chromium (Cr), and arsenic (As) showed variable contamination depending on the sample. The results revealed that powdered energy drinks, particularly samples such as EJ and KR, generally exhibited higher contamination levels than many liquid samples, suggesting possible contributions from raw materials, processing methods, or packaging sources. Contamination Factor (CF) analysis showed that cadmium contamination was widespread across the samples, and lead contamination was especially severe wherever detected. Similarly, the Metal Pollution Index (MPI) indicated that most of the samples had elevated cumulative metal loads, with only a few samples falling within acceptable limits.

Furthermore, the Estimated Daily Intake (EDI) assessment revealed that children are more vulnerable to heavy metal exposure through energy drink consumption than adults because of their lower average body weight. Although the EDI values for cobalt, chromium, and arsenic were generally below tolerable daily intake limits, cadmium, nickel, and lead exceeded recommended thresholds in several samples, raising concerns about possible long-term toxicological effects such as neurological impairment, kidney dysfunction, cardiovascular complications, and bioaccumulation. Overall, the findings of this study indicate that frequent consumption of certain energy drinks may constitute a significant public health concern. It is therefore essential for regulatory agencies such as NAFDAC and manufacturers to strengthen routine surveillance, enforce strict quality control measures, ensure compliance with permissible heavy metal limits, and improve production practices to safeguard consumers. Public awareness should also be increased, especially regarding the potential risks of excessive energy drink consumption among children and adolescents.

REFERENCES

[1] European Food Safety Authority (EFSA). (2011). Statement on tolerable weekly intake for cadmium. EFSA Journal, 9(2), 1975. https://doi.org/10.2903/j.efsa.2011.1975.

[2] European Food Safety Authority (EFSA). (2020). Update of the risk assessment of nickel in food and drinking water. EFSA Journal, 18(11), e06268. https://doi.org/10.2903/j.efsa.2020.6268.

[3] Hamza Abubakar Hamza, Ishiyaku Ibrahim Babayo, Ahmadu Muhammad Aliyu, Yusuf Mohammed Auwal, Abubakar Danjuma Bajoga and Hankouraou Seydou (2026). Analysis of Heavy Metals and Health Risk Assessment of Selected Energy Drinks in Nigeria. Journal of Science, Engineering and Technology, 14:2 1-11.

[4] Hamza, H. A., Bajoga, A. D., Auwal, Y. M., & Seydou, H. (2025). Determination of some physicochemical properties, heavy metals and micronutrients of some energy drinks available in Nigeria. Communication in Physical Sciences, 12(3), 933–950. https://dx.doi.org/10.4314/cps.v12i3.19.

[5] Ureso, J.,Gonzalez–Regalado, E.,Gracia,L., (1997). Trace element in bivalve Mollusks Rudita pesdecussates and Rudita pesphillippinarum from Atlantic Coast of Southern Spain. Environ.Int.23 (3), 291–298.

[6] World Health Organization (WHO). (2022a). Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda. World Health Organization.

[7] World Health Organization (WHO). (2022b). Lead in drinking-water: Health risks, monitoring and corrective actions. World Health Organization.

[8] World Health Organization (WHO), (2011). Guidelines for Drinking Water quality, 4th edn.

[9] World Health Organization, Geneva, 2011, pp. 564.