

Levels and Health Risk Assessment of Heavy Metals in Selected Skin-Whitening Creams Marketed in Lafia Town

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Abstract

The rising popularity of skin-whitening creams in Nigeria raises alarms about potential exposure to harmful metals that may occur either as impurities or as intentionally added ingredients. This study assessed the levels of cadmium, chromium, copper, iron, and lead in various skin-whitening creams available in Lafia Town. Samples from different brands were randomly collected from shops in Lafia Modern Market, pre-treated through acid digestion, and analyzed using Atomic Absorption Spectroscopy (AAS). The findings indicated diverse concentrations of metals across the creams, which were compared with six international standards. Pb, Cr, and Cd were found exceeding the recommended limits of one or more international standards in at least one of the tested brands. The trend of metal concentrations was recorded as: $\text{Cr} > \text{Fe} > \text{Pb} > \text{Cd} > \text{Cu}$. However, there was no statistically significant difference in total metal concentrations across the samples ($p = 0.749$). Apart from the fear of gradual environmental toxicity, health risk assessments suggested that prolonged use of these products could eventually cause adverse health effects such as dermatitis, kidney toxicity, and cancer risk, since the TCR and HI values for all the samples (A–E) were above the safety zones, posing both carcinogenic and non-carcinogenic risks. The HQs and LCRs indicated Cr as the major contributor to those threats. Hence, there is a critical need for regulatory measures, quality assurance in manufacturing, and regular monitoring of cosmetic items in Lafia. Furthermore, an increased effort in consumer education initiatives is required to deter the use of harmful skin-whitening creams and advocate for safer alternatives.

Keywords:

Accumulation, Contamination, Cosmetics, Hazardous, Heavy metal, Safe limit

Article History

Submitted

August 08, 2026

Revised

September 30, 2026

First Published Online

October 02, 2026

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doi.org/10.62050/ljsir2026.v4n2.918

Introduction

Skin-whitening creams, similarly known as skin-lightening agents or bleaching products, are cosmetic formulations designed to reduce skin pigmentation, lighten skin tone, or address hyperpigmentation issues such as melasma, age spots, or freckles. These products typically work by inhibiting melanin production, exfoliating the skin, or altering skin cell turnover through active ingredients such as azelaic acid, hydroquinone, kojic acid, arbutin, or retinoids [1]. These active components in skin-whitening creams typically target the enzyme tyrosinase, which plays a central role in melanin synthesis. By inhibiting this enzyme, active ingredients help in reducing the pigmentation of the skin [2]. Nevertheless, these skin-brightening creams are also widely used to address conditions such as age spots, and post-inflammatory discoloration [3]. The global demand for whitening creams has surged, particularly in regions like Asia, Africa, and the Middle East, driven by cultural perceptions of beauty that associate lighter skin with attractiveness, social status, and professional success [4]. The global skin-lightening market was valued at approximately USD 8.6 billion in 2020 and is projected to grow significantly, reflecting widespread consumer use [5].

In recent years, there has been a growing trend in African countries, including Nigeria, where lighter skin is often culturally associated with beauty, affluence, and social mobility. This perception drives the demand for skin-lightening products in both urban and rural markets, which directly relates to the general recognition of cosmetic products worldwide, as highlighted by Mgbemena *et al.* [6]. However, many of these products are sold without appropriate regulation and may contain harmful or unlisted substances, including mercury and heavy metals such as Pb, Cd, and Cr which can be absorbed through the skin, and are likely to pose serious health risks to users, over time [7]. Thus, the safety of these products has come under scrutiny due to the potential presence of toxic heavy metals, including Cd, Pb, Cr, Cu, and Fe.

Heavy metals are defined as metallic elements with high atomic weights and densities (typically greater than 5 g/cm³), many of which exhibit toxicological properties even at low concentrations [8]. In cosmetics, heavy metals may be introduced unintentionally as contaminants during raw material extraction, manufacturing, or packaging processes, or, in some cases, deliberately added as pigments or stabilizers [9]. For instance, Pb may be present in color additives, while Cr compounds are sometimes used in cosmetic



dyes. Even though these heavy metals are toxic, however, in minute quantities that are within the permissible limits of the existing international standards, some of these metals are still vital to the human body. For instance, Cu and Fe, are part of essential trace elements in human biology, each of which can become harmful in excessive amounts [10]. Conversely, Cd which serves as a non-essential and highly toxic metal, has no biological role and stands as a well-known carcinogen [11].

The health risks associated with heavy metals in cosmetics are significant, particularly because these products are applied repeatedly to the skin, a permeable organ capable of absorbing substances into the bloodstream [12]. Prolonged exposure to heavy metals through dermal application can lead to systemic toxicity. Furthermore, the presence of heavy metals in cosmetic products may be seen as a strong indicator for potential environmental pollution [13] to emerge within a particular habitat, and which may get back to human internal system through the use of contaminated drinking water or food being sourced from both crops and livestock. Consequently, when such heavy metals leak constantly into water bodies through washing, bathing and swimming activities of human, it may result in the disruption of the food chain, by seriously affecting the aquatic life [14].

The presence of heavy metals in lightening creams is particularly alarming in regions with limited regulatory oversight. International bodies such as the World Health Organization (WHO) and Health CANADA have established guidelines for permissible levels of heavy metals in cosmetics (e.g. Pb $\leq$ 10 ppm for WHO and Health CANADA, Cd $\leq$ 3 ppm for Health CANADA, and Cd $\leq$ 0.3 for WHO) [15]. However, enforcement varies widely, and studies have detected unsafe levels of heavy metals in cosmetics sold in both developed and developing countries. For instance, Al-Saleh *et al.* [16] reported Pb concentrations as high as 65 ppm in skin-lightening creams sold in Saudi Arabia, far exceeding the safe limits. Similarly, a study in Lagos, Nigeria found elevated levels of toxic metals such as Cd, Cr and Hg, in locally produced cosmetics, highlighting the devastating nature of this issue [17]. The widespread use of body whitening creams has thus attracted serious public health concerns due to the possibility of contamination from toxic heavy metals such as Cd, Pb, Cr, Cu, and Fe, in such topical products. These heavy metals in cosmetics may pose serious health risks, especially when present in concentrations exceeding safe limits. For example, Pb, which remains a potent neurotoxin, can cause neurological impairments, developmental delays in children, and cardiovascular issues in adults [18]. Cd, classified as a human carcinogen, is associated with kidney damage and bone fragility [11]. Hexavalent Cr is a known carcinogen, while excessive Cu and Fe can induce oxidative stress, leading to skin irritation and organ damage [10, 19]. Another concern with this heavy metal issue in cosmetics, is the misleading marketing strategies used by manufacturers, which often

exaggerate product benefits and fail to warn consumers of potential risks. Some cosmetics, including some of those products marketed as “natural” or “herbal” have been found to contain synthetic chemicals and banned substances upon laboratory analysis [20].

Therefore, in order to remain on the safe side, the global popularity of whitening creams, driven by cultural preferences for lighter skin in regions such as Asia, Africa, and the Middle East, needs to be treated as a practice of particular concern [4]. Despite all the efforts produced by regulatory bodies including the National Agency for Food and Drug Administration and Control (NAFDAC) in Nigeria, enforcement remains weak, and many harmful products continue to circulate, especially in open markets and online platforms [21]. Consequently, there is a pressing need for greater consumer education, stricter quality control, and the promotion of safer alternatives in the cosmetic industry [22]. Even though, certain studies concerning heavy metal assessment in cosmetic items being sold in Nigeria reported low contamination [23], continuous research is necessary to analyze the quality of such products. This is to ensure that cosmetic products have met the standards with regard to the degree of contaminations due to these metallic elements, which in addition to a specific gravity greater than 5.0 are also characterized by having high atomic weights of between 63.5 to 200.6 [24].

The current study aimed to investigate the concentration levels of five heavy metals – lead (Pb), chromium (Cr), cadmium (Cd), iron (Fe), and copper (Cu), present in various skin-whitening creams sold in Lafia town, and to evaluate potential health risks associated with the use of these products. The result of the study is expected to feed the relevant authority with accurate tools that guide it in making a well-informed decision that prevents potential health risk of its subjects, while simultaneously promoting public health and consumer safety, and to also raise consumer awareness concerning the use of safer cosmetic alternatives. The present study adopted the use of Atomic Absorption Spectroscopy (AAS), as evidence from the literature shows that, this method has been repeatedly used in several but recent studies for the assessment of various cosmetic products against heavy metal contaminations. For example, Akpe *et al.* [23] applied the BUCK Scientific 210 VGP AAS to analyze heavy metals in lip gloss and mascara, confirming the technique's suitability. Similarly, Mgbemena *et al.* [6] used a Varian AA240 AAS in their study of heavy metals in cosmetics sold in Rivers State, Nigeria. Iwegbue *et al.* [7] also applied the use of Flame Atomic Absorption Spectroscopy (FAAS) to evaluate cosmetic products, and came up with eventual report which shows that, this method is effective for detecting even minute concentrations of toxic metals. These and several other related studies, underscore the credibility of AAS in such contexts. The robustness, accuracy, and adoptability of the process as seen in recent applications, in the related field, made FAAS one of the strong instrumentation alternatives for the current study.

Materials and Methods

Chemicals and reagents

Chemicals used in this study were of analytical grade, obtained from May and Baker (M & B). They include nitric acid, hydrochloric acid, deionized water, and standard solutions for Pb, Cr, Cd, Fe, and Cu.

Sample collection and preparation

A total of five different brands of body whitening creams were collected randomly from cosmetic shops in Lafia Modern Market. The selection was based on product availability, popularity among consumers, and variety in origin (both locally made and imported products). Each sample was labeled with an identification code to maintain anonymity and facilitate easy referencing during analysis. The body whitening creams include brand: A, B, C, D, and E. All samples were collected in their original packaging to prevent being tampered [6]. Sampling was done using the purposive sampling technique to focus on products specifically marketed for body whitening purposes, in line with previous studies such as that of Akpe *et al.* [23], who adopted similar criteria for cosmetics sampling in urban markets. All samples were stored in airtight, clean containers and transported to the laboratory under controlled temperature conditions to preserve their integrity before the analysis.

Sample Preparation was carried out following the standard procedures recommended by the Association of Official Analytical Chemists [25] and modified for cosmetic matrices. Each cream sample was thoroughly homogenized to ensure uniform distribution of constituents.

Approximately 1.00 g of each sample was accurately weighed into a 100 mL beaker using an analytical balance. The sample was digested using a wet digestion method, which involved the addition of 30 mL of concentrated nitric acid and 10 mL hydrochloric acid. This acid combination effectively breaks down the organic components of the cosmetic matrix, releasing the metal ions into solution [26]. The beakers were then placed on a hot plate and heated gently in a fume cupboard until the digestion was complete—indicated by a clear, colorless solution. This typically took 1 to 2 h depending on the complexity of the matrix. After cooling, the digested solution was filtered using Whatman No. 42 filter paper into a 100 mL volumetric flask and diluted to the mark with deionized water. Wet digestion method is widely accepted in trace metal analysis due to its high recovery and reproducibility [27].

Sample analysis

A BUCK Scientific 210 VGP Atomic Absorption Spectrophotometer was employed for this analysis. The instrument is equipped with metal-specific hollow cathode lamps and was operated under the manufacturer's optimized conditions. Each metal was analyzed at its respective wavelength: 283.3 nm for Pb,

357.9 nm for Cr, 228.8 nm for Cd, 248.3 nm for Fe, and 324.8 nm for Cu [28, 29]. The concentrations of heavy metals (Pb, Cr, Cd, Fe, and Cu) in the skin-whitening creams were determined using Flame Atomic Absorption Spectrophotometry (FAAS), a widely accepted technique for trace metal analysis due to its sensitivity, specificity, and precision [7]. Before sample analysis, the spectrophotometer was calibrated using a series of standard solutions for each target metal. Quality control procedures included the use of reagent blanks, triplicate sample analyses, and certified reference materials to ensure reliability and accuracy of results [6, 7].

Statistical analysis

Data obtained from the heavy metal (Pb, Cr, Cd, Fe, and Cu) analyses were statistically evaluated to ensure accuracy and reliability of results. Descriptive and inferential statistics were processed using Microsoft Excel and SPSS (version 23), respectively. This was conducted to ensure high precision in handling numerical data and to minimize manual error [7].

Quality control

To guarantee the accuracy of metal detection, the AAS was calibrated using standard solutions with known concentrations of Pb, Cr, Cd, Fe, and Cu, and calibration curves were prepared freshly each day of analysis [7]. Reagent blanks were used to identify background contamination, while sample replicates (triplicate analyses) were conducted to confirm the precision of the method [6, 7]. Recovery studies were carried out by spiking known quantities of standard metals into randomly selected cream samples and calculating the recovery percentage to validate the method's accuracy. Certified Reference Materials (CRMs) were analyzed alongside the samples to validate the overall analytical performance and check for deviations from accepted values [7]. All glassware used were pre-soaked in nitric acid and rinsed thoroughly with deionized water to prevent contamination, and the entire procedure was conducted under controlled laboratory conditions [7].

Results and Discussion

The distribution of heavy metal concentrations with regard to cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), and lead (Pb) across five cosmetic brands A–E was analyzed and presented together with the standards of six selected organizations, in Table 1. Figs 1–5 display and compare the concentration of the heavy metals analyzed in all five samples with the given standards. The results show diverse concentrations of these heavy metals with Pb, Cr and Cd concentrations in one or more samples exceeding, at least one of the six compared standards.

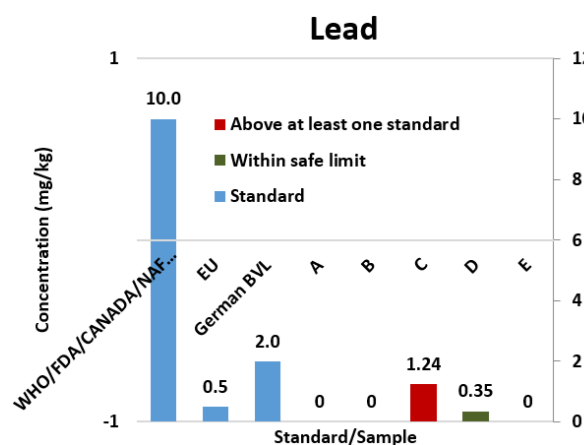
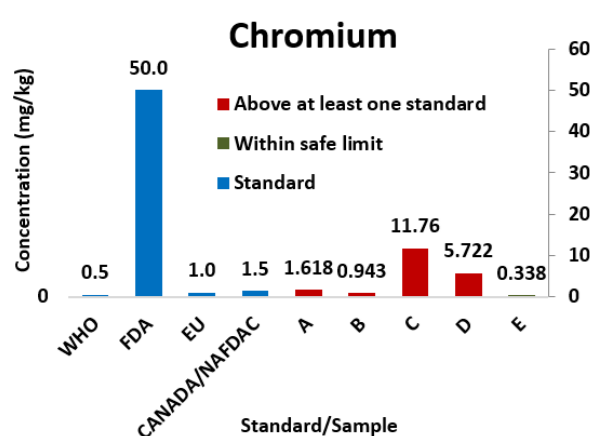
**Table 1: (a) Concentration of heavy metals in skin-whitening creams and the mean values (b) Regulatory standards of skin-whitening creams [27-30]**

(a) Heavy metal (mg/kg)/samples		Concentration (mg/kg)				
Heavy metal	Sample A	Sample B	Sample C	Sample D	Sample E	Mean
Pb	0.000	0.000	1.240	0.350	0.000	0.3180
Cr	1.618	0.943	11.760	5.722	0.338	4.0762
Cd	0.137	0.101	0.087	0.046	0.114	0.0970
Fe	0.045	0.600	0.550	0.468	0.633	0.4592
Cu	0.092	0.056	0.066	0.060	0.083	0.0714
(b) Regulatory Standards (mg/kg)		Heavy Metal				
	Pb	Cr	Cd	Fe	CU	
WHO	10.0	0.5	0.3	30.0	NA	
US FDA	10.0	50.0	3.0	20.0	NA	
EU	0.5	1.0	0.5	NA	NA	
Health CANADA	10.0	1.5	3.0	40.0	NA	
German BVL	2.0	NA	0.1	NA	NA	
NAFDAC	10.0	1.5	3.0	40.0	NA	

NA = Not available

Concentration of lead in cream samples

The results of the concentrations of Pb as given by Fig. 1 showed that Pb was detected only in samples C and D, and it was below the limit of detection in the rest of the samples (A, B, and E). The range of Pb detected in the five samples (A–E) was recorded as 0.00–1.240 mg/kg, which showed close agreement with the result (Pb, 0.066–0.789 mg/kg) obtained by Udiba *et al.* [30] after analyzing a series of facial cosmetic brands. All the cream samples (A–E) were found to be within the safe range of the international standards regarding Pb concentration, except for the European Union (EU) guidelines in sample C [28, 30–32]. Even though Pb was completely undetected in sample A, B, and E, the presence of the same metal at high level in sample C, which was above EU recommendation [28], indicated hazardous contamination that requires significant attention due to serious health concerns attached to this toxic element. Prolonged use of cream containing elevated amount of Pb can cause neurological harm, renal dysfunction, anemia, infertility, and developmental issues in children [24]. The levels of Pb obtained, except for sample C, were also found in consistency with the findings of Mgbemena *et al.* [6], who recorded low Pb contamination (Pb, 0.15–0.31 mg/kg) in cosmetic items sold in Rivers State, Nigeria.

**Figure 1: Concentration of Pb in cream samples as compared to international standards****Figure 2: Concentration of Cr in cream samples as compared to international standards****Concentration of chromium in cream samples**

Although Cr in its oxidation state of Cr(III) is an essential part of our diet, the metal is still harmful in its oxidation state of Cr(VI); as it clearly represents a potential carcinogenic material [33]. This makes it necessary for the regulatory control of Cr levels in all cosmetic products. Fig. 2 describes the result for the Cr concentrations in all the five brand samples. Cr was detected in each sample with concentrations ranging between 0.338–11.760 mg/kg. Obviously, Cr was found above the safe limit of WHO [30] in all except for sample E, with sample C and D indicating exceptionally alarming concentrations of the toxic metal. In addition to sample C and D, Cr in sample A, was also detected above both EU [28], Health CANADA [30], and NAFDAC [30] limits, respectively. Notably, sample C showed the highest Cr contamination, far exceeding international safety standards, except in the case of U.S. FDA, where Cr detection level was seen far below the organizational threshold [30]. Since, most of the cream samples existed above international standards with regard to Cr contamination, and considering the potential health risks attached to this metal especially in its hexavalent form; Cr(VI), serious efforts are needed towards ensuring strict regulations for such topical products. These findings aligned with earlier report by

Iwegbue *et al.* [7], who reported high Cr contamination (Cr, 18–288 µg/g) in facial cosmetics collected from the southern part of Nigeria. However, the findings of this study with regard to Cr have shown tremendous increase in concentration as compared to the result (Cr, 0.049–0.543 mg/kg) obtained by Udiba *et al.* [30]; suggesting higher risk for the products used in this study. Elevated Cr levels, particularly in hexavalent form; Cr(VI), are associated with allergic dermatitis, skin rashes, irritation in the respiratory tract, organ toxicity, pulmonary disorders, brain tumors and lung cancer in humans [34, 35]. Consequently, the high Cr level in sample B, which exceeded the WHO safety limit, plus the elevated level of the metal in samples A, C, and D, which, in addition to the WHO safety threshold, surpassed one or more other international standards, pose a serious health threat and may need urgent intervention.

Concentration of iron in cream samples

Although Fe is an essential nutrient, high levels of this metal in topical products can lead to oxidative stress as well as photo-induced skin damage, particularly for those with sensitive skin [36]. A research conducted by Ezech *et al.* [37] suggested that elevated Fe levels in

cosmetics may reflect inadequate control over formulations or contamination occurring during production or packaging. Nonetheless, based on the results of the concentrations of Fe as given in Fig. 3, Fe was only detected in trace amounts in each of the five tested samples, with concentrations ranging between 0.045–0.633 mg/kg. This result indicated the highest degree of conformity with the findings of Udiba *et al.* [30] on facial cosmetics, which reported detected levels of Fe concentrations ranging between 0.021–0.641 mg/kg. According to U.S. FDA [38] and WHO [22], neither organization has specific upper limit for Fe in cosmetics; following its role as an essential trace element. However, the two organizations recommended minimizing unnecessary metal exposure in skincare products. Alternatively, according to Udiba *et al.* [30], the recommended standards for Fe of WHO, Health CANADA/NAFDAC, and U.S. FDA are 30.0 mg/kg, 40.0 mg/kg, and 20.0 mg/kg, respectively. These values are still very large as compared to the trace levels of Fe obtained from the analysis of sample A – E. Thus, the amounts of Fe quantified in all the analyzed samples, as in accordance with this research findings, are not expected to present any significant risk to public health.

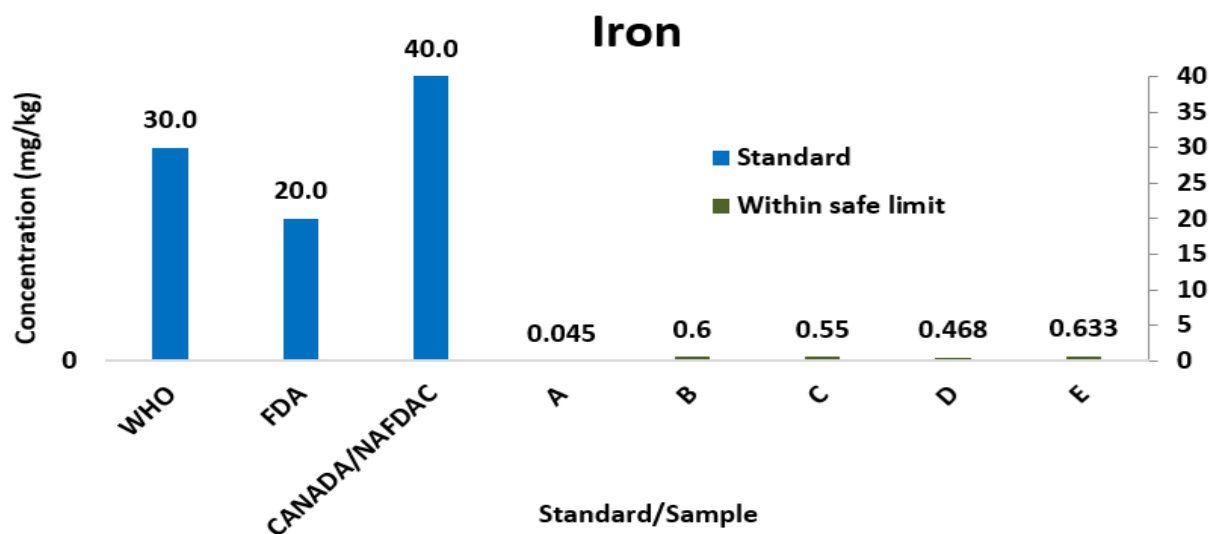


Figure 3: Concentration of Fe in cream samples as compared to international standards

Concentration of cadmium in cream samples

The results for the concentrations of Cd is given in Fig. 4. Cd was found in all five samples analyzed, with concentrations between 0.046–0.137 mg/kg. This result is in close alignment with the range of Cd values (Cd, 0.012–0.046 mg/kg) as obtained by Akpe *et al.* [23], while evaluating the concentrations of heavy metals in cosmetic products used in Calabar, Nigeria. Although the amounts obtained from the analysis of Cd in all the samples (A–E), were all found below that of the recommendations of WHO [28, 31], EU [28], U.S. FDA [30], Health CANADA [28, 30], and NAFDAC [30], these detected concentrations of Cd were found to slightly surpass the German BVL limit in sample A, B, and E, respectively [32]. According to the safety limit

of German BVL, all tested samples except for sample C and D were unsafe to apply to the skin, indicating hazardous levels of contamination. Cd is extremely harmful even in minimal quantity, because it accumulates in living organisms with the long-term exposure being able to cause kidney damage, loss of bone density or osteoporosis, reproductive harm, diabetes, and lung cancer [39, 40]. The sample with the highest concentration of Cd (sample A), has pointed to the greatest level of Cd contamination, which may result from the use of low-quality raw materials, contaminated packaging, or manufacturing practices that do not meet regulatory standards, as noted by Ezech *et al.* [37].

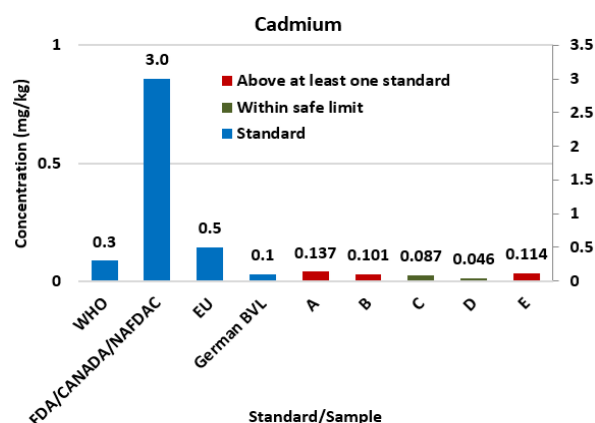


Figure 4: Concentration of Cd in cream samples as compared to international standards

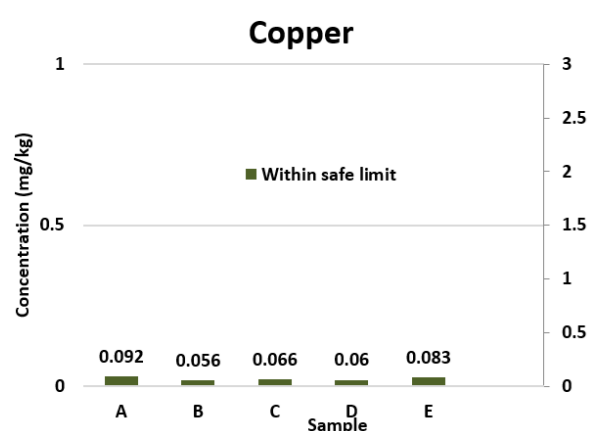


Figure 5: Concentration of Cu in cream samples with no defined international standard

Concentration of copper in cream samples

Cu is a vital trace element that contributes to enzymatic activities and skin coloring. Nevertheless, too much exposure can lead to oxidative stress, cirrhosis, liver injury, and gastrointestinal issues [41]. Fig. 5 displays the results of the amount of Cu detected in all five samples screened. Cu was present in every sample analyzed, with concentrations ranging between 0.056–0.092 mg/kg. The detected levels of Cu in all the samples (A–E) were directly linked to minute amounts of the metal under discussion. While Cu serves as an important micronutrient useful for essential biological processes such as bone formation and enzyme synthesis, the metal still remains toxic and carcinogenic in its divalent form of Cu(II) [24]. This underscores the need for the regulatory analysis of this metal in cosmetic items, so as to keep its concentration within a well-justified level. Nevertheless, with respect to the available literature, there is no recommended limit of Cu in cosmetic items from any international organization. All samples analyzed were within safe limit, suggesting only negligible level of contamination, which may be resulting from careless formulation approaches or from the use of contaminated raw material [37]. The result showed significant drop when compared to the reported findings of Sani *et al.* [42] on

the level of Cu detected (Cu, 4.24–8.48 mg/kg) from the screening of skin-lightening creams. The levels of Cu found in all the investigated samples due to this current study, were deemed safe, and hence harmless to consumers. The findings also comply with the result of Manu *et al.* [13], who recorded trace quantities of heavy metals such as Cd and Cu, in majority of a series of screened cosmetics obtained from Jimeta – Yola of Adamawa State.

Non-carcinogenic risk assessments

The assessment of non-carcinogenic health risks associated with prolonged use of the skin-whitening creams, concerning the heavy metal contamination, was conducted through the application of Estimated Daily Index (EDI) values to determine the Hazard Quotients (HQs) and Hazard Indices (HIs). The HI and HQ values were eventually used to rate the non-carcinogenic effects of these cream samples as elaborated in the discussion below. While all the HIs for the five samples (A–E) exceeded the standard limit, only the mean HQ value of Cr was found above the standard, while the mean HQ values for Pb, Cd, Fe, and Cu were all found below the standard limit.

Estimated daily intake for chronic exposure in a 70 kg person

The calculations of Estimated Daily Intake (EDI) from the use of skin-whitening creams were computed using Eq. (1) as developed by the United States Environmental Protection Agency [43]. As presented in Table 2, the EDI (mg/kg/day) as calculated for an adult with the mass of 70 kg ranged between 0.00 to 6.8E-3 for Pb, 0.02 to 0.64 for Cr, 2.6E-4 to 7.8E-4 for Cd, 2.5E-4 to 3.6E-3 for Fe, and 3.1E-3 to 5.1E-3 for Cu.

Estimated Daily Intake (EDI)

$$EDI = \frac{C * SA * AF * ABS * EF * ED}{BW * AT} \dots \dots \dots (1)$$

Where: C= Concentration; SA= Exposed skin area (cm²) = 5700 cm² (average for adults using body cream on arm and face); AF= Adherence factor = 0.07 mg/cm²/day; ABS = Dermal absorption fraction (Pb = 0.001, Cd = 0.001, Cr = 0.01, Cu = 0.01, Fe = 0.001) [44, 45]; EF = Exposure frequency = 350 days/year; ED = Exposure duration = 30 years; BW = Body weight = 70 kg; AT = Average time = ED*365

Table 2: Estimated daily intake for chronic exposure in a 70 kg person

Sam	EDIPb (mg/kg/day)	EDICr (mg/kg/day)	EDICd (mg/kg/day)	EDIFE (mg/kg/day)	EDICu (mg/kg/day)
A	0.00	0.09	7.8E-4	2.5E-4	5.1E-3
B	0.00	0.05	5.7E-4	3.4E-3	3.1E-3
C	6.8E-3	0.64	4.9E-4	3.1E-3	3.6E-3
D	1.9E-3	0.31	2.6E-4	2.6E-3	3.3E-3
E	0.00	0.02	6.4E-4	3.6E-3	4.5E-3

Sam = Sample

Table 3: Hazard quotient and hazard index for a 70 kg person

Sample	HQPb	HQCr	HQCd	HQFe	HQCu	HI
A	0.00	30.00	0.78	3.5E-4	0.13	30.91
B	0.00	16.67	0.57	4.8E-3	0.08	17.32
C	1.94	213.33	0.49	4.4E-3	0.09	215.85
D	0.55	103.33	0.26	3.7E-3	0.08	104.22
E	0.00	6.67	0.64	5.1E-3	0.11	7.43
Mean	0.50	74.00	0.55	3.7E-3	0.10	75.15

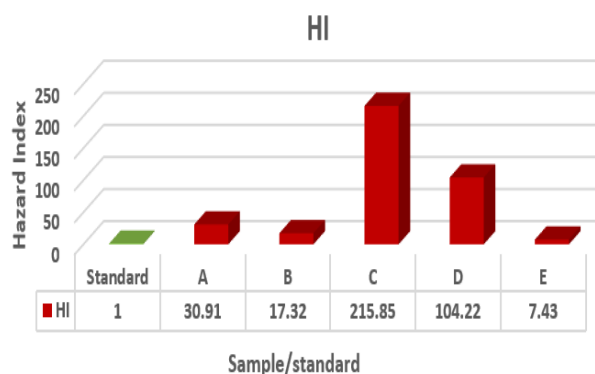


Figure 6: Hazard indices of the samples as compared to international standard

Hazard quotient and hazard index for a 70 kg person

HQ value, which represents the ratio of the EDI to the RfD, was applied to estimate non-carcinogenic risk with respect to each of the metals among the exposed population. For each of the tested metals, HQ values were computed across all samples using Eq. (2), and the result was presented in Table 3. HI values, which stand for the overall potential risk for non-carcinogenic effects of the respective cream samples as contributed by the detected metals in each brand, were estimated using Eq. (3), and presented in Table 3 [35]. Fig. 6 compares the HI values of the respective samples (A–E) with the standard value, and indicates that all samples were above the standard value. Following its elevated HQ values, Cr was identified as the major contributor to the non-carcinogenic effects of all the analyzed samples.

The Hazard Quotients were calculated individually for each of the five heavy metals (Cd, Cr, Cu, Fe, and Pb) in all the five samples (A, B, C, D, and E), and the summations of all the Hazard Quotient values of all the metals present in each particular sample were computed as Hazard Indices for the respective samples. The findings show diverse range of HQs for different metals (in Table 3) as: 0.00 to 1.94 for Pb, 6.67 to 213.33 for Cr, 0.26 to 0.78 for Cd, 3.5E-4 to 5.1E-3 for Fe, and 0.08 to 0.13 for Cu. Except for Pb in sample C, the contributions of Pb, Cd, Fe, and Cu, are still negligible since the HQ values of these metals in the respective samples were within the acceptable range of less than unity (1). Alternatively, Cr in all the samples and Pb in sample C were in the range of HQ value > 1 with the order of mean values: Cr >> Pb. This result suggests that, apart from the additional contribution of Pb in

sample C alone, non-carcinogenic effects were significant across all five tested samples due to Cr. Consequently, all the samples, A–E (except for sample C due to Pb), seem to pose negligible effects from Pb, Cd, Fe, and Cu. However, Cd in sample A (HQ = 0.78) seems to require serious attention following the close proximity of the value to unity (1).

The findings also estimated the overall non-carcinogenic effects of each particular sample (A–E) due to heavy metal concentrations under investigation, with each sample indicating an HI value significantly greater than 1. Sample C and D displayed the most hazardous HI values, resulting from the elevated concentrations of Cr in each of the two samples, plus the significant amount of Pb in sample C. However, the overall non-cancer effect for the tested skin-whitening creams obviously arose from the tremendous contribution of Cr, in addition to the significant contamination due to Pb and Cd – in at least one of the five tested samples. The contribution of Fe in the HI values was obviously low, which can be affirmed from the HQs of the individual metals. The result of this study was found in harmony with the previous research conducted by Udiba *et al.* [30], which also affirmed the resultant HI values due to screened toxic metals in facial cosmetics, exceeding unity (1). The findings of this study affirmed the association of the cosmetic products with cumulative non-carcinogenic health risks. Hazard Quotient (HQ)

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

Where: RfD = Reference dose in mg/kg/day (0.0035 for Pb, 0.003 for Cr, 0.001 for Cd, 0.7 for Fe, and 0.04 for Cu) [46–47]

- If HQ<1: No significant risk
- If HQ≥1: Potential health risk

Hazard Index (HI)

$$HI = \sum HQ \dots \dots \dots (3)$$

Carcinogenic risk assessment

The probable cancer risks that result from the exposure of an individual to heavy metals popularly known as carcinogenic effects were computed through evaluating the respective Lifetime Cancer Risks (LCRs) posed by toxic metals in the samples, and the Total Cancer Risks (TCRs) posed by each sample to public health. All samples (A–E) were found to be associated with carcinogenic risk due to prolonged exposure to the cosmetic materials, with Cr and Cd identified as primary contributors to the effect.

Lifetime cancer risks (LCR) and total cancer risk (TCR) for a 70 kg person

The LCRs and TCRs were calculated in accordance with the provisions of Eq. (4) and (5) and presented in Table 4. The tolerable limits for the Lifetime Cancer Risk (LCR) are considered to range between 10⁻⁶–10⁻⁴ (i.e. 0.000001–0.0001) [45, 48]. Fig. 7 compares the



TCR values of all the respective samples (A–E) and were all found above the standard limit, with samples C and E showing the highest and lowest values, respectively.

Table 4: Lifetime cancer risk and total cancer risk due to carcinogenic metals present in the samples

Sample	LCR _{Pb}	LCR _{Cr}	LCR _{Cd}	TCR
A	0	4.50E-2	4.91E-3	4.99E-2
B	0	2.50E-2	3.59E-3	2.86E-2
C	5.78E-5	3.20E-1	3.09E-3	3.23E-1
D	1.62E-5	1.55E-1	1.64E-3	1.57E-1
E	0	1.00E-2	4.03E-3	1.40E-2

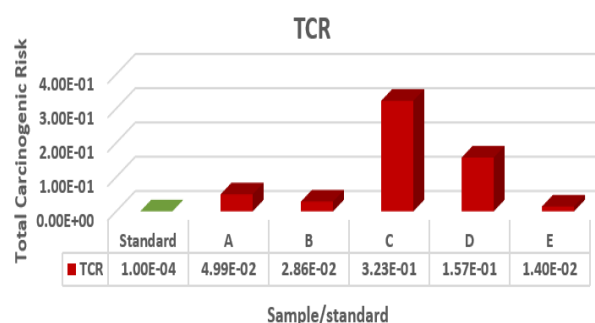


Figure 7: Total carcinogenic risks of the samples as compared to international standard

The LCRs discovered for all the three carcinogenic metals ranged between 0.00–5.78E-5 for Pb, 1.00E-2–3.20E-1 for Cr, and 1.64E-3–4.91E-3 for Cd. Cr and Cd were found to pose drastic carcinogenic effects in all the samples, A–E (LCR > 1.0E-4), while Pb in all the samples was found to have negligible carcinogenic threat, especially with respect to samples A, B, and E, each of which displayed an LCR value with zero effect. However, considering that the LCR values produced by Pb in sample C were closer to the upper safety limit (1.0E-4), this indicates alarming contamination that needs serious attention. According to the LCRs, Cr showed the greatest effect among the three metals, with the most hazardous effects observed in sample C and D, respectively.

The overall carcinogenic risk (TCR) analysis per sample indicated potential cancer risk for the consumers due to prolonged use of the tested products (sample A–E), as each of these skin-whitening creams resulted in a TCR value far above the safety threshold. While the findings of this study indicate greater effects in samples C and D, it is obvious that all the five tested skin-whitening creams are unsafe for prolonged use. The findings of this study have shown agreement with the result of previous research conducted by Sagay *et al.* [48], which recorded higher LCR and TCR values (as compared to the standard limits), in certain facial cosmetics sold in Kano metropolis due to contamination from heavy metals such as Cr and Cd.

Lifetime Cancer Risk (LCR)

$$LCR = EDI * CSF \dots \dots \dots (4)$$

Where: LCR = Lifetime cancer risk; CSF = Cancer slope factor in mg/kg/day (0.0085 for Pb, 0.5 for Cr, 6.3 for Cd, and no CSF for Fe and Cu) [28, 49, 50]; EDI = Estimated daily

intake of carcinogens in mg/kg/day (it is also popularly known as chronic daily intake, CDI)

Total Cancer Risk (TCR)

$$TCR = \sum LCR_x \dots \dots \dots (5)$$

Where: TCR = Total or overall cancer risk due to lifetime exposure to carcinogenic metals present in a sample; LCR_x = Respective cancer risk values for the individual metals in a particular sample: LCR_{Pb}, LCR_{Cr}, and LCR_{Cd} (Note: x = Pb, Cr, and Cd)

Statistical Significance

All analyses were performed in triplicate, and the resulting data of the detected concentrations obtained were subjected to statistical analysis, in order to compare variations of metal concentrations across different cream samples (A–E), and then to evaluate statistical significance of the data [7]. Kruskal-Wallis Test was applied because the data distribution significantly departed from normality, as tested via Shapiro – Wilk Test ($W = 0.428$, $p < 0.001$). The result of the Kruskal-Wallis Test described that, while significant differences were observed among concentrations of different metals ($p = 0.020$), total heavy metal concentration did not differ significantly across the cream samples ($p = 0.749$).

Conclusion and Recommendations

Conclusion

This study examined the concentrations of Pb, Cr, Cd, Fe, and Cu in various skin-whitening creams sold in Lafia town, Nigeria. The results indicate that all analyzed brand samples of skin-whitening creams had detectable levels of certain, if not all, of these five tested heavy metals. Notably, Cr, Cd, Cu and Fe were detected in all the sample while Pb were detected only in sample C and D. The hazardous levels of Cr particularly in sample C and D, the elevated concentration of Pb in sample C, and the significant amount of Cd in sample A, B, and E; which surpassed one or more international safety recommendations like that of WHO, EU, Health CANADA, NAFDAC, and German BVL, suggest substantial health risks which demands urgent intervention. However, Fe and Cu were found within limits that were considered by this study, insignificant to have posed serious threat to public health, as only trace amounts of such essential metals were detected in each of the samples analyzed. Moreover, the overall trend of metal concentrations as identified from the average values, was in the order of $Cr > Fe > Pb > Cd > Cu$. Additionally, the result of statistical analysis indicated no significant difference of overall heavy metal concentrations across the cream samples with p -value > 0.05.

Health risk evaluations show that Hazard Quotient (HQ) values were greater than unity for Cr in all the samples (A–E), and for Pb in sample C. However, the HQ values were in the range $HQ < 1$ for Pb in sample A, B, D, and, E, and for Cd, Cu and Fe in all the tested samples (A–E). Nonetheless, the Hazard Index (HI) values were well above one ($HI > 1$) for each of the tested cream samples, indicating a drastic risk of non-

cancer health issues such as neurotoxicity, nephrotoxicity, oxidative stress, and skin irritation. Moreover, the emergence of large range of HI values (HI, 7.43–215.85) acquired from the analysis of these heavy metals in the cream samples, led to a growing fear of rapid and intense development of deteriorating health effects like cancer and lung problems. This necessitated an investigation of carcinogenic effect via LCR and TCR analysis. The result of the carcinogenic analysis indicated high risk of cancer due to prolonged application of the tested creams, since all these samples resulted in TCR values far above the recommended limit. The LCR values of the respective carcinogenic metals present in the samples suggest that, the elevated TCR values were majorly contributed by Cr.

It is obvious that the presence of heavy metals in concentrations above the recommended level in chemical products such as cosmetics, may indirectly pose significant threat to both aquatic life and human beings. As these heavy metals leach from topical applications into water bodies and agricultural soil, due to human activities such as bathing and swimming, potential accumulation is highly possible, which may lead to disruption in the food chain, simply by affecting aquatic organisms, and eventually get ingested into human body through drinking water and meals. Hence, in order to avoid potential disasters, this issue of heavy metal contamination in cosmetic products must be taken with absolute seriousness and be properly addressed by the relevant authorities.

Recommendations

Based on the findings of the current study, the following recommendations were proposed. The National Agency for Food and Drug Administration and Control (NAFDAC) should enhance its monitoring, inspection, and testing of cosmetics sold in both formal and informal markets in Lafia and other cities within Nigeria. Mandatory periodic quality control evaluations of skincare products, particularly skin-whitening creams, should be instituted.

Nigerian government ought to create and enforce a national policy on cosmetic safety that aligns with international best practices and stipulates permissible limits for heavy metals. Manufacturers should be encouraged and aided in developing safe, natural alternatives to harmful skin lightening products. Grants aimed at research and development should be available to foster the use of locally sourced and safe cosmetic ingredients. Additionally, protocols for testing heavy metals must be enforced for all cosmetic products, whether imported or locally produced, prior to their distribution, while stricter penalties and sanctions should be applied to companies or vendors that sell non-compliant or unregistered products.

Government-based health agencies should on regular basis, conduct extensive public awareness campaigns to inform citizens about the health hazards associated with unregulated skin lightening creams. Health promotion initiatives in schools, hospitals, and market places can help to deter unsafe beauty practices, particularly among young women.

Conflict of interest: The authors declare no conflict of interest.

Acknowledgment: Authors acknowledge the support of the Department of Chemistry, Federal University Lafia for providing suitable environment that was highly instrumental to the actualization and success of this research work.

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Citing this Article

Abel, A. U., Abubakar, M. S., & Muhammad, H. I. (2026). Levels and health risk assessment of heavy metals in selected skin-whitening creams marketed in Lafia Town. *Lafia Journal of Scientific and Industrial Research*, 4(2), 151–161. <https://doi.org/10.62050/ljsir2026.v4n2.918>