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Health Risk Assessment of Heavy Metals and Radiation Exposure in Locally Produced Cosmetic Powders used in Benue State

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Abstract *: This study evaluates the health risks of heavy metals (HMs) and naturally occurring radionuclides (NRs) in fourteen locally produced cosmetic powders from Benue State, using Atomic Absorption Spectrophotometry (AAS) and a NaI(Tl) detector. Mean concentrations of HMs were Cd (0.104 ± 0.002 ppm), Co (0.022 ± 0.002 ppm), Cr (0.006 ± 0.001 ppm), Ni (0.236 ± 0.002 ppm), and Pb (0.785 ± 0.002 ppm), all below WHO limits (0.30, 1.0, 5.0, 0.60, and 10.0 ppm, respectively). Only Cd in one sample (1.24 ppm) exceeded its limit, yielding a 7.1% exceedance rate. Carcinogenic risk (10^{-6}–10^{-7}), hazard index (<0.1), and hazard quotient values confirm negligible non-carcinogenic or carcinogenic risk. Mean activity concentrations of ^{232}Th (22.5 ± 1.3 Bq/kg), ^{238}U (18.9 ± 1.1 Bq/kg), and ^{40}K (312.6 ± 5.7 Bq/kg), together with absorbed dose (0.11 mSv/yr), radium equivalent (46.3 Bq/kg), and hazard indices (≤0.23), are all below IAEA/UNSCEAR safety thresholds. These results suggest that the cosmetic powders pose no significant toxicological or radiological health risks, supporting safe patronage and the growth of micro, small, and medium enterprises (MSMEs) in the region.*

Keywords*: Natural radionuclides, Cosmetic powder, Health Risk Assessment, Heavy metal, Safe limit*

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1. 1.0 Introduction

The growing use of radiation in all sectors of human endeavour, especially in medical diagnosis and therapy, has contributed greatly to humans' exposure to radiation (Eddy *et* al., 2025a;Gerba *et al.*, 2019). Radionuclides have adverse effects on human health depending on the type, dosage, and exposure time (Eddy *et* al., 2025b; Mgbemere *et al.*, 2021). Consequently, assessing the health implications of the public to radiation exposure from locally produced cosmetic products is very important. Natural and synthetic materials are used in the production of cosmetic products (Osabuohien *et al.*, 2021). Common ingredients used are: emollients (e.g. oils, butter, and glycerin), surfactants (e.g. sodium lauryl sulfate and sodium laureth sulfate), preservatives (e.g. parabens and phenoxyethanol), colorants (e.g. iron oxides, titanium dioxide, ultramarines), fragrances (e.g. perfume), thickeners (e.g. gums and polysaccharides), sunscreen agents (e.g. zinc oxide and titanium oxide), and antioxidants (e.g. vitamin C and vitamin E). Therefore, the ingredients used in the formulation of cosmetic products can be potentially harmful to human's health (Osabuohien, 2019; Pratibha *et al.*, 2018). Although these ingredients enhance the appearance and functionality of cosmetics, many of them may contain or introduce trace levels of heavy metals (HMs) and radioactive materials (RMs) that can be harmful to health (Pratibha et al., 2018).

Cosmetic products are widely used as lipstick, perfume, nail polish, eye shadow, powders, creams, and lotions, and they also serve medicinal purposes such as in skin treatment, hair care, facial care, and dental applications (Sharma et al., 2018; Hani et al., 2021). According to Hani et al. (2021), cosmetic ingredients should ideally exhibit minimal or no toxicity. However, even at trace levels, exposure to RMs and HMs such as lead (Pb), cadmium (Cd), chromium (Cr), and nickel (Ni) can result in adverse health effects. As cosmetics are consumed largely by vulnerable groups such as children, young adults, and the elderly, product safety is essential. Although regulations prohibit the incorporation of certain HMs and RMs into cosmetics, lack of compliance by some producers remains a major concern.

In Nigeria, many locally produced cosmetic powders are manufactured in informal settings rather than certified factories, limiting effective monitoring by agencies such as the Standard Organisation of Nigeria (SON). Furthermore, claims of safety and health benefits by producers are rarely supported by scientific evidence, and the concentrations of harmful substances in these products are often undisclosed. This creates a potential risk for consumers, particularly because economic hardship and poverty drive many people to patronize cheaper, uncertified products. Hence, systematic assessment of heavy metals and natural radionuclides (NRs) in these products is necessary to safeguard public health.

Over the years, the Nigerian government has encouraged the growth of micro, small, and medium enterprises (MSMEs), including the cosmetics industry, because production often requires minimal capital. This has led to the proliferation of locally made powders, creams, perfumes, and soaps. However, the rapid increase in the number of these products underscores the need for continuous safety assessments, as unregulated items may expose users to harmful substances.

Several researches have been carried out to assess HMs in cosmetic products (Kumar *et al*., 2016; Al-zahrani and Fakeha, 2017; Abdulrahman and Sani, 2018; Vaphiades *et al*., 2019; Arshad *et al*., 2020). Arshad *et al*. (2020) evaluated HMs in cosmetic products using an Atomic Absorption Spectrophotometer (AAS). They reported that the concentrations of HMs differed based on the brand of cosmetic products. Working on HMs concentrations in fifty-six (56) talcum powders used in southeast Nigeria, Nnorom (2011) observed mean concentrations of 5.0±1.0, 2.1±0.3, 0.7±0.1, and 0.2±0.1 $mgkg^{-1}$ for Pb, Cd, Co, and Cr respectively. Similarly, Sani (2016) investigated HMs (Mn, Ni, Cu, Cd, Cr, and Pb) in ten (10) face powders used in Kano. Surajo *et al*. (2021) studied HMs (Pb, Cd, Ni, and Cr) in nine (9) face powders used in Katsina. Olayinka *et al*. (2020) investigated concentrations of HMs (Cd, Pb, Cr, and Ni) in cosmetic products used in Ado-Ekiti. Idris *et al*. (2019) reported 1.46, 103.07, 27.581, and 39.455 for Cd, Pb, Cr, and Ni in talcum powders used in Keffi, Nasarawa State.

Despite these studies on HMs content in cosmetics both within and outside the country (Sani *et al.*, 2016; Goulart *et al.*, 2018; Chatzimichael *et al.*, 2019), most of these studies are not current. Nnorom (2011) and Sani *et al*. (2016), who investigated HMs in locally produced cosmetics in Nigeria, among others, are, however, not recent and are in a different region. This depicts the need for recent studies, since new products are always available in the market. Furthermore, there are few or no recent studies on NRs in cosmetic powder (Almugren *et al*., 2023). This research will, therefore, help producer of these products to make informed decisions during production that will improve the quality of their products based on safety standards. It will also help regulatory agencies such as SON in monitoring and regulating these locally made beauty powders.

2,0 Materials and Methods

This study employed systematic procedures for sample collection, preparation, analysis, and health risk assessment of radionuclides (NRs) and heavy metals (HMs) in selected cosmetic powders.

2.1 Washing of Glassware and Accessories

All glassware and analytical accessories were thoroughly washed with detergent, rinsed with distilled water, and finally treated with 10% nitric acid to prevent contamination of the collected samples and ensure accuracy of results.

2.2 Sample Collection

A total of fourteen (14) cosmetic powder samples were randomly selected. These included commonly used powders for babies, children, youths, and adults, which were recently introduced into the Nigerian market. Approximately 90% of the newly available products at the time of this research were sampled. Samples were obtained from the three main markets in each geopolitical zone of the state, ensuring wide representation. The powders contained constituents such as fragrance, perfume, talc, calcium carbonate, magnesium carbonate, zinc oxide, titanium dioxide, benzoic acid, salicylic acid, starch, herbal extracts (e.g., Mentha piperita, Aloe barbadensis, Calendula officinalis, Cassia alata), kaolin, camwood, cassava starch, aloe vera, and cayenne. The details of the surveyed cosmetic powders are presented in Table 1.

2.3 Preparation of Sample

The collected samples were weighed, and about 320 g were sealed in plastic containers for radionuclide analysis. Similarly, about 10 g of each sample was digested and packaged in sample bottles for HMs analysis.

Radiological analysis was performed to determine the activity concentration of radionuclides at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, using NaI(TI) detector crystal. The activity concentration of radionuclide (C) measured in each sample was computed using the expression:

$$C(Bqkg^{-1}) = \frac{C_a}{\varepsilon \times M_s \times I_{eff}} \qquad (1)$$

where C_a = net gamma counting rate, ε = detected efficiency of the gamma-ray, I_{eff} = intensity of the gamma line in the radionuclides, and M_s = mass of powder samples (in kilogram).

2.5 Heavy Metal Analysis

The digested samples were used for HM analysis at Federal University, Wukari. An Atomic Absorption Spectrophotometer (AAS) was used to determine the concentrations of Cd, Co, Cr, Ni, and Pb in each of the samples following standard procedures.

Table 1: Surveyed Cosmetic Powders used in this Study

S/No.	Samples	Code	Producer	Place of Production	Production Date	Expiry Date	Weight
1	Cacatin Mentholated Dusting Powder	P01	Layus Investment Ltd	Ipaja, Lagos State	03-2022	03-2025	100 g
2	Jumi Mentholated Dusting Powder	P02	Jumi-Dap Ltd	Olaogun, Ogun State	03-2024	03-2027	80 g
3	Herbal Aloe Vera Dusting Powder	P03	Jim Products Ltd	Sango-Otta, Ogun State	04-2024	04-2026	100 g
4	Tinu Red Moju Powder	P04	Tinu Commercial Enterprises	Ibadan, Oyo State	01-2021	01-2023	40 g
5	Harmaderm Anti-bacterial	P05	Copaci FRN	Okota-Isolo, Lagos State	05-2024	05-2027	90 g
6	Skin Clinique	P06	Imperio Int'l Ltd	Ikeja, Lagos State	02-2023	02-2026	250 g
7	Baby & Me Baby Powder	P07	Imperio Int'l Ltd	Ikeja, Lagos State	04-2024	04-2027	450 g
8	Nursing Nurse Baby Powder	P08	Rejoice Joice Ventures	Nkpor, Anambra State	02-2022	02-2025	250 g
9	mp3 Cool Refreshing Talcum Powder	P09	Imperio Int'l Ltd	Ikeja, Lagos State	02-2023	02-2026	250 g
10	Passion Talcum Powder	P10	Cybele Cosmetics Ltd	Mushin, Lagos State	08-2023	07-2026	200 g
11	Rising Raving Baby Powder	P11	Rising Ventures	Benin, Edo State	05-2024	04-2028	100 g

12	Everyone Herbal Dusting Powder	P12	Fana Labresults Nig. Ltd	Ketu, Lagos State	03-2024	03-2027	100 g
13	Eklass Moju Baby Powder	P13	Andy King Integrated Services Ltd	Isashi, Lagos State	01-2024	11-2027	120 g
14	Get Me Oil Control Talc	P14	Prestige Cosmetics Ltd	Kirikiri, Lagos State	06-2022	06-2025	450

2.6 Health Risk Assessment of HMs and NRs

Empirical models presented in equations 2 to 16were employed to assess the health risk of consumers due to exposure to the HMs and NRs in the sampled beauty powders (Avwiri *et al*., 2014; Olanrewaju and Avwiri, 2017; Ojelabi *et al*., 2018; Arshad *et al*., 2020; SCCS, 2021; Onjefu *et al*., 2022).

From equations 2 – 16, C_u, C_{Th}, and C_k are concentrations of U-238, Th-232, and K-40, DL is the average life span (i.e. 70 years), RF is the Risk Factor (0.05 Sv^{-1}), UF is uncertainty factor (1.0), MF is modifying factor (100), RFD is reference doses (mg/kg/day) for Cd (1×10^{-3}), Cr (3×10^{-3}), Pb (4×10^{-3}), Co (3×10^{-4}), and Ni (2×10^{-2}), Cs is HMs concentration, SSA is skin surface area onto which the face powder is applied (563 cm^2), AA is the daily amount of face powder used (0.51), RF is retention factor (1.0), F is the frequency of daily use of the face powder (2.0), BF is a bio-accessibility factor, BW is body weight (i.e. 60 kg for adult and 16 kg for children), and SF slope factor (mg/kg/d) with values 0.0085, 0.5, 0.91, and 6.7 for Pb, Cr, Ni, and Cd respectively (Idris *et al*., 2019; Surajo *et al*., 2021).

To evaluate the radiological and non-radiological health risks associated with natural and anthropogenic sources of radioactivity and heavy metals, several standard dose and risk assessment models were applied. The absorbed dose rate (Eq. 1) provides the basis for estimating external gamma radiation exposure from terrestrial radionuclides, while the annual effective dose equivalent (Eqs. 3 and 5) quantifies the potential radiation burden to individuals. Additional indices such as the radium equivalent activity (Eq. 4), radioactivity level index (Eq. 6), annual gonadal dose equivalent (Eq. 7), external and internal hazard indices (Eqs. 8 and 9), and excess lifetime cancer risk (Eq. 10) were employed to assess radiological safety in relation to international limits. Furthermore, chemical toxicity risk was evaluated using toxicological parameters, including the margin of safety (Eq. 11), no observed adverse effect level (NOAEL) (Eq. 12), systematic exposure dosage (Eq. 13), hazard quotient (Eq. 14), hazard index (Eq. 15), and carcinogenic risk (Eq. 16). Collectively, these models provide a comprehensive framework for assessing potential hazards and risks to human health arising from environmental exposure.

$$\text{Absorbed Dose Rate, } D = 0.462C_u + 0.604C_{Th} + 0.0417C_K \quad (1)$$

$$AEDE_{out} = D(nGyh^{-1})\ x\ 24hr\ x\ 365.25d\ x\ 0.2\ x\ 0.7\ SvGy^{-1}\ x\ 10^{-6} \quad (3)$$

$$Radium\ Equivalent, Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \quad (4)$$

$$Annual\ Effective\ Dose\ Equivalent, AEDE = 3.09C_u + 4.18C_{Th} + 0.314C_K \quad (5)$$

$$Radioactivity\ level\ index, I_r = \frac{C_u}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \quad (6)$$

$$Annual\ Gonadal\ Equivalent\ Dose, AGED = 3.09C_u + 4.18C_{Th} + 0.314C_K \quad (7)$$

$$External\ hazard\ index, ext = \frac{C_u}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (8)$$

$$Internal\ hazard\ index, H_{int} = \frac{C_u}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (9)$$

$$Excess\ Lifetime\ Cancer\ Risk, ELCR = AEDE_{out}\ x\ DL\ x\ RF \quad (10)$$

$$Margin\ of\ safety, MoS = \frac{NOAEL}{SED} \quad (11)$$

$$NOAEL = RFD\ x\ \ UF\ x\ MF \quad (12)$$

$$Systematic\ exposure\ Dosages, SED = \frac{C_s \times AA \times SSA \times F \times RF \times BE \times 10^{-3}}{BW} \quad (13)$$

$$Hazard\ Quotient, HQ = \frac{SED}{RfD} \quad (14)$$

$$Hazardous\ Index, HI = \sum HQ = HQ_{Cd} + HQ_{Cr} + HQ_{Ni} + HQ_{Co} + HQ_{Pb} \quad (15)$$

$$Carcinogenic\ risk = SED\ x\ SF \quad (16)$$

3.0 Results and Discussion

3.1 Activity Concentrations of NRs and Radiological Health Risk Parameters

Table 2 presents the activity concentrations of naturally occurring radionuclides (NRs), namely ^{232}Th, ^{238}U, and ^{40}K, in the sampled cosmetic powders. The concentrations ranged from 7.60 ± 0.43 to 49.70 ± 2.75 Bq/kg for ^{232}Th, 2.55 ± 0.25 to 43.24 ± 4.19 Bq/kg for ^{238}U, and 54.92 ± 2.99 to 237.26 ± 12.86 Bq/kg for ^{40}K. In samples P05 and P09, ^{238}U was below detectable limits (BDL), highlighting possible variability in raw materials or differences in the mineral composition of talc and other excipients used in cosmetic formulations.

When compared with international data, the concentrations reported in this study are higher than those of Almugren et al. (2023), who found very low levels of ^{232}Th (0.317–0.556 mBq/kg), ^{238}U (0.174–0.623 mBq/kg), and ^{40}K (0.610–0.742 mBq/kg) in talcum powders from Malaysia. However, the mean activity concentrations obtained here—25.30 ± 1.31 Bq/kg (^{232}Th), 11.36 ± 1.00 Bq/kg (^{238}U), and 131.53 ± 7.09 Bq/kg (^{40}K)—remain well below the recommended safety limits of 50 Bq/kg for both ^{232}Th and ^{238}U and 500 Bq/kg for ^{40}K (Medhat et al., 2015).

Comparatively, Medhat et al. (2015) reported higher average activity concentrations (40 ± 18 Bq/kg for ^{226}Ra, 35 ± 10 Bq/kg for ^{232}Th, and 739 ± 19 Bq/kg for ^{40}K) in cosmetics, suggesting that the powders examined in the present study are radiologically safer. Such disparities may be attributed to geological variations in the source of raw materials, differences in processing technology, or improved regulatory control in cosmetic production.

The absorbed dose rate (D) calculated for the samples ranged from 8.06 to 42.56 nGy/h, significantly below the global average limit of 59 nGy/h for soils and consumer products (UNSCEAR, 2000). Similarly, other radiological health risk parameters were within safe thresholds: AEDE (0.01–0.052 mSv/y), Raeq (17.65–91.66 Bq/kg), H_ex (0.05–0.25), H_in (0.05–0.36), Iγ (0.13–0.66), AGED (56.89–295.82 μSv/y), and ELCR (0.03×10^{-3} – 0.16×10^{-3}). These findings confirm that the surveyed powders do not pose radiological health hazards to consumers, aligning with international recommendations for radiological safety in consumer products.

3.2 Mean Concentration of HMs in the Surveyed Cosmetic Powders

The atomic absorption spectrophotometer (AAS) working conditions adopted for heavy metal (HM) determination (Table 3) were consistent with previous studies (Sani et al., 2016; Surajo et al., 2021). Results revealed the presence of Cd, Cr, Ni, Co, and Pb in varying concentrations across all powders (Table 4). The concentration ranges were 0.0128–1.2418 ppm (Cd), 0.001–0.010 ppm (Cr), 0.100–0.400 ppm (Ni), 0.007–0.030 ppm (Co), and 0.247–1.852 ppm (Pb). Pb recorded the highest concentration, while Cr showed the lowest. This order (Pb > Ni > Cd > Co > Cr) is consistent with reports by Nnorom (2011) and Surajo et al. (2021), highlighting Pb as a recurring dominant contaminant in cosmetic powders.

The maximum concentrations were found in specific powders: Cd in P08, Cr in P10, Ni in P04, Co in P01, and Pb in P13. Such variability reflects differences in formulation or potential contamination from raw materials and processing environments. Importantly, except for Cd in P08, the concentrations of Pb, Cd, and Ni were below WHO permissible limits of 10, 0.3, and 0.6 mg/kg, respectively, suggesting minimal immediate health risks. However, given the cumulative nature of heavy metals in biological systems, long-term use could result in bioaccumulation and toxicity.

Comparative evaluation with earlier studies showed declining trends in HM concentrations. Omenka and Adeyi (2016) reported higher levels of Cd, Pb, and Ni in powders such as *mp3*, *Passion*, and *Rising Raving*, all produced by the same companies as in this study. This suggests improvements in raw material sourcing and regulatory compliance over time. The difference may also be linked to changes in production dates, with earlier powders (2014–2018) containing higher HMs compared to those analyzed here (2023–2028). Such progress reflects positive impacts of consumer safety awareness, regulatory oversight, and alignment with global best practices in the cosmetics industry.

When compared with international data, the concentrations of Cd were lower than those reported for local Nigerian powders (Nnorom, 2011; Idris et al., 2019) but comparable to foreign powders (Sani et al., 2016; Ullah et al., 2017). Cr concentrations were generally lower than in most local and foreign powders, while Ni and Co were lower than values reported in Pakistan and other regions (Ullah et al., 2017; Manu et al., 2023). Pb levels were comparable to those observed globally, confirming Pb as a universal concern in cosmetic formulations. The relatively lower concentrations in this study indicate steady progress in product safety and quality in Nigeria's cosmetic industry.

The observed Pb concentrations were below the WHO and U.S. FDA maximum permissible level of 10 ppm but still raise concern due to Pb's cumulative toxicity (Table 5).. Compared with earlier findings by Omenka and Adeyi (2016), where Pb levels in some powders reached 468 ppm, the present study recorded a dramatic decline (≤ 1.852 ppm). Similarly, Cd, Ni, and Co levels were lower than those reported by Nnorom (2011) and Idris et al. (2019), suggesting that product safety has improved over the years, likely due to better manufacturing oversight. Globally, our results were comparable to those of Ullah et al. (2017) in Pakistan but significantly safer than some products reported in South Asia (Manu et al., 2023).

3.3 Systematic Exposure Dosage (SED) for Adults and Children

The calculated SED values for adults and children under 50 % and 100 % bioaccessibility scenarios are displayed in Fig. 1**.** As expected, children consistently showed higher SED values than adults because of their lower body weights and higher skin surface area-to-body weight ratios. Doubling the bioaccessibility assumption from 50 % to 100 % led to a proportional increase in exposure, simulating a worst-case scenario.

3.3.1 Vulnerability of children

The results confirm findings by Oyekunle et al. (2021), who demonstrated that children are more vulnerable to heavy metal exposure from cosmetics and personal care products. Although SED values fell within acceptable toxicological thresholds, the elevated exposure levels in children warrant precautionary regulation and consumer advisories.

3.4 Margin of Safety (MoS)

MoS values, shown in Table 6b, provide an integrated measure of consumer safety. For most metals, MoS values were ≥ 100, indicating adequate safety margins. However, Pb and Cd breached safety margins in selected powders. Pb values were unsafe in P01, P02, P04, P05, P07, P10, P11, and P12 at 50 % bioaccessibility and in P01 and P02 at 100 % bioaccessibility. Cd in P08 also registered an unsafe MoS.

3.4.1 Public health implications

These findings suggest that prolonged exposure, particularly among children, could lead to toxicological effects despite compliance with regulatory limits. The MoS results therefore, support the argument that cumulative and chronic exposure scenarios should be incorporated into cosmetic risk assessments.

3.4 Margin of Safety (MoS)

MoS analysis demonstrated that Cd, Co, Cr, and Ni were within safe margins (MoS ≥ 100) in most powders, except for Cd in P08. Pb exceeded safe MoS values in some powders (P01, P02, P04, P05, P07, P10, P11, and P12 at 50 %; P01 and P02 at 100 %), indicating Pb as a key contaminant of concern. Among children, MoS values revealed even higher risks, with 37–40 % of powders falling below safe thresholds at different bioaccessibility levels. This underscores children’s greater vulnerability to Pb toxicity.

3.5 Hazard Quotient (HQ), Hazard Index (HI), and Carcinogenic Risk

HQ and HI values for all HMs were below unity, suggesting no immediate non-carcinogenic risks under typical exposure conditions. However, carcinogenic risk assessments revealed concerns: Cd exceeded safe limits in some powders (P03 and P08 for adults at 50 % bioaccessibility, and additional powders at 100 %), while Ni posed moderate risks in both adults and children. Children were again found to be at higher risk, particularly for Cd exposure.

For Cr and Pb, the values are within the safe limit for adults and children at both 50 % and 100 % bio-accessibility. This implies no carcinogenic risk for Cr and Pb in the sampled powders; however, the carcinogenic risk for Cd and Ni varied. This indicates that the surveyed cosmetic powders pose no radiological risk, while carcinogenic risk from HMs varies with 50% and 100% bio-accessibility.

Our observation generally suggests improvement in the quality of the cosmetic powders, which could promote the growth of micro, small, and medium enterprises (MSME) and patronage of locally made cosmetic powders.

3.5 Hazard Quotient (HQ), Hazard Index (HI), and Carcinogenic Risk

The HQ and HI values were below unity across all samples, implying that non-carcinogenic risks are minimal. However, carcinogenic risks (Tables 7a and 7b) were elevated for Cd and Ni under certain exposure scenarios, particularly in children. For instance, Cd exceeded carcinogenic risk thresholds in P03 and P08 at both 50 % and 100 % bioaccessibility. Ni contributed additional moderate carcinogenic risks, again disproportionately affecting children. Pb, despite its presence, had relatively lower carcinogenic contributions but remains a critical toxicant of concern.

3.6 Regulatory and Public Health Perspectives

The results underscore significant progress in cosmetic powder safety compared with earlier Nigerian studies, particularly concerning Pb and Cd concentrations. This improvement likely reflects enhanced quality control and regulatory enforcement. However, the persistence of Pb in nearly all samples highlights the need for stricter manufacturing oversight.

Regulatory authorities such as NAFDAC in Nigeria and international bodies like the WHO and FDA should consider periodic heavy metal monitoring and enforce stricter import and local production standards.

From a public health standpoint, the results stress the vulnerability of children to both radiological and heavy metal exposure. Educational campaigns to raise consumer awareness about the risks of low-quality powders are essential. Additionally, manufacturers should adopt safer raw materials, implement cleaner production processes, and conduct regular quality assurance testing.

3.6 Statistical Analysis of Experimental Data

To further validate the experimental observations, statistical analyses were performed to examine relationships among variables, compare elemental concentrations, and evaluate compliance with international safety thresholds. The results are presented in Tables 8–11.

Table 8 presents the regression analysis of absorbed dose rate (D) as a function of activity concentrations of ^{232}Th, ^{238}U, and ^{40}K. The regression model returned coefficients (β_1 = 0.604, β_2 = 0.462, β_3 = 0.042) that closely reproduce the theoretical dose conversion factors, with an R^2 value approaching unity (0.99999997). This nearly perfect fit demonstrates that the experimentally determined absorbed dose rates are strongly governed by the concentrations of the measured radionuclides. Technically, this confirms the robustness of the absorbed dose equation in predicting dose rates from radionuclide activity concentrations, thereby reinforcing its reliability in radiological risk assessment. Table 9 summarizes the results of a one-way ANOVA performed across heavy metal concentrations (Cd, Cr, Ni, Co, Pb). The analysis revealed significant differences among the group means ($F = 24.84$).

Tukey's post-hoc comparisons showed that Pb concentrations were statistically higher than those of Cd, Cr, Ni, and Co ($p < 0.001$), while Ni was significantly higher than Cd and Co. These findings confirm that Pb is the dominant heavy metal in the powders, consistent with the order Pb > Ni > Cd > Co > Cr observed in the descriptive analysis.

Table 2: Activity Concentrations of NRs and Radiological Health Risk Parameters

Code	^{232}Th (Bq/Kg)	^{238}U (Bq/Kg)	^{40}K (Bq/Kg)	D nGyh^{-1}	AEDE mSvy^{-1}	Ra$_{eq}$ BqKg^{-1}	H$_{ex}$	H$_{in}$	Iy	AGED mSvy^{-1}	ELCR x 10^{-3}
P01	25.26	9.22	94.39	23.45	0.029	52.61	0.14	0.17	0.38	163.72	0.09
P02	20.20	4.60	99.04	18.46	0.023	41.11	0.11	0.12	0.30	129.75	0.07
P03	7.60	2.55	54.92	8.06	0.010	17.65	0.05	0.05	0.13	56.89	0.03
P04	26.28	6.84	68.52	21.89	0.027	49.70	0.13	0.15	0.35	152.50	0.08
P05	18.45	**BDL**	237.26	-	-	-	-	-	-		-
P06	9.61	10.05	225.14	19.84	0.024	41.13	0.11	0.14	0.31	141.92	0.07
P07	45.83	10.93	59.23	35.20	0.043	81.03	0.22	0.25	0.57	243.94	0.13
P08	37.14	7.30	106.99	30.27	0.037	68.65	0.19	0.21	0.49	211.40	0.11
P09	40.56	BDL	231.7	-	-	-	-	-	-		-
P10	14.74	22.01	100.73	23.27	0.029	50.84	0.14	0.20	0.36	161.25	0.09
P11	8.88	13.50	66.17	14.36	0.018	31.29	0.08	0.12	0.22	99.61	0.05
P12	28.56	2.85	54.67	20.85	0.026	47.90	0.13	0.14	0.34	145.35	0.08
P13	21.34	43.24	232.5	42.56	0.052	91.66	0.25	0.36	0.66	295.82	0.16
P14	49.7	3.21	210.2	40.27	0.049	90.47	0.24	0.25	0.66	283.67	0.15
UNSCEAR	**50**	**50**	**500**	**59**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

****BDL=below detectable limit, UNSCEAR = United Nations Scientific Committee on the Effects of Atomic Radiation**

Table 3: Working conditions for HMs determination using AAS

HM	Wavelength (nm)	Slit Width (nm)	Detection Limit (mg/L)	Lamp Current (mA)	Linear Range (mg/L)	Flame Type (Colour)
Cd	228.9	0.7	0.01	10	2.00	A–A, Lean/Blue
Cr	240.7	0.2	0.05	20	5.00	A–A, Lean/Blue
Ni	357.9	0.7	0.04	20	5.00	A–A, Lean/Blue
Co	232.0	0.2	0.05	20	4.00	A–A, Lean/Blue
Pb	217.0	0.7	0.04	15	10.00	A–A, Lean/Blue

Table 4: Mean concentration of HMs in the surveyed cosmetic powders

Code	Cd (ppm)	Cr (ppm)	Ni (ppm)	Co (ppm)	Pb (ppm)
P01	0.0128±0.002	0.004±0.001	0.300±0.002	0.030±0.002	0.247±0.001
P02	0.0220±0.002	0.007±0.002	0.300±0.002	0.017±0.002	0.309±0.001
P03	0.0550±0.002	0.004±0.001	0.200±0.001	0.026±0.002	1.111±0.002
P04	0.0164±0.002	0.007±0.002	0.400±0.002	0.024±0.002	0.494±0.001
P05	0.0147±0.002	0.008±0.002	0.300±0.001	0.009±0.001	0.432±0.001
P06	0.0128±0.002	0.007±0.002	0.200±0.001	0.023±0.002	1.173±0.002
P07	0.0220±0.002	0.001±0.001	0.200±0.001	0.017±0.002	0.617±0.002
P08	1.2418±0.002	0.004±0.001	0.300±0.002	0.029±0.002	1.852±0.002
P09	0.0073±0.001	0.005±0.002	0.100±0.001	0.007±0.001	1.111±0.002
P10	0.0037±0.001	0.010±0.002	0.200±0.002	0.014±0.002	0.617±0.002
P11	0.0183±0.002	0.001±0.001	0.200±0.001	0.019±0.002	0.617±0.002
P12	0.0128±0.002	0.008±0.002	0.100±0.001	0.027±0.002	0.679±0.002
P13	0.0073±0.001	0.007±0.002	0.200±0.001	0.030±0.002	0.864±0.002
P14	0.0110±0.002	0.004±0.001	0.300±0.002	0.029±0.002	0.864±0.002
WHO/ U.S FDA	**0.300**	**5.00**	**0.600**	**1.0**	**10.00**

WHO = World health Organisation, U.S FDA = U.S. Food and Drug Administration

Table 5a. Comparison of HMs Concentration (ppm or mg/kg) Observed with Omenka and Adeyi (2016) for Same Powders and Manufacturer

Sample Name	Code	Cd (ppm)	Pb (ppm)	Ni (ppm)	Production Date	Expiry Date	Reference
mp3 Cool Refreshing Talcum Powder	P09	0.0073 ± 0.001	1.111 ± 0.002	0.100 ± 0.001	02-2023	02-2026	Present study
	003P	0.25 ± 0.0	3.75 ± 1.8	2.75 ± 0.4	05-2014	05-2017	Omenka & Adeyi (2016)
Passion Talcum Powder	P10	0.0037 ± 0.001	0.014 ± 0.002	0.200 ± 0.002	08-2023	07-2026	Present study
	01PP	0.13 ± 0.2	6.25 ± 1.8	4.63 ± 2.7	05-2014	05-2017	Omenka & Adeyi (2016)
Rising Raving Baby Powder	P11	0.0183 ± 0.002	0.617 ± 0.002	0.200 ± 0.001	05-2024	04-2028	Present study
	07PP	ND	468	5.75	04-2014	03-2018	Omenka & Adeyi (2016)

Table 5b. Comparison of Concentrations of HMs (mg/kg, ppm, or µg/g) Observed with Previous Results for Local and Foreign Powders Used in Nigeria

Origin	Cd (mg/kg) / (ppm / µg/g)	Cr (mg/kg)	Ni (mg/kg)	Co (mg/kg)	Pb (mg/kg)	Reference
Local	0.0128 ± 0.002 – 1.2418 ± 0.002	0.001 ± 0.001 – 0.010 ± 0.002	0.100 ± 0.002 – 0.400 ± 0.001	0.007 ± 0.001 – 0.030 ± 0.002	0.247 ± 0.002 – 1.852 ± 0.002	Present study
Local	2.10 ± 0.30	0.20 ± 0.10	–	0.70 ± 0.10	5.00 ± 1.00	Nnorom (2011)
Local	ND – 36.3	–	0.13 – 107	–	ND – 468	Omenka & Adeyi (2016)
Local	0.139 ± 0.063	0.183 ± 0.119	–	–	0.043 ± 0.027	Olayinka et al. (2020)
Local	1.46	27.581	39.455	–	27.581	Idris et al. (2019)
Foreign	0.520	0.725	1.825	–	0.061	Manu et al. (2023)
Foreign	0.07 – 1.74	0 – 0.03	3.68 – 11.03	–	0.08 – 0.33	Sani et al. (2016)
Foreign	0.007 ± 0.003	0.205 ± 0.089	0.042 ± 0.008	–	0.624 ± 1.508	Surajo et al. (2021)
Foreign	0.258 – 0.360	ND – 0.262	0.720 – 1.425	0.660 – 1.225	2.325 – 3.975	Ullah et al. (2017)

Note: ND = Not Detectable.

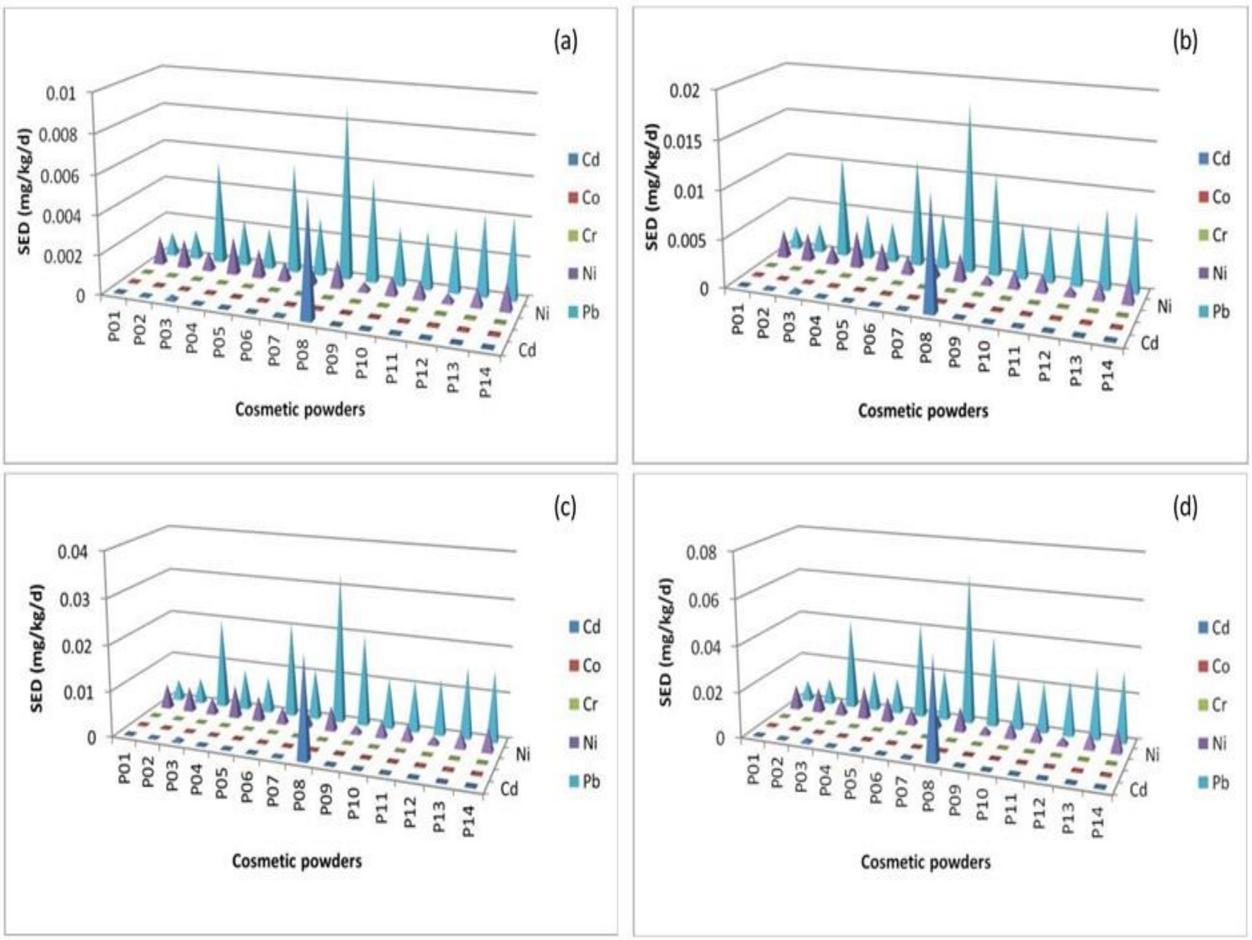

Fig. 1: SED at (a) 50 % (b) 100 % for adults and (c) 50 % and (d) 100 % bio-accessibilty levels for children for the surveyed cosmetic powders

Table 6b: Margin of Safety (MoS) for Heavy Metals (HMs) in the surveyed cosmetic powders upon usage by children

Code	50% bio-accessibility factor					100% bio-accessibility factor				
	Cd	Cr	Ni	Co	Pb	Cd	Cr	Ni	Co	Pb
P01	435.34	4179.29	371.49	55.72	90.24	217.67	2089.65	185.75	27.86	45.12
P02	253.29	2388.17	371.49	98.34	72.13	126.65	1194.08	185.75	49.17	36.07
P03	101.32	4179.29	557.24	64.30	20.06	50.66	2089.65	278.62	32.15	10.03
P04	339.78	2388.17	278.62	69.65	45.12	169.89	1194.08	139.31	34.83	22.56
P05	379.07	2089.65	371.49	185.75	51.60	189.54	1044.82	185.75	92.87	25.80
P06	435.34	2388.17	557.24	72.68	19.00	217.67	1194.08	278.62	36.34	9.50
P07	253.29	16717.17	557.24	98.34	36.13	126.65	8358.58	278.62	49.17	18.06
P08	4.49	4179.29	371.49	57.65	12.04	2.24	2089.65	185.75	28.82	6.02
P09	763.34	3343.43	1114.48	238.82	20.06	381.67	1671.72	557.24	119.41	10.03
P10	1506.05	1671.72	557.24	119.41	36.13	753.03	835.86	278.62	59.70	18.06
P11	304.50	16717.17	557.24	87.99	36.13	152.25	8358.58	278.62	43.99	18.06
P12	435.34	2089.65	1114.48	61.92	32.83	217.67	1044.82	557.24	30.96	16.41
P13	763.34	2388.17	557.24	55.72	25.80	381.67	1194.08	278.62	27.86	12.90
P14	506.58	4179.29	371.49	57.65	25.80	253.29	2089.65	185.75	28.82	12.90

Table 7a: Carcinogenic risk in adults

Code	50% bio-accessibility factor				100% bio-accessibility factor			
	Cd	**Cr**	**Ni**	**Pb**	**Cd**	**Cr**	**Ni**	**Pb**
P01	4.10E-04	9.57E-06	1.31E-03	1.00E-05	8.21E-04	1.91E-05	2.61E-03	2.01E-05
P02	7.05E-04	1.67E-05	1.31E-03	1.26E-05	1.41E-03	3.35E-05	2.61E-03	2.51E-05
P03	1.76E-03	9.57E-06	8.71E-04	4.52E-05	3.53E-03	1.91E-05	1.74E-03	9.04E-05
P04	5.26E-04	1.67E-05	1.74E-03	2.01E-05	1.05E-03	3.35E-05	3.48E-03	4.02E-05
P05	4.71E-04	1.91E-05	1.31E-03	1.76E-05	9.43E-04	3.83E-05	2.61E-03	3.51E-05
P06	4.10E-04	1.67E-05	8.71E-04	4.77E-05	8.21E-04	3.35E-05	1.74E-03	9.54E-05
P07	7.05E-04	2.39E-06	8.71E-04	2.51E-05	1.41E-03	4.79E-06	1.74E-03	5.02E-05

P08	3.98E-02	9.57E-06	1.31E-03	7.53E-05	7.96E-02	1.91E-05	2.61E-03	1.51E-04
P09	2.34E-04	1.20E-05	4.35E-04	4.52E-05	4.68E-04	2.39E-05	8.71E-04	9.04E-05
P10	1.19E-04	2.39E-05	8.71E-04	2.51E-05	2.37E-04	4.79E-05	1.74E-03	5.02E-05
P11	5.87E-04	2.39E-06	8.71E-04	2.51E-05	1.17E-03	4.79E-06	1.74E-03	5.02E-05
P12	4.10E-04	1.91E-05	4.35E-04	2.76E-05	8.21E-04	3.83E-05	8.71E-04	5.52E-05
P13	2.34E-04	1.67E-05	8.71E-04	3.51E-05	4.68E-04	3.35E-05	1.74E-03	7.03E-05
P14	3.53E-04	9.57E-06	1.31E-03	3.51E-05	7.05E-04	1.91E-05	2.61E-03	7.03E-05

.Table 7b: Carcinogenic risk for children

Code	**50 % bio-accessibility factor**				**100 % bio accessibility factor**			
	Cd	**Cr**	**Ni**	**Pb**	**Cd**	**Cr**	**Ni**	**Pb**
P01	1.54E-03	3.59E-05	4.90E-03	3.77E-05	3.08E-03	7.18E-05	9.80E-03	7.54E-05
P02	2.65E-03	6.28E-05	4.90E-03	4.71E-05	5.29E-03	1.26E-04	9.80E-03	9.43E-05
P03	6.61E-03	3.59E-05	3.27E-03	1.69E-04	1.32E-02	7.18E-05	6.53E-03	3.39E-04
P04	1.97E-03	6.28E-05	6.53E-03	7.54E-05	3.94E-03	1.26E-04	1.31E-02	1.51E-04
P05	1.77E-03	7.18E-05	4.90E-03	6.59E-05	3.53E-03	1.44E-04	9.80E-03	1.32E-04
P06	1.54E-03	6.28E-05	3.27E-03	1.79E-04	3.08E-03	1.26E-04	6.53E-03	3.58E-04
P07	2.65E-03	8.97E-06	3.27E-03	9.41E-05	5.29E-03	1.79E-05	6.53E-03	1.88E-04
P08	**1.49E-01**	3.59E-05	4.90E-03	2.83E-04	2.99E-01	7.18E-05	9.80E-03	5.65E-04
P09	8.78E-04	4.49E-05	1.63E-03	1.69E-04	1.76E-03	8.97E-05	3.27E-03	3.39E-04
P10	4.45E-04	8.97E-05	3.27E-03	9.41E-05	8.90E-04	1.79E-04	6.53E-03	1.88E-04
P11	2.20E-03	8.97E-06	3.27E-03	9.41E-05	4.40E-03	1.79E-05	6.53E-03	1.88E-04
P12	1.54E-03	7.18E-05	1.63E-03	1.04E-04	3.08E-03	1.44E-04	3.27E-03	2.07E-04
P13	8.78E-04	6.28E-05	3.27E-03	1.32E-04	1.76E-03	1.26E-04	6.53E-03	2.64E-04
P14	1.32E-03	3.59E-05	4.90E-03	1.32E-04	2.65E-03	7.18E-05	9.80E-03	2.64E-04

The implication of this result is that Pb, although within acceptable safety limits, accounts for the largest contribution to the overall heavy metal burden and thus represents the primary target for continued regulatory surveillance.

Table 8: Regression: absorbed dose D vs Th, U, K40

Coefficient	Estimate
const	0.001236
Th (β_1)	0.603974
U (β_2)	0.461816
K40 (β_3)	0.041722
R^2	~0.99999997

Table 10: ANOVA (one-way) across metals & Tukey post-hoc

Source	Sum of_ square	df	F	p-value
Metal	5.8455	4	24.8396	1.66E-12
Residual	3.8241	65	—	—

Table 11 presents the contamination factors (CF) and enrichment factors (EF) for the heavy metals, providing a normalized measure of relative risk. The CF values for all metals were <1, indicating concentrations below WHO limits on average. However, the EF analysis revealed a striking anomaly for Cd, where one sample (P08) showed enrichment far above the dataset median (mean EF ≈ 24). This highlights that while the general contamination risk is low, localized enrichment can occur in specific powders, potentially due to raw material inconsistencies or production practices.

The results from the analyses provide converging evidence that radionuclide activity concentrations in the cosmetic powders are well within international radiological safety limits, while heavy metals—particularly Pb and Cd—remain critical factors for toxicological and regulatory assessment. The combined experimental and statistical evaluation confirms product safety in most cases but emphasizes the need for sustained monitoring and stricter quality assurance protocols to eliminate anomalous exceedances.

Table 11: Compliance/exceedance vs WHO limits (empirical)

Metal	# samples > WHO limit (out of 14)	% exceedance
Cd	1	7.14%
Cr	0	0%
Ni	0	0%
Co	0	0%
Pb	0	0%

4.0 Conclusion

The mean activity concentrations of ^232Th (25.30 ± 1.31 Bq kg^{-1}), ^238U (11.36 ± 1.00 Bq kg^{-1}), and ^40K (131.53 ± 7.09 Bq kg^{-1}) were all far below the recommended safe limits of 50, 50, and 500 Bq kg^{-1}, respectively. This indicates that exposure to the surveyed cosmetic powders poses no radiological health risk. Heavy metals were detected in the order Pb > Ni > Cd > Co > Cr, with Pb recording the highest and Cr the lowest concentration. The levels of Pb, Cd, and Ni in all the samples, except Cd in sample P08, were below the acceptable limits of 10, 0.3, and 0.6 mg kg^{-1}, respectively, for cosmetic products as set by WHO. Overall, the results suggest a significant decline in heavy metal concentrations compared with earlier reports, reflecting improvement in the quality of locally produced cosmetic powders. However, Margin of Safety (MoS) values reveal that prolonged exposure could pose health risks at both 50 % and 100 % bio-accessibility, particularly in children.

The study confirms that the cosmetic powders analyzed are radiologically safe, but the presence of trace heavy metals—though largely within permissible limits—warrants caution. The findings highlight progress in product safety compared with earlier studies, yet potential risks remain under conditions of long-term exposure and higher bio-accessibility.

Continuous monitoring and enforcement of safety standards are recommended to ensure consistent product safety. Manufacturers should maintain stringent quality control to further minimize heavy metal contamination, while regulatory agencies should intensify routine checks. Public awareness programs are also needed to inform consumers about potential risks from prolonged use, especially for children. Future studies should investigate bio-accessibility and long-term exposure effects to provide a more comprehensive risk assessment.

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Declaration

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data public

Ethical Considerations

The ethical considerations for this study centered on ensuring transparency, safety, and integrity in research. All cosmetic powder samples were purchased openly from the market, with no human or animal subjects involved, thus minimizing ethical concerns. Laboratory procedures were conducted in compliance with standard safety protocols to avoid environmental contamination and researcher exposure. Data were analyzed and reported honestly, without manipulation, and findings were presented objectively to guide policy and consumer safety. Confidentiality of manufacturers was also respected.

Competing interest

The authors report no conflict or competing interest

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Contribution of Authors

AMO conceived and designed the study, supervised the research, coordinated radiological analyses, and contributed to drafting and final editing of the manuscript. TJN carried out the heavy metal analysis using AAS, interpreted HM data, and assisted in writing the methodology and results. AIO helped with study design, validated analytical procedures, and contributed to the discussion. AAP assisted with sample collection, preparation, and data organization, while EIS provided guidance, critically reviewed, and approved the final manuscript.