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Assessment of heavy metals and natural radionuclides in locally produced soaps used in Benue State, Nigeria: implications for human health risk

Moses Owoicho **Audu**^{a,*}, Inikpi Ojochenemi **Agada**^a, Julius Nyiyayem **Tsaviv**^b, Aondohemba Paschal **Achu**^b, Ishaq Shaibu **Eneji**^b

^aJoseph Sarwuan Tarka University, Department of Physics, Makurdi, P.M.B. 2373, Nigeria

^bJoseph Sarwuan Tarka University, Department of Chemistry, Makurdi, P.M.B. 2373, Nigeria

ABSTRACT

Human exposure to ionizing radiation and toxic metals remains a major concern for physicists, chemists, environmentalists, and the public. In this study, heavy metals (HMs: Ni, Pb, Co, Cr, and Cd) and natural radionuclides (NRs: ^{238}U , ^{232}Th , and ^{40}K) were analyzed in thirty locally produced soaps used in Benue State, Nigeria. The HMs were determined using Atomic Absorption Spectrophotometry (AAS), while NRs were measured using a NaI(Tl) detector. The concentration ranges of Ni, Pb, Co, Cr, and Cd were 0.100–0.400, 0.124–1.235, 0.003–0.034, 0.001–0.010, and 0.0037–0.115 ppm, respectively. These values were below the recommended safe limits set by the WHO and the U.S. FDA, indicating no immediate health risk except under prolonged exposure that could lead to HM accumulation. The results further showed that only three of the thirty surveyed soaps posed a severe radiological health concern because of elevated NR concentrations. The margin of safety, systemic exposure dose, and carcinogenic-risk estimates at 50% and 100% bio-accessibility indicated a higher health risk for children than for adults. Overall, the findings support safer production and use of locally produced soaps in Benue State and may encourage the growth of micro, small, and medium enterprises (MSMEs).

Keywords: Exposure, Health risk, Heavy metals, Locally produced soap, Natural radioactivity.

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1. INTRODUCTION

One major issue that is of great concern to physicists, chemists, environmentalists, and the general public in recent years is human exposure to radiation and toxic metals from both natural and artificial sources [1]. It is a known fact that our immediate environment (i.e. air, water, and soil) emits radiation in small quantities, thereby exposing humans to radiation at different doses.

Globally, humans are exposed to about 2.401 mSv y^{-1} of background ionizing radiation. The sources of this background radiation are both natural (80 %) and artificial (20 %), depending on the nature and composition of the environment [1].

In addition, the increasing application of radionuclides in industry, medicine, and the production of radionuclides by nuclear reactors due to technological advancement has increased human exposure to radiation. Thus, radionuclides can be found in nature but they are artificially produced for various purposes as they exhibit unique properties that make them valuable tools in a wide range of applications such as diagnosis, treatment, and research.

*Corresponding Author Tel. No.: +234-703-5829-620.

e-mail: audu.moses@uam.edu.ng (Moses Owoicho Audu)

Cosmetic products are produced from both natural and synthetic materials. The ingredients used in the formulation of cosmetic products may pose health risks. Thus, the use of cosmetic products could contribute to human exposure to natural radioactivity (NRs) and heavy metals (HMs). Cosmetic products are applied on the face, body, lips, eyes, teeth, hands, nails, and hair generally to cleanse, improve or change the appearance [2].

It has been reported that radiation in the right proportion in cosmetic products “energizes” the skin thereby making it look younger [3] and references therein. Manufacturers of cosmetics and healthcare products incorporate radioactive substances to enhance their products. Radionuclides such as radium have been added to cosmetic products [3]. Therefore, the use of cosmetic products could contribute to human exposure to radiation, depending on the concentration of NRs in the products. This is, therefore, part of the basis for this research.

Similarly, HMs are essential ingredients in the formulation of cosmetics, as they are used as pigments, fillers, and preservatives. However, there are restrictions on their concentrations in cosmetic products. This is because an accumulation of these metals in the body over time poses significant potential toxicity to human health, thereby leading to severe health problems. To reduce the health risks associated with exposure to HMs, several regulating agencies such as the U.S. Food and Drug Administration (U.S. FDA) and the European Commission have set limits for HM concentrations in cosmetic products [4]. This shows that scientists are concerned about the concentrations of HMs in cosmetic products due to their health risks.

Some manufacturers may however, use substandard or even prohibited materials due to the current high exchange rate, taxation, inflation, and increase in the price of goods and services in the country; thereby producing low-quality products (including cosmetic products) which may endanger consumers’ health. This can only be ascertained if the products are assessed regularly, hence, the urgent need for this study. Thus, the purpose of this study is to determine the presence and concentrations of NRs and HMs in different brands of new locally made soaps commonly used in Benue State.

Several studies have investigated exposure to NRs or HMs focused mostly on food, water, soil and medication (i.e. through inhalation and ingestion) [5–8], with few studies on cosmetic products like soaps and powders which are applied directly on the skin [8–13]. Investigating HMs in soaps used in Akure, Ref. [14] suggested continuous vigilance of HMs content in soaps and detergents. [15] reported Pb concentration in the range of 6.4 – 22.4 $\mu\text{g/g}$ in soaps used in the district of Ciamis. Similar works were also carried out on HMs in cosmetic products (soaps) both within and outside the country [16, 17].

Studies on activity concentration of NRs (^{40}K , ^{238}U and ^{232}Th) and their potential health hazard in cosmetic products have not received much attention; as only a few researchers have considered NRs in cosmetic products [18, 19]. Thus, the need for this study, since NRs are used in the formulation of cosmetic products, as stated earlier. In order to update the general public on the NRs and HMs concentrations in locally made soaps, there is a need for regular assessment; especially brands of new products which have not been assessed. This is another research gap for this study.

2. MATERIALS AND METHODS

The following procedures were used in sample collection, preparation and analysis.

2.1. WASHING OF APPARATUS

All apparatus used were thoroughly cleaned to avoid contamination.

2.2. SAMPLE COLLECTION

Samples of soap (30 brands of bathing and washing soaps) used by babies, children, youths and the elderly were selected randomly. This sampling technique hopes to give better results as compared to the use of a questionnaire or other sampling techniques; since the sampled products are brands of new products in the market which most consumers may not have used before. It is pertinent to note that the samples selected are brands of soaps that are newly introduced into the market and may not have been certified by the Standards Organisation of Nigeria (SON). The samples are the commonly available soaps in the main markets in the state (i.e. Modern Market Makurdi, Otukpo main market, and Gboko main market). The sampled soaps and their production details are presented in Table 1.

Major ingredients listed on the soap labels include: sodium palmitata, sodium palmate, aloe vera, sodium chloride, hexyl, milk extract, glycerin, CI 12490, titanium dioxide, talc, shea butter, coconut oil, BHT, benzotriazolyl dodecyl P-cresol, camwood, palm oil, sea salt, citric acid, colour, vitamin E acetate, titanium dioxide, TFM: 55 - 60%, perfume, carrot extract, sodium sulphate, soap base. Other ingredients include honey, disodium distyrylbiphenyl disulfonate, cucumber extract, milk protein, mica, mineral oil, pentaerythrityl tetraditbutyl, water, hydroxyl hydrocinnamate, CI 74160, oud fragrance, EHDP, Papaya extract, sodium palm kernelate, lemon organic extract, glycerine, sodium silicate, EHDP, vegetable oil, Menthol, chloroxylenol-0.3%, tetrasodium EDTA, cocoa pod and palm bunch ash solution, vegetable soap noodles, SLES, benzyl alcohol, benzyl benzoate, citronellol, fragrance, papaya extract, stabilizers, sodium lauryl sulphate, titanium dioxide, sorbitol (moisturizing agents), coconut oil, shea butter, castor oil, caustic soda, dionized water, zinc oxide, turmeric pine oil, neem, Epsom salt, palm kernel oil, cassia alata, citrus acida, lemon extract, CI 77891, CI 11680, CI 77891, and sodium carbonate.

2.3. SAMPLE PREPARATION

The samples of soap were dried between 50 and 105 °C in a temperature-controlled oven. They were then ground with pestle and mortar made of porcelain into fine powder and sieved. The prepared samples were then used for radiological and HM analyses.

2.4. RADIONUCLIDE ANALYSIS

About 320 g of each sample were weighed and sealed for at least 28 days in clean and uncontaminated air-tight random impermeable plastic containers. The activity concentrations of radionuclides in the samples were analyzed using NaI(Tl) detector at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan.

Table 1. Locally produced soaps used in this study.

S/No	Sample	Code	Producer	Place of production	Production date	Expiry date	Weight
1	Mama Joy Multi-purpose soap	S01	Mamuda Care Nig. Ltd	Kano, Kano State	09-2024	08-2027	300 g
2	Niceone	S02	UR Home Industries	Igbesa, Ogun State	06-2024	06-2027	250 g
3	Fizz Multi-purpose	S03	Aspira Nig. LTD	Kano, Kano State	11-2023	11-2025	400 g
4	Baby & me Multi-purpose soap	S04	Aspira Nig. LTD	Kano, Kano State	05-2024	05-2025	200 g
5	Too clean Multi-purpose soap	S05	Mamuda Care Nig. Ltd	Kano, Kano State	05-2023	05-2025	250 g
6	Canoe Extra care	S06	PZ Cussons Nig. Ltd	Aba, Abia State	05-2024	05-2027	230 g
7	Home fresh	S07	–	Amuwo, Lagos State	09-2024	08-2027	250 g
8	UNIK Four seasons	S08	Evans Industries Ltd	Ikeja, Lagos State	03-2023	03-2025	150 g
9	Fressia macho	S09	Daraju Industries Ltd	Ota, Ogun State	01-2024	12-2025	140 g
10	Family care	S10	Aspira Nig. LTD	Kano, Kano State	03-2023	10-2026	200 g
11	Freshglow Moisturizing bar	S11	Godrej Nig. Ltd	Ikeja, Lagos State	07-2024	06-2027	150 g
12	Nova Love your skin	S12	Mamuda Care Nig. Ltd	Kano, Kano State	05-2023	04-2026	150 g
13	Joy beauty bar Moisturises	S13	PZ Cussons Nig. Ltd	Aba, Abia State	31-01-2024	29-01-2027	140 g
14	Diva Moisturising beauty bar	S14	Golden soap industries Ltd	Kano, Kano State	03-2023	04-2025	150 g
15	Hala Beauty soap	S15	Givanas Industry Nig. Ltd	Amuwo, Lagos State	02-2024	01-2027	150 g
16	Mama's love	S16	Mamuda Care Nig. Ltd	Kano, Kano State	06-2024	05-2027	150 g
17	She Beauty soap	S17	Mamuda Care Nig. Ltd	Kano, Kano State	02-2024	01-2027	80 g
18	Lyday Toilet bar	S18	Dops Products Ltd	Ojota, Lagos State	06-2023	05-2026	200 g
19	Bea Complex care soap	S19	Saso Industries Ltd	Amuwo Odofin, Lagos State	02-2023	01-2026	140 g
20	Siri Forever young	S20	Aspira Nig. LTD	Kano, Kano State	07-2024	07-2027	150 g
21	Classy Soft & gentle	S21	Mamuda Care Nig. Ltd	Kano, Kano State	09-2024	08-2027	180 g
22	Zinc + castor oil soap	S22	Jim Products Ltd	Sango-Otta, Ogun State	10-22	10-24	60 g
23	Neem soap	S23	Jim Products Ltd	Sango-Otta, Ogun State	10-2022	10-2024	30 g
24	Noble tablet soap	S24	Noble Bright Nig. Ltd	Ikeja, Lagos State	09-2024	08-2027	80 g
25	Ghana soap	S25	–	Olaogun, Ogun State	–	–	200 g
26	Black native soap	S26	–	Olaogun, Ogun State	–	–	200 g
27	Supreme	S27	Godrej Nig. Ltd	Ikeja, Lagos State	08-2024	07-2027	170 g
28	Kampe Multipurpose soap	S28	Pure Hyginen Ltd	Isolo, Lagos State	04-2024	09-2027	200 g
29	Waw soap	S29	Expand Global Industries Ltd	Ibadan, Oyo State	01-2023	01-2026	80 g
30	Zee Black soap	S30	Alcanah LTD	Ibadan, Oyo State	09-22	08-2027	85 g

2.5. HEAVY-METAL ANALYSIS

About 10.0 g of each sample (in triplicate) were weighed into a 300 mL calibrated digestion tube. Exactly 6 mL of concentrated HNO₃ was added (in the fume hood) and swirled carefully and the tubes were placed in the rack. The tube racks were then placed in block-digester and a glass funnel was placed on the neck of the tubes. The temperature of the setting was then increased slowly to about 145 °C for 1 hour. About 8 mL of concentrated perchloric acid, HClO₄ were then added and then heated to about 240 °C for a further 1 hour.

The tube racks were removed from the block digester and placed on the rack holder, and allowed to cool to room temperature. It was filtered through Whatman No. 42 filter paper and

diluted up to 100 mL with deionized water and then packaged in sample bottles for HM analysis. The sample solutions were then analyzed for HMs using an Atomic Absorption Spectrophotometer (Buck Scientific: MODEL 210 VGP) at Federal University, Wukari. Each sample was analyzed for Ni, Pb, Cr, Cd, and Co following standard procedures.

2.6. QUALITY ASSURANCE AND QUALITY CONTROL MEASURES FOR HM ANALYSIS

Calibration curve with different concentrations for Ni, Pb, Co, Cr, and Cd were prepared. The working conditions for HMs determination using AAS is shown in Table 2.

The analytical method was validated employing limit of de-

tection (LOD) and limit of quantification (LOQ) as validation parameters. The LOD and LOQ for each metal were determined using equations (1) and (2), respectively [7]. See Ref. [7] and references therein for details on LOD and LOQ.

$$\text{LOD} = 3 \times SD, \quad (1)$$

$$\text{LOQ} = 10 \times SD, \quad (2)$$

where SD is the standard deviation of the method blank solution.

3. HEALTH RISK ASSESSMENT

Health risk of consumers due to exposure to radiation and HMs were assessed employing the following empirical models [18, 20].

3.1. HEALTH RISK ASSESSMENT DUE TO EXPOSURE TO RADIATION

The health risks resulting from exposure to radiation were assessed using the following radiological hazard indices or parameters:

3.1.1. Absorbed dose rate (D)

The absorbed dose rate (D) in nGy h^{-1} was computed using [21, 22]:

$$D = 0.462C_U + 0.604C_{Th} + 0.0417C_K. \quad (3)$$

3.1.2. Annual effective dose equivalent (AEDE)

The annual effective outdoor dose ($AEDE_{out}$) in mSv y^{-1} was estimated using the expressions [21]:

$$AEDE_{out} = D (\text{nGy h}^{-1}) \times 24 \text{ h} \times 365.25 \text{ d} \\ \times 0.2 \times 0.7 \text{ Sv Gy}^{-1} \times 10^{-3}. \quad (4)$$

3.1.3. Excess lifetime cancer risk (ELCR)

The Excess Lifetime cancer risk (ELCR) was estimated using equation (5) [21]:

$$ELCR = AEDE_{out} (\text{mSv y}^{-1}) \times DL \times RF (\text{Sv}^{-1}), \quad (5)$$

where DL and RF are mean life span (70 years) and Risk Factor (Sv^{-1}) given as 0.05 for the public [21].

3.1.4. Radium equivalent (Ra_{eq})

Radium Equivalent (Ra_{eq}) was estimated using equation (4) [22, 23].

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K. \quad (6)$$

3.1.5. Annual gonadal equivalent dose (AGED)

The AGED in mSv y^{-1} is concerned with the effect of radiation on bone marrow and the bone surface cells which may lead to cancer of the blood called leukaemia. It is measured in mSv y^{-1} . The AGED for the samples under study were estimated from equation (5) [21, 24].

$$AGED = 3.09C_U + 4.18C_{Th} + 0.314C_K. \quad (7)$$

Table 2. Mean concentrations and relative standard deviations of metals determined in the sampled soaps.

Metal	Mean (ppm)	SD	LOD (ppm)	LOQ (ppm)	RSD (%)
Pb	5.800	0.00040	0.0012	0.012	0.0068
Cd	1.000	0.00033	0.0010	0.010	0.0333
Cr	0.028	0.00033	0.0010	0.010	1.1904
Ni	1.000	0.00033	0.0010	0.010	0.0333
Co	0.028	0.00033	0.0010	0.010	1.1904

3.1.6. Radioactivity level index (I_γ)

The radioactivity level index (I_γ) value is less than or equal to unity. The I_γ was calculated using the expression [21]:

$$I_\gamma = \frac{C_U}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500}. \quad (8)$$

3.1.7. External hazard index (H_{ex})

External Hazard Index (H_{ex}) is given as [18].

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810}. \quad (9)$$

3.1.8. Internal hazard index (H_{in})

The internal hazard index (H_{in}) is given as [18]:

$$H_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}. \quad (10)$$

From equations (1) – (8), C_U , C_{Th} , and C_K are radionuclide concentrations (Bq kg^{-1}) of U-238, Th-232 and K-40, respectively.

3.2. HEALTH RISK ASSESSMENT DUE TO EXPOSURE TO HEAVY METALS

Health risk due to exposure to metallic impurities in samples was assessed using the following expressions [20]:

3.2.1. Margin of safety (MoS)

The margin of safety (MoS) is used to assess health risk of humans due to exposure to HM impurities present in the cosmetics. It is expressed as: [25]:

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

where NOAEL is No Observed Adverse Effect Level and SED is Systemic Exposure Dosage express as:

$$NOAEL = RfD \times UF \times MF, \quad (12)$$

where UF and MF are the uncertainty and modifying factors with default values of 100 and 1, respectively, while RfDs is the dermal reference doses for Cd, Co, Cr, Ni and Pb are 1×10^{-3} , 3×10^{-4} , 3×10^{-3} , 2×10^{-2} and $4 \times 10^{-3} \text{ mg kg}^{-1} \text{ d}^{-1}$, respectively [26, 27].

3.2.2. Systemic exposure dose (SED)

The systemic exposure dose (SED) is expressed as [20]:

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

where C_s is concentration of metal in the soap (ppm), AA daily quantity of soap applied (20 g), SSA is the skin surface area

Table 3. Working conditions for heavy-metal determination using AAS.

Parameter	Cd	Co	Cr	Ni	Pb
Wavelength (nm)	228.9	240.7	357.9	232	217
Slit width (nm)	0.7	0.2	0.7	0.2	0.7
Detection limit (mg/l)	0.01	0.05	0.04	0.05	0.04
Lamp current (mA)	10	20	20	20	15
Linear range (mg/l)	2.00	5.00	5.00	4.00	10.00
Flame type (colour)	A–A Lean/blue	A–A Lean/blue	A–A Lean/blue	A–A Rich/yellow	A–A Lean/blue

Table 4. Activity concentrations of ⁴⁰K, ²³⁸U, and ²³²Th and radiological health-risk indices.

Code	⁴⁰ K (Bq/Kg)	²³⁸ U (Bq/Kg)	²³² Th (Bq/Kg)	D nGyh ⁻¹	AEDE mSvy ⁻¹	Ra _{eq} BqKg ⁻¹	H _{ex}	H _{in}	Iy	AGED mSvy ⁻¹	ELCR ×10 ⁻³
S01	117.34±6.39	22.8±2.13	38.87±2.99	38.90	0.048	87.42	0.24	0.30	0.619	269.77	0.14
S02	199.53±10.84	4.52±0.46	8.23±0.47	15.38	0.019	31.65	0.09	0.10	0.245	111.02	0.06
S03	BDL	16.52±1.18	5.36±0.30	–	–	–	–	–	–	–	–
S04	37.87±2.06	3.33±0.35	24.56±1.39	17.95	0.022	41.37	0.11	0.12	0.293	124.84	0.07
S05	45.01±2.45	6.68±0.69	19.84±1.12	16.95	0.021	38.52	0.10	0.12	0.273	117.71	0.06
S06	133.91±7.30	14.22±1.50	63.93±3.61	50.77	0.062	115.95	0.31	0.35	0.823	353.21	0.19
S07	BDL	36.99±3.26	30.38±1.72	–	–	–	–	–	–	–	–
S08	137.92±7.50	2.13±0.21	14.62±0.83	15.57	0.019	33.66	0.09	0.10	0.252	111.00	0.06
S09	136.71±7.44	31.54±2.95	43.21±2.45	46.37	0.057	103.86	0.28	0.37	0.734	321.00	0.17
S10	160.25±8.71	BDL	38.51±2.18	–	–	–	–	–	–	–	–
S11	142.2±7.95	12.71±0.92	33.88±1.88	32.27	0.040	72.11	0.19	0.23	0.518	225.54	0.12
S12	94.99±5.07	35.87±2.53	54.27±3.01	53.31	0.065	120.79	0.33	0.42	0.845	367.51	0.20
S13	133.52±7.26	13.71±1.32	70.51±3.40	54.49	0.067	124.82	0.34	0.37	0.886	379.02	0.20
S14	117.57±6.28	9.41±0.66	48.48±2.69	38.53	0.047	87.79	0.24	0.26	0.626	268.64	0.14
S15	177.83±9.49	5.05±0.36	29.05±1.61	27.29	0.033	60.28	0.16	0.18	0.443	192.87	0.10
S16	141.79±7.57	19.75±1.40	41.39±2.29	40.04	0.049	89.86	0.24	0.30	0.640	278.56	0.15
S17	30.57±1.66	17.51±1.79	9.09±0.52	14.85	0.018	32.86	0.09	0.14	0.228	101.70	0.05
S18	172.95±9.23	4.12±0.29	48.75±2.70	38.56	0.047	87.15	0.24	0.25	0.630	270.81	0.14
S19	112.9±6.03	11.11±0.80	12.68±0.70	17.50	0.021	37.94	0.10	0.13	0.276	122.78	0.06
S20	241.07±13.12	40.84±3.74	34.32±1.94	49.65	0.061	108.48	0.29	0.40	0.776	345.35	0.18
S21	138.66±7.40	2.53±0.18	23.36±1.29	21.06	0.026	46.61	0.13	0.13	0.343	149.00	0.08
S22	110.49±5.90	5.25±0.39	25.77±1.43	22.60	0.028	50.61	0.14	0.15	0.366	158.63	0.08
S23	237.23±12.67	9.82±0.69	50.03±2.77	44.65	0.055	99.63	0.27	0.30	0.724	313.96	0.16
S24	47.95±2.61	2.55±0.24	15.53±0.88	12.56	0.015	28.45	0.08	0.08	0.204	87.85	0.05
S25	2770.11±148.18	1.87±0.19	66.07±3.75	156.28	0.192	309.65	0.84	0.84	2.520	1151.77	0.58
S26	3841.15±203.96	30.87±2.19	60.07±3.33	210.72	0.259	412.54	1.11	1.20	3.367	1552.60	0.78
S27	151.36±8.24	2.13±0.21	14.7±0.83	16.17	0.020	34.81	0.09	0.10	0.262	115.55	0.06
S28	117.79±6.42	6.68±0.71	35.18±1.99	29.25	0.036	66.06	0.18	0.20	0.475	204.68	0.11
S29	5197.23±277.42	347.41±24.65	998.23±55.28	980.16	1.203	2175.07	5.87	6.81	15.763	6878.03	3.61
S30	540.81±29.34	0.59±0.06	56.47±3.18	56.93	0.070	122.98	0.33	0.33	0.929	407.68	0.21

BDL=below detectable limit

for which the soap was applied (860 cm²), *F* is the application frequency (2), *RF* is the retention factor (0.01), *BF* is the bio-accessibility factor, 10⁻³ is the unit conversion factor, and *BW* is the mean body weight for adult (60 kg) and children (16 kg) [20, 28].

3.2.3. Hazard quotient (HQ)

The expression for the HQ is given in equation (11) [20]:

$$HQ = \frac{SED}{RfD}, \tag{14}$$

where *RfD* is the dermal reference dose.

3.2.4. Carcinogenic risk

Carcinogenic risk is computed for carcinogenic metals from the SED and SF. Equation (12) was used to estimate the carcinogenic risk for each sample [20]:

$$\text{Carcinogenic risk} = SED \times SF, \tag{15}$$

where *SF* is carcinogenicity slope factor (mg kg⁻¹ d⁻¹). The values of *SF* are 6.7, 0.5, 0.91 and 0.0085 for Cd, Cr, Ni and Pb, respectively [20].

The results obtained from equations (3)–(15) were used to draw conclusions about the nature and extent of the risk from exposure to radiation and HMs in these products.

4. RESULTS AND DISCUSSION

4.1. QUALITY ASSURANCE AND QUALITY-CONTROL MEASURES FOR HM ANALYSIS

Table 2 presents the quality control parameters of HMs (Pb, Cd, Cr, Ni and Co) in the surveyed soaps. The relative standard deviation (R.S.D.), limit of detection (LOD), and limit of quantification (LOQ) of HMs determined in the sampled soaps ranged from 0.006 % to 1.190 %, 0.001 to 0.0012 ppm, and 0.01 to 0.012 ppm, respectively. The observed values for LOD and LOQ are relatively low for detecting and quantifying AAS sensitive to the HMs in the sampled soaps [7]. R.S.D., LOD, and LOQ are qual-

Table 5. Mean concentrations of heavy metals in the sampled soaps.

Code	Ni (ppm)	Pb (ppm)	Co (ppm)	Cr (ppm)	Cd (ppm)
S01	0.100±0.001	0.370±0.001	0.007±0.001	0.006±0.002	0.0202±0.001
S02	0.300±0.002	0.494±0.001	0.010±0.002	0.007±0.002	0.0128±0.001
S03	0.200±0.001	0.370±0.001	0.010±0.002	0.001±0.001	0.0092±0.001
S04	0.100±0.001	0.432±0.001	0.005±0.001	0.003±0.001	0.0110±0.002
S05	0.100±0.001	0.247±0.001	0.008±0.001	0.002±0.001	0.0110±0.002
S06	0.200±0.001	0.124±0.001	0.028±0.002	0.002±0.001	0.0110±0.002
S07	0.100±0.002	0.124±0.001	0.014±0.002	0.001±0.001	0.0073±0.001
S08	0.200±0.001	0.432±0.001	0.012±0.002	0.002±0.001	0.0110±0.002
S09	0.200±0.001	0.308±0.001	0.014±0.002	0.001±0.001	0.0073±0.001
S10	0.200±0.001	0.679±0.002	0.014±0.002	0.001±0.001	0.0092±0.001
S11	0.100±0.001	0.247±0.001	0.004±0.001	0.006±0.002	0.0128±0.002
S12	0.200±0.002	0.370±0.001	0.004±0.001	0.010±0.002	0.0110±0.002
S13	0.200±0.001	0.309±0.001	0.008±0.001	0.004±0.001	0.0037±0.001
S14	0.200±0.002	0.617±0.002	0.003±0.001	0.004±0.001	0.0073±0.001
S15	0.400±0.002	0.679±0.001	0.027±0.002	0.001±0.001	0.0164±0.002
S16	0.300±0.002	0.309±0.001	0.007±0.001	0.002±0.001	0.0055±0.001
S17	0.200±0.001	1.049±0.002	0.005±0.001	0.001±0.001	0.0073±0.001
S18	0.200±0.001	0.370±0.001	0.010±0.002	0.002±0.001	0.0037±0.001
S19	0.200±0.001	0.494±0.001	0.024±0.002	0.001±0.001	0.0128±0.002
S20	0.200±0.002	0.247±0.001	0.034±0.002	0.001±0.001	0.0037±0.001
S21	0.100±0.001	0.494±0.001	0.018±0.002	0.004±0.001	0.0055±0.001
S22	0.100±0.001	0.741±0.002	0.007±0.001	0.005±0.002	0.1154±0.002
S23	0.100±0.001	0.556±0.001	0.003±0.001	0.004±0.001	0.0165±0.002
S24	0.200±0.001	0.432±0.001	0.008±0.001	0.010±0.002	0.0128±0.002
S25	0.100±0.001	0.309±0.001	0.017±0.002	0.002±0.001	0.0202±0.002
S26	0.100±0.001	0.185±0.001	0.029±0.002	0.002±0.001	0.0128±0.002
S27	0.100±0.001	0.370±0.001	0.024±0.002	0.006±0.002	0.0092±0.001
S28	0.200±0.002	1.235±0.002	0.007±0.001	0.004±0.001	0.0110±0.002
S29	0.200±0.002	0.741±0.002	0.023±0.002	0.004±0.001	0.0183±0.002
S30	0.200±0.001	0.864±0.001	0.010±0.001	0.002±0.001	0.0092±0.001
WHO/U.S. FDA	0.600	10.00	1.00	5.00	0.300

WHO = World Health Organization; U.S. FDA = U.S. Food and Drug Administration.

ity control parameters observed in metal analysis. The values reported varied from one research to another based on the surveyed samples. The R.S.D., LOD, and LOQ reported by [7] on HMs levels in palm oil used in Kogi State Nigeria ranged from 0.054 to 1.37 %, 0.0561 to 0.138 ppm, and 0.187 to 0.460 respectively. These values are, however, higher than that observed in this study.

The R^2 values of the calibration lines for Ni, Pb, Co, Cr, and Cd observed are 0.9978, 0.9935, 0.9987, 0.9980, and 0.9975, respectively (Table 3). This is consistent with the range value of R^2 (0.9995 - 0.9999) reported by [17] and 0.9897 - 0.9991 by [28] from their study of HMs in soaps used in Nigeria.

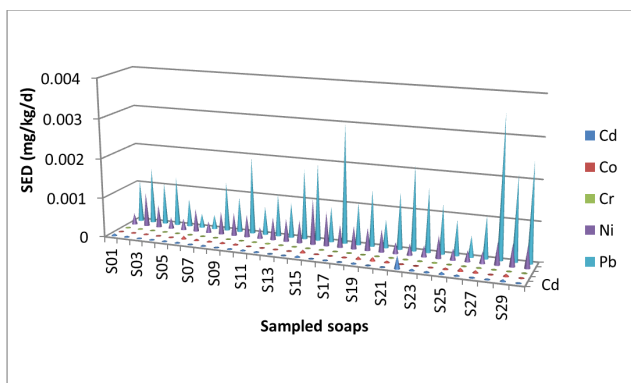
4.2. MEAN ACTIVITY CONCENTRATIONS OF NRS AND HEALTH-RISK ASSESSMENT

It could be observed from Table 4 that mean activity concentrations of ^{40}K , ^{238}U and ^{232}Th in most of the sampled soaps are below the acceptable limits for ^{238}U (50 Bq kg^{-1}), ^{232}Th (50 Bq kg^{-1}), and ^{40}K (500 Bq kg^{-1}) in cosmetic products [29]. Mean activity concentrations of ^{40}K (S25, S26, S29 and S30), ^{238}U (S29) and ^{232}Th (S12, S13, S25, S26, S29 and S30) are, however, above the limits. Another notable observation is that ^{238}U was below the detectable limit (BDL) in S10. Similarly, ^{232}Th in S03 and S07 are BDL. This shows that exposure to some of the

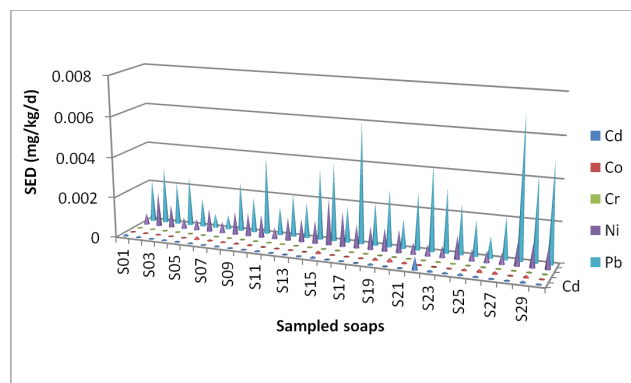
soaps poses no radiological health hazard.

It is pertinent to note that mean activity concentrations of ^{40}K and ^{232}Th in S25 (2770.11±148.18 and 66.07±3.75 Bq kg^{-1}) and S26 (3841.15±203.96 and 60.07±3.33 Bq kg^{-1}) are far above the acceptable limits. Similarly, mean activity concentrations of ^{40}K , ^{238}U and ^{232}Th in S29 (5197.23±277.42, 347.4124.65 and 998.23±55.28 Bq kg^{-1}) are also far above the limit. The high NRs observed could be attributed to the raw materials used as ingredients in the formulation of the soaps. This indicates that S25, S26, and S29 pose a higher health risk. Worthy of mention is that S25 and S26 have no label that indicate ingredients used in the formulation, unlike S29. This suggests for stricter regulation by the concerned agencies.

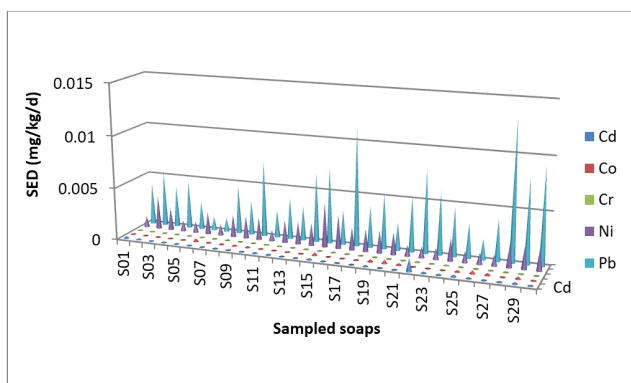
Mean activity concentration of ^{40}K , ^{238}U and ^{232}Th observed by [18] in their study on radionuclide concentration levels in some locally produced soaps in Nigeria (Lux, Septol, Premier, Dettol, and Dudu Osun) were 97.0±24.5, 29.7±9.1 and 40.4±13.9 Bq kg^{-1} , respectively. This agrees with the results of NRs observed in this study, except for few samples. The internal hazard index (H_{in}) and external hazard index (H_{ex}) observed are below the acceptable limit of unity, except in S29. This shows that the surveyed soaps pose no health risk (except in S29). Similarly, Radium equivalent dose (Ra_{eq}) observed are below the safe limit of 370 Bq kg^{-1} except in S29 (2175.07 Bq kg^{-1}). This is



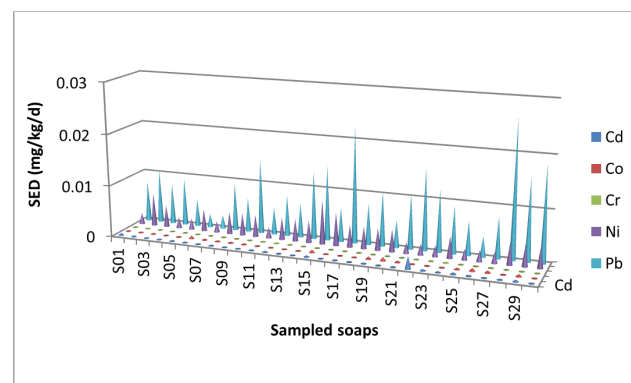
(a) Adults, 50% bio-accessibility



(b) Adults, 100% bio-accessibility



(c) Children, 50% bio-accessibility



(d) Children, 100% bio-accessibility

Figure 1. Systemic exposure dose (SED) for adults and children at 50% and 100% bio-accessibility for the soap samples.

consistent with the range (93.1 ± 21.1 to 246 ± 24.1 Bq kg⁻¹) and mean (134.7 ± 22.74 Bq kg⁻¹) of $R_{a_{eq}}$ reported by [18] in some local Nigerian soaps.

Furthermore, the Absorbed Dose Rate (D) observed is above the safe limit of 59 nGy h⁻¹ in few samples (S25, S26, and S29). Similarly, the hazardous indices (H_{ex} and H_{in}) are above the safe limit of unity in S26 and S29. The Radioactivity Level Index (I_{γ}), Annual Gonadal Equivalent Dose (AGED), and Annual Effective Dose Equivalent (AEDE) were relatively low for most of the sampled soaps. The carcinogenic risk obtained is below the safe limit (10^{-6} – 10^{-4}) for cosmetic products. Generally, the observed health risk due to exposure to the NRs in the surveyed soaps indicates negligible non-carcinogenic or carcinogenic risk. The health risk assessment due to exposure to NRs in the surveyed soaps generally indicates negligible non-carcinogenic or carcinogenic risk.

4.3. MEAN CONCENTRATIONS OF HMS IN THE SAMPLED SOAPS

Mean concentration of HMs (Ni, Pb, Co, Cr, and Cd) in the sampled soaps is presented in Table 5. Notable observation is the presence of Ni, Pb, Co, Cr, and Cd at varying concentrations in all the samples. It could be observed that the mean concentration of Ni, Pb, Co, Cr, and Cd are 0.177 ± 0.002 , 0.473 ± 0.002 , 0.013 ± 0.002 , 0.003 ± 0.001 , and 0.014 ± 0.002 ppm, respectively (Table 5). These values are below the recommended safe limit for Ni (0.60 ppm), Pb (10.00 ppm), Co (1.00 ppm), Cr (5.00

ppm), and Cd (0.300 ppm); set by the WHO (World Health Organisation) and U.S. FDA (U.S. Food and Drug Administration) [29]. This implies that the surveyed soaps are safe and pose no danger except in prolonged exposure, due to accumulation of HMs. The highest concentration of Ni (0.400 ± 0.002 ppm), Pb (1.235 ± 0.002 ppm), Co (0.034 ± 0.002 ppm), Cr (0.010 ± 0.002 ppm), and Cd (0.115 ± 0.002 ppm) were observed in S15, S28, S20, S12, and S22.

The results observed were compared with earlier findings of Ref. [14] who reported mean concentration of Pb, Ni and Cr as 3.78 ± 1.31 , 2.20 ± 0.50 and 1.33 ± 0.61 mg/kg, respectively while Cd was not detected (ND) in the indigenous soaps (Kasimu, Septol, Imperial, Black, Lux, Joy, Canoe, Premier, USA, Soda, S.T., and Zentel). Similarly, Ref. [28] reported mean concentration of Pb and Cd in local soaps produced from cocoa pods as 22.57 ± 0.42 µg/g and 4.72 ± 0.35 µg/g and from palm bunches as 15.03 ± 0.06 µg/g and 4.51 ± 0.21 µg/g, respectively. These values are above the mean concentration of Pb and Cd observed in this study.

Similarly, HMs concentrations reported by [17] in seven Nigeria bar soaps (Soda white, Canoe extra care, Soda blue, Klin soap, B29 soap, Canoe quality, and Black native soap) are Cd (0.6 ± 0.2 – 2.2 ± 0.1 µg/g), Pb (0.5 ± 0.0 - 15.5 ± 0.0 µg/g), Cr (ND – 43.7 ± 0.7 µg/g), Co (2.0 ± 0.2 – 7.0 ± 0.0 µg/g), and Ni (5.0 ± 1.4 – 11.5 ± 1.0 µg/g) are also above the mean concentration observed in this study except in Pb. Ref. [30] observed mean concentrations for Cd (0.006 – 1.422 ppm), Cr (0.000 – 1.427 ppm), Ni

Table 6. Margin of safety (MoS) for adults in the sampled soaps.

Code	Ni (50%)	Pb (50%)	Co (50%)	Cr (50%)	Cd (50%)	Ni (100%)	Pb (100%)	Co (100%)	Cr (100%)	Cd (100%)
S01	6976.74	377.12	1495.02	17441.86	1726.92	3488.37	188.56	747.51	8720.93	863.46
S02	2325.58	282.46	1046.51	14950.17	2725.29	1162.79	141.23	523.26	7475.08	1362.65
S03	3488.37	377.12	1046.51	104651.16	3791.71	1744.19	188.56	523.26	52325.58	1895.85
S04	6976.74	323.00	2093.02	34883.72	3171.25	3488.37	161.50	1046.51	17441.86	1585.62
S05	6976.74	564.92	1308.14	52325.58	3171.25	3488.37	282.46	654.07	26162.79	1585.62
S06	3488.37	1125.28	373.75	52325.58	3171.25	1744.19	562.64	186.88	26162.79	1585.62
S07	6976.74	1125.28	747.51	104651.16	4778.59	3488.37	562.64	373.75	52325.58	2389.30
S08	3488.37	323.00	872.09	52325.58	3171.25	1744.19	161.50	436.05	26162.79	1585.62
S09	3488.37	453.04	747.51	104651.16	4778.59	1744.19	226.52	373.75	52325.58	2389.30
S10	3488.37	205.50	747.51	104651.16	3791.71	1744.19	102.75	373.75	52325.58	1895.85
S11	6976.74	564.92	2616.28	17441.86	2725.29	3488.37	282.46	1308.14	8720.93	1362.65
S12	3488.37	377.12	2616.28	10465.12	3171.25	1744.19	188.56	1308.14	5232.56	1585.62
S13	3488.37	451.57	1308.14	26162.79	9428.03	1744.19	225.78	654.07	13081.40	4714.02
S14	3488.37	226.15	3488.37	26162.79	4778.59	1744.19	113.08	1744.19	13081.40	2389.30
S15	1744.19	205.50	387.60	104651.16	2127.06	872.09	102.75	193.80	52325.58	1063.53
S16	2325.58	451.57	1495.02	52325.58	6342.49	1162.79	225.78	747.51	26162.79	3171.25
S17	3488.37	133.02	2093.02	104651.16	4778.59	1744.19	66.51	1046.51	52325.58	2389.30
S18	3488.37	377.12	1046.51	52325.58	9428.03	1744.19	188.56	523.26	26162.79	4714.02
S19	3488.37	282.46	436.05	104651.16	2725.29	1744.19	141.23	218.02	52325.58	1362.65
S20	3488.37	564.92	307.80	104651.16	9428.03	1744.19	282.46	153.90	52325.58	4714.02
S21	6976.74	282.46	581.40	26162.79	6342.49	3488.37	141.23	290.70	13081.40	3171.25
S22	6976.74	188.31	1495.02	20930.23	302.29	3488.37	94.15	747.51	10465.12	151.14
S23	6976.74	250.96	3488.37	26162.79	2114.16	3488.37	125.48	1744.19	13081.40	1057.08
S24	3488.37	323.00	1308.14	10465.12	2725.29	1744.19	161.50	654.07	5232.56	1362.65
S25	6976.74	451.57	615.60	52325.58	1726.92	3488.37	225.78	307.80	26162.79	863.46
S26	6976.74	754.24	360.87	52325.58	2725.29	3488.37	377.12	180.43	26162.79	1362.65
S27	6976.74	377.12	436.05	17441.86	3791.71	3488.37	188.56	218.02	8720.93	1895.85
S28	3488.37	112.98	1495.02	26162.79	3171.25	1744.19	56.49	747.51	13081.40	1585.62
S29	3488.37	188.31	455.01	26162.79	1906.21	1744.19	94.15	227.50	13081.40	953.11
S30	3488.37	161.50	1046.51	52325.58	3791.71	1744.19	80.75	523.26	26162.79	1895.85

Table 7. Margin of safety (MoS) for children in the sampled soaps.

Code	Ni (50%)	Pb (50%)	Co (50%)	Cr (50%)	Cd (50%)	Ni (100%)	Pb (100%)	Co (100%)	Cr (100%)	Cd (100%)
S01	1860.47	100.57	398.67	4651.16	460.51	930.23	50.28	199.34	2325.58	230.26
S02	620.16	75.32	279.07	3986.71	726.74	310.08	37.66	139.53	1993.36	363.37
S03	930.23	100.57	279.07	27906.98	1011.12	465.12	50.28	139.53	13953.49	505.56
S04	1860.47	86.13	558.14	9302.33	845.67	930.23	43.07	279.07	4651.16	422.83
S05	1860.47	150.64	348.84	13953.49	845.67	930.23	75.32	174.42	6976.74	422.83
S06	930.23	300.08	99.67	13953.49	845.67	465.12	150.04	49.83	6976.74	422.83
S07	1860.47	300.08	199.34	27906.98	1274.29	930.23	150.04	99.67	13953.49	637.15
S08	930.23	86.13	232.56	13953.49	845.67	465.12	43.07	116.28	6976.74	422.83
S09	930.23	120.81	199.34	27906.98	1274.29	465.12	60.40	99.67	13953.49	637.15
S10	930.23	54.80	199.34	27906.98	1011.12	465.12	27.40	99.67	13953.49	505.56
S11	1860.47	150.64	697.67	4651.16	726.74	930.23	75.32	348.84	2325.58	363.37
S12	930.23	100.57	697.67	2790.70	845.67	465.12	50.28	348.84	1395.35	422.83
S13	930.23	120.42	348.84	6976.74	2514.14	465.12	60.21	174.42	3488.37	1257.07
S14	930.23	60.31	930.23	6976.74	1274.29	465.12	30.15	465.12	3488.37	637.15
S15	465.12	54.80	103.36	27906.98	567.21	232.56	27.40	51.68	13953.49	283.61
S16	620.16	120.42	398.67	13953.49	1691.33	310.08	60.21	199.34	6976.74	845.67
S17	930.23	35.47	558.14	27906.98	1274.29	465.12	17.74	279.07	13953.49	637.15
S18	930.23	100.57	279.07	13953.49	2514.14	465.12	50.28	139.53	6976.74	1257.07
S19	930.23	75.32	116.28	27906.98	726.74	465.12	37.66	58.14	13953.49	363.37
S20	930.23	150.64	82.08	27906.98	2514.14	465.12	75.32	41.04	13953.49	1257.07
S21	1860.47	75.32	155.04	6976.74	1691.33	930.23	37.66	77.52	3488.37	845.67
S22	1860.47	50.21	398.67	5581.40	80.61	930.23	25.11	199.34	2790.70	40.30
S23	1860.47	66.92	930.23	6976.74	563.78	930.23	33.46	465.12	3488.37	281.89
S24	930.23	86.13	348.84	2790.70	726.74	465.12	43.07	174.42	1395.35	363.37
S25	1860.47	120.42	164.16	13953.49	460.51	930.23	60.21	82.08	6976.74	230.26
S26	1860.47	201.13	96.23	13953.49	726.74	930.23	100.57	48.12	6976.74	363.37
S27	1860.47	100.57	116.28	4651.16	1011.12	930.23	50.28	58.14	2325.58	505.56
S28	930.23	30.13	398.67	6976.74	845.67	465.12	15.06	199.34	3488.37	422.83
S29	930.23	50.21	121.33	6976.74	508.32	465.12	25.11	60.67	3488.37	254.16
S30	930.23	43.07	279.07	13953.49	1011.12	465.12	21.53	139.53	6976.74	505.56

(0.021 – 3.456 ppm), Zn (0.131 – 1.376 ppm), As (0.000 – 0.624 ppm), Cu (0.223 – 2.144 ppm), and Pb (0.000 – 0.135 ppm) in some cosmetic products; in concordant with the results observed

in this study.

Furthermore, among the sampled soaps, three soaps (Cano extra care, Black native soap, and Waw soap) were ear-

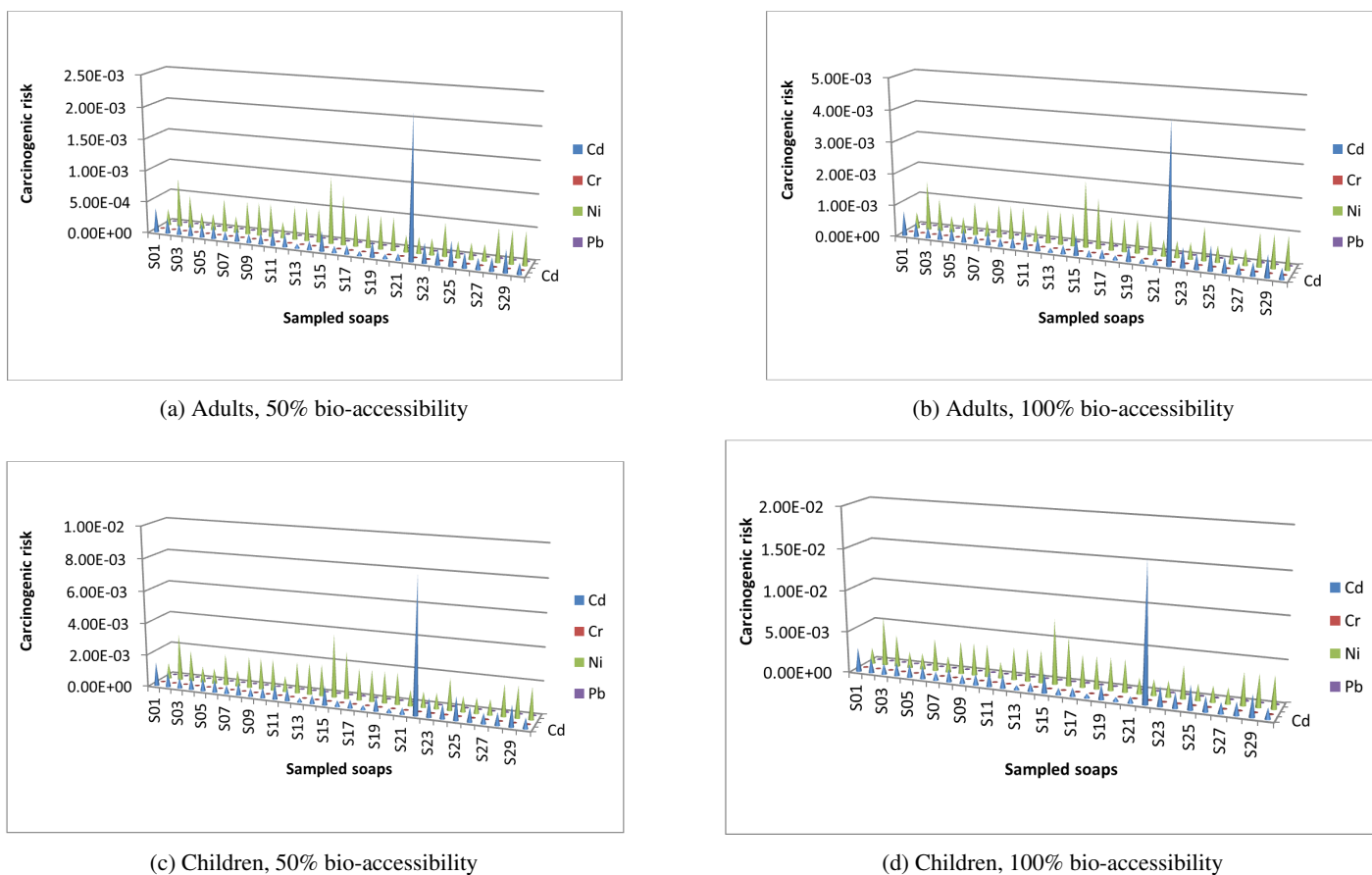


Figure 2. Carcinogenic risk for adults and children at 50% and 100% bio-accessibility for the soap samples.

lier studied by Ref. [17]. The concentration of Ni, Pb, Co, Cr, and Cd observed for Canoe extra care (11.5 ± 1.0 , 7.0 ± 1.5 , 3.0 ± 0.1 , ND, and $1.0 \pm 0.0 \mu\text{g/g}$), Black native soap (5.0 ± 1.4 , 15.5 ± 0.0 , 2.0 ± 0.6 , ND, and $1.7 \pm 0.1 \mu\text{g/g}$), and Waw soap (7.0 ± 1.2 , 2.0 ± 0.5 , 2.0 ± 0.2 , 33.2 ± 0.8 , and $1.6 \pm 0.1 \mu\text{g/g}$) by Ref. [17] are all above the concentrations of Ni, Pb, Co, Cr, and Cd observed for these soaps (S06, S26, and S29) in this study (Table 5). Significant reductions were observed in the HMs concentrations, which could indicate improvement in the quality of the soaps in recent years; because the soap samples used in their study were produced earlier than those used in the present study.

4.4. SYSTEMIC EXPOSURE DOSE (SED)

In evaluating the safety of the sampled soaps, this study assumed 50 % (as the mid-point scenario) and 100 % (as the worst-case scenario) systemic availability of the HMs under study [28]. It could be observed that SED for Cd, Co, Cr, Ni, and Pb at 50 % bio-accessibility for adults are in the range of 1.06×10^{-5} - 3.31×10^{-4} , 8.60×10^{-6} - 9.75×10^{-5} , 2.87×10^{-6} - 2.87×10^{-5} , 2.87×10^{-4} - 1.14×10^{-3} , and 3.55×10^{-4} - $3.54 \times 10^{-3} \text{ mg kg}^{-1} \text{ d}^{-1}$; while at 100 % bio-accessibility are 2.12×10^{-5} - 6.62×10^{-4} , 1.72×10^{-5} - 1.95×10^{-4} , 5.73×10^{-6} - 5.73×10^{-5} , 0.573×10^{-4} - 2.29×10^{-3} , and 7.11×10^{-4} - $7.08 \times 10^{-3} \text{ mg kg}^{-1} \text{ d}^{-1}$, respectively (Figure 1). Similarly, SED for Cd, Co, Cr, Ni, and Pb at 50 % bio-accessibility for children are 2.17×10^{-4} - 1.24×10^{-3} , 3.23×10^{-5} - 3.66×10^{-4} , 1.08×10^{-5} - 1.08×10^{-4} , 1.07×10^{-3} -

4.30×10^{-3} , and 1.33×10^{-3} - $1.32 \times 10^{-2} \text{ mg kg}^{-1} \text{ d}^{-1}$, while at 100 % bio-accessibility are 7.96×10^{-5} - 2.48×10^{-3} , 6.45×10^{-5} - 7.31×10^{-4} , 2.15×10^{-5} - 2.15×10^{-4} , 2.15×10^{-3} - 8.60×10^{-3} , and 2.66×10^{-3} - $2.65 \times 10^{-2} \text{ mg kg}^{-1} \text{ d}^{-1}$, respectively (Figure 1). The SED for adults at 100 % bio-accessibility in the sampled soaps is higher than at 50 % bio-accessibility, as expected. This is similar to the SED observed for children as shown in Figure 1. This is consistent with earlier reports on SED [20, 28].

4.5. MARGIN OF SAFETY (MOS)

Margin of safety (MoS) for adults and children in the sampled soaps at 50 % and 100 % bio-accessibility is shown in Table 6. Notable observation from Table 6 is the high values of MoS above the acceptable limit of 100 in all the samples at 50 % and 100 % bio-accessibility, except in S17, S22, S28, S29, and S30 at 100 % bio-accessibility. This indicates that there is no health risk from exposure to Ni, Co, Cr, and Cd at 50 % and 100 % bio-accessibility by adults. Health risk was not observed for Pb at 50 % bio-accessibility, however, MoS for Pb below the safe limit at 100 % bio-accessibility is 16.66 % (i.e. S17, S22, S28, S29, and S30).

Similarly, MoS for Ni and Cr at 50 % and 100 % bio-accessibility are above 100, indicating no health risk from exposure to Ni and Cr in these soaps by children. However, MoS for Pb, Co, and Cd are below the safe limits at 50 % bio-accessibility are 50.00 %, 10.00 %, and 3.33 %, while at 100

% bio-accessibility are 90.00 %, 30.00 %, and 3.33 %, respectively (Table 7). This implies that the health risk from exposure to Pb, Co, and Cd is higher in children, especially in the worst scenario (100 % bio-accessibility), than in adults.

4.6. CARCINOGENIC RISK

It is seen from Figure 2 that carcinogenic risk in the sampled soaps varied based on the carcinogenic HMs (Cd, Cr, Ni and Pb). Notable observation is that the carcinogenic risk for Cr and Pb at 50 % and 100 % bio-accessibility is above the recommended limit (10^{-6} – 10^{-4}). This implies no carcinogenic risk from exposure to Cd and Pb in the soaps. In the case of adults, the carcinogenic risk for Cd and Pb at 50 % bio-accessibility is above the acceptable limit except in S22 (2.22×10^{-3}) and S15 (1.04×10^{-3}), respectively. At 100 % bio-accessibility, only S22 (4.43×10^{-3}) in Cd and 63 % in Ni are above the safe limit.

Similarly, in the case of children, 20 % and 63 % of carcinogenic risk for Cd and Ni at 50 % bio-accessibility are above the limit, while 83 % and 100 % are above the limit at 50 % bio-accessibility, respectively. This suggests that carcinogenic risk from exposure to Cd and Ni varied at 50 % and 100 % bio-accessibility based on the sampled soaps. Another notable observation is the high carcinogenic risk in S22 from exposure to Cd above the acceptable limit at 50 % and 100 % bio-accessibility by adults and children. This shows that among the surveyed soaps, S22 pose a higher carcinogenic risk as compared to other samples.

This study has provided useful insight on human exposure to radiation and heavy metals which is of great concern to Physicists, Chemists, environmentalists, etc. and the general public in recent years. The insight from this study will promote the production and patronage of indigenous soaps. This will enhance the growth of micro, small and medium enterprises (MSMEs) in the country; thereby contributing immensely to Nigeria's economy.

5. CONCLUSION

The following conclusions were drawn from this study:

- The observed natural radionuclide concentrations and radiological indices indicate that most surveyed soaps pose no radiological health hazard to consumers, except for a few samples that exceeded the recommended radiological safety limits.
- Exposure to about 3% of the studied soaps poses radiological health risk, indicating a substantial improvement in the quality of indigenous soaps.
- The mean concentrations of Ni, Pb, Co, Cr, and Cd were below the recommended safe limits set by the WHO and U.S. FDA for heavy metals in cosmetic products. This indicates that the sampled soaps have no immediate potential health risk, except under prolonged exposure that could lead to HM accumulation.
- The margin of safety (MoS) indicates a higher health risk from HM exposure in children, especially under the worst-case scenario (100% bio-accessibility), than in adults.
- The carcinogenic risk from exposure to the sampled soaps varied according to the carcinogenic HMs (Cd, Cr, Ni, and Pb).
- Among the surveyed soaps, sample S22 posed the highest carcinogenic risk.

DATA AVAILABILITY

The data used for this study are available from the corresponding author upon reasonable request.

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References

- C. J. Mgbemere & C. P. Ononugbo, "Assessment of Radionuclides in some fruits from Niger Delta and it Risks", *Asian Journal of Research and Reviews in Physics*, **5** (2021) 2584-5992. <https://doi.org/10.9734/ajr2p/2021/v5i330167>.
- K. G. Sharma, J. Gadiya, & M. Dhanawat, "Textbook on cosmetic formulation", Kbuuk publications, Houston and Pothi.com, India, 2016, pp 59 – 90.
- Z. Hani, S. Hashim, H. Hassan, N. N. Yusof & D. A. Bradley, "Radioactive material in cosmetic and healthcare products: Regulatory controls. *Radiation Physics and Chemistry* **188** (2021) 109673. <https://doi.org/10.1016/j.radphyschem.2021.109673>.
- O. Idoko, S. Emmanuel, A. Salau & P. Obigwa, "Quality assessment on some soaps sold in Nigeria". *Nigerian Journal of Technology* **37** (2018) 1137 – 1140. <https://doi.org/10.4314/njt.v37i4.37>
- A. Koray, G. Akkaya, A. Kahraman, G. Kaynak & R. Baldik, "The Investigation of Radionuclide concentration in soil and Lifetime Cancer Risk Due to Gamma Radioactivity in Zonguldak, Turkey". *Acta Physica Polonica* **2017** (2016) 3 - 11. <https://doi.org/10.12693/APhysPolA.132.1122>.
- N. N. Jibirili & C. B.Eke, "Radionuclide Content in Yam Samples and Health Risks Assessment in Oguta Oil Producing Locality Imo State Nigeria". *International Journal of Physics Research and Applications* **4** (2021) 006 – 014. <https://doi.org/10.29328/journal.ijpra.1001034>.
- J. A. Egwumah, I. S. Eneji, R. A. Wuana, & A. U. Itodo, "Determination of heavy metals levels in Palm Oil obtained from Ankpa, Alamaboro and Dekina Local Government Areas of Kogi State, Nigeria". *FUAM Journal of Pure and Applied Science*, **3** (2023) 55 – 60. <https://www.fuamjpas.org/article/detail.php?id=aj0smfoa1fgu22ap>
- M. O. Audu, T. Sombo, M. J. Ogabo, I. O. Agada & C. C. Akoso, "Natural Radionuclide Distribution in Surface Soil and Water within Doma LGA, Nasarawa State-North Central Nigeria". *Asian Basic and Applied Research Journal* **7** (2025) 337 - 349. <https://doi.org/10.56557/abaarj/2025/v7i1178>.
- O. E. Orisakwe & J. O. Otaraku, "Metal concentrations in cosmetics commonly used in Nigeria", *The Scientific World Journal* **2013** (2013) 95963. <http://dx.doi.org/10.1155/2013/959637>.
- P. Dinake, O. Motswetla, T. T. Kereeditse & R. Kelebemang, "Assessment of level of heavy metals in Cosmetics", *Toxicology Research and Application* **7** (2023) 1 – 8. <http://dx.doi.org/10.1177/23978473231156620>.
- O. Gyamfi, J. Aboko, E. Ankapong, J. T. Marfo, N. Y. Awuah-Boateng, K. Sarpong, & E. Dartey, "A systematic review of heavy metals contamination in cosmetics", *Cutaneous and Ocular Toxicology* **43** (2024) 5–12. <https://doi.org/10.1080/15569527.2023.2268197>.
- M. F. Alam, M. Akhter, B. Mazumder, A. Ferdous, M. D. Hossain, N. C. Dafader, F. T. Ahmed, S. K. Kundu, T. Taheri & A. K. M. Atique Ullah, "Assessment of some heavy metals in selected cosmetics commonly used in Bangladesh and human health risk". *Journal of Analytical Science & Technology* **10** (2019) 1 – 8. <https://dx.doi.org/10.1186/s40543-018-0162-0>.
- M. O. Audu, J. N. Tsaviv, I. O. Agada, A. P. Achu & I. S. Eneji, "Health risk assessment of heavy metals and radiation exposure in locally produced cosmetic powders used in Benue State, Nigeria". *Communication in Physical Sciences* **12** (2025) 1929 -1948. <https://journalcps.com/index.php/volumes/article/view/680>.
- F. O. Abulude, M. O. Ogunkoya, R. F. Ogunleye, O. Emidun & A. I. Abulude, "Assessment of the content of Pb, Cd, Ni and Cr in soaps and deter-

- gents from Akure, Nigeria”. *Research Journal of Environmental Toxicology* **1** (2007) 102 – 104. <https://dx.doi.org/10.3923/rjet.2007.102.104>.
- [15] S. R. N. Endah & S. I. Surantaatmadja, “The Determination of Heavy Metals Level: Lead in Cosmetic Soap Preparation by Atomic Absorption Spectrophotometer (AAS)”. *IOP Conference Series: Journal of Physics* **1179** (2019) 012178. <https://iopscience.iop.org/article/10.1088/1742-6596/1179/1/012178>
- [16] A. Sani, M. B. Gaya & F. A. Abubakar, Determination of some heavy metals in selected cosmetic products sold in Kano Metropolis, Nigeria. *Toxicology Reports* **3** (2016) 866 – 869. <https://doi.org/10.1016/j.toxrep.2016.11.001>.
- [17] C. M. A. Iwegbue, O. S. Emakunu, B. Lari, E. Francis, F. E. Egbueze, G. O. Tesi, G. E. Nwajei & B. S. Martincigh, “Risk of human exposure to metals in some household hygienic products in Nigeria”. *Toxicology Reports* **6** (2019) 914 – 923. <https://doi.org/10.1016/j.toxrep.2019.08.014>.
- [18] A. H. Ojelabi, M. I. Lateef & B. H. Lawal, “Determination and comparative analyses of radionuclide concentration levels of some imported and local bathing soaps used in Nigeria”. *International Journal of Research* **5** (2018) 1012 – 1023. <https://journals.pen2print.org/index.php/ijr/article/view/16857/0>
- [19] K. S. Almugren, S. F. Abdul Sani, M. K. M. Azim, N. N. Ismail, M. U. Khandaker, S. J. Alsufyani, F. H. Alkallas, H. F. Almajid, D. A. Bradley & K. A. Naseer, “The presence of NORMs and toxic heavy metals in talcum baby powder”. *Journal of Radiation Research and Applied Sciences*, **16** (2023) 100660. <https://doi.org/10.1016/j.jrras.2023.100660>.
- [20] H. Arshad, Z. M. Mehmooda, M. H. Shahb & A. M. Abbasi, “Evaluation of heavy metals in cosmetic products and their health risk assessment”. *Saudi Pharmaceutical Journal*, **28** (2020) 779 – 790. <https://doi.org/10.1016/j.jsps.2020.05.006>.
- [21] G. O. Avwiri, C. P. Ononugbo & I. E. Nwokeoji, “Radiation hazard indices and excess lifetime cancer risk in soil, sediment and water around Mini-Okoro/Oginigba Creek, Port Harcourt, Rivers State, Nigeria”. *Comprehensive Journal of Environment and Earth Sciences* **3** (2014) 38-50. <https://journals.sagepub.com/doi/10.1177/11786302231224581>
- [22] S. A. Onjefu, A. N. I. Kauluma, M. Zivuku, E. Ejembi, R. H. Hamunyela & B. M. Tyobeka, “Assessment of radioactivity levels in shore sediments along the coastline of the Orange River, Oranjemund, Namibia”. *Heliyon*, **8** (2022): e10579. <https://doi.org/10.1016/j.heliyon.2022.e10579>.
- [23] E. O. Echewezoa, C. I. Nworiea, A. O. Ojobeagua, P. B. Otaha & I. J. Okoro, “Health risk assessment due to environmental radioactivity and heavy metal contamination at the central solid waste dumpsite in Ebonyi State, Nigeria”. *Journal of the Nigerian Society of Physical Sciences* **7** (2025) 2160. <http://dx.doi.org/10.46481/jnsps.2025.2160>.
- [24] A. I. Olanrewaju & G. O. Avwiri, “Quantification of Activity Concentrations and Radiation Hazard Indices in the Solid Minerals Exploration Fields of Benue State, Nigeria with Multivariate Statistical Approach”. *Advances in Research* **10** (2017) 1 - 13. <http://dx.doi.org/10.9734/AIR/2017/33432>.
- [25] Scientific Committee on Consumer Safety (SCCS), (2012). The scientific Committee on Consumer Safety (SCCS), The SCCS’s Notes of Guidance for Testing of Cosmetic Substances and Their Safety Evaluation (SCCS/1501/12), 8th Ed. (Scientific Committee on Consumer Safety, European Union, Belgium, 2012). The SCCS adopted this opinion at the 17th plenary meeting of 11 December, 2012. https://health.ec.europa.eu/publications/scs-notes-guidance-testing-cosmetic-ingredients-and-their-safety-evaluation-12th-revision_en
- [26] M. T. Bello-Hassan, T. A. Samuel & P. O. Emmanuel, “Health Risk Assessment of Heavy and Trace Metals in Personal Care Products in Nigeria”. *International Journal of Biochemistry Bioinformatics and Biotechnology Studies* **9** (2024) 22 – 32. <https://doi.org/10.37745/ijbbbs.15/vol9n12232>.
- [27] N. M. Mgbemena, I. Ilechukwu, O. U. Akoh & A. C. Adinnu, “Risk assessment of heavy metals in some commonly used cosmetics in Rivers State Nigeria. *Journal of Chemical Society of Nigeria* **49** (2024) 508 – 510. <https://doi.org/10.46602/jcsn.v49i3.986>.
- [28] J. A. O. Oyekunle, O. T. Ore, O. H. Ogunjumelo & M. S. Akanni, “Comparative chemical analysis of indigenous Nigeria soaps with conventional ones”. *Heliyon* **7** (2021) e06689. <https://doi.org/10.1016/j.heliyon.2021.e06689>.
- [29] M. E. Medhat, V. P. Singh & S. P. Shirmardi, “Determination of Lead and radioactivity in cosmetic products: hazard assessment”. *Nuclear Technology and Radiation Protection* **30** (2015) 219 - 224. <https://doi.org/10.2298/NTRP1503219M>.
- [30] J. M. Manu, S. Norah, F. Vincent & S. Francis, “Levels of Cd, Cr, Cu, Ni, Zn, As and Pb in Some Cosmetic Products in Jimeta – Yola Modern Market, Adamawa State, Nigeria”. *Journal of Applied Sciences and Environmental Management* **27** (2023) 1739 - 1743. <https://dx.doi.org/10.4314/jasem.v27i8.18>.