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ARTICLE

Dose Measurement and Cancer Risk from Natural Radioactivity in Cleaning Powders at Kurdistan Markets, Iraq

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Abstract: The Kurdistan region of Iraq has seen a rise in the use of cleaning powders due to their favorable effects on health. However, various levels of radioactive isotopes, including ^{238}U, ^{232}Th, and ^{40}K, can be found in the ore used to make some cleaning powders. Therefore, washing powder is regarded as one of the environmental sources of radionuclides and radioactivity. In this study, 25 samples of ordinary cleaning powder were analyzed to estimate the specific activities of ^{238}U, ^{232}Th, and ^{40}K using a gamma-ray sodium iodide NaI(Tl) detector. The mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were found to be 0.27±0.027, 1.881±0.149, and 19.213±0.899 Bq.kg^{-1}, respectively, which are well below the recommended values set by UNSCEAR 2000: 32, 45, and 400 Bq/kg for ^{238}U, ^{232}Th, and ^{40}K, respectively. The radiological hazard parameters determined for each sample of detergent were also found to be lower than the maximum allowable values recommended by international organizations. Therefore, cleaning powders sold in the Kurdistan region markets pose no radioactive risk to users.

Keywords: Cancer risk, NaI(Tl) detector, Detergent, Radioactivity, Primordial radionuclide.

1. Introduction

Radionuclides are present in all raw materials and minerals. However, some human activities can increase exposure to naturally occurring radioactive materials (NORM). This enhanced exposure necessitates strict regulatory supervision. Since the earth's origin, the planet has accumulated primordial radionuclides that continue to persist in various environments [1]. Environments contain natural radionuclides at all times. Natural radionuclides are found ubiquitously in water, air, soil, food, and raw material products.

Due to the ionization that is formed when radiation interacts with living things, it can have a negative impact on an organism's shape and functionality, which can disrupt the normal operation of cells, organs, and tissues and cause cancer and a rise in mortality [2].

Cleaning is an essential part of daily life, helping to maintain hygiene in our clothes, homes, and other belongings. For example, purification materials are collected from multiple resources containing varying amounts of these energy powders such as sodium sulfate, phosphate, sodium silicate, soda ash, sodium chloride, clay, and moisture [3].

Cleaning products, like all man-made products, are made from raw materials from which radioactive substances cannot escape, so it is important to adhere to tolerance limits for these substances [3]. Detergents are a major group of products containing chemical raw

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materials such as phosphates, which contain radioactive elements that can migrate into consumer products, raising health concerns in some instances [4].

Earlier studies of natural radioactivity were carried out on detergent powder samples from surrounding and neighboring regions [4-8]. However, there is a lack of comprehensive studies on the levels of natural radiation in detergents available in the local Erbil market, which is open to a wide range of manufactured goods.

In general, radiation special effects can be evaluated by estimating radiation threat factors using gamma spectroscopy. This study focused on the assessment of natural primordial radionuclide levels in detergent powder samples used for washing clothes that were present in a local market in Erbil and the determination of dose and cancer risk due to ^{40}K, ^{232}Th, and ^{238}U radionuclide activity concentrations.

2. Method and Analytical Techniques

2.1 Sampling

As shown in Table 1, 25 detergent samples, imported from 10 neighboring countries, were collected from markets in Erbil, the capital of the Kurdistan region of Iraq. A constant weight of 1 kg and a 1 L Marinelli beaker filled with detergents were used to convert the activity to a specific activity. The samples, in powder form, were brought to the laboratory and oven-dried at a temperature of 70 °C until they reached a constant weight. Collected samples were stored and sealed in Marinelli beakers for approximately one month before being counted for secular equilibrium between parents and progeny. The gamma-ray spectrum of each sample was acquired by placing it in contact with the detector for 21 600 seconds. This duration is sufficient to obtain the spectrum and reduce uncertainty due to the high efficiency of the NaI(Tl) detector [9].

TABLE 1. The collected samples' type and country of origin.

Sample code	Cleaning powder type	Country of production
ST1	Bright	UAE
ST2	Altunsa	Turkey
ST3	Polex	Iraq - Kurdistan
ST4	Maria	Iran
ST5	Liby	China
ST6	Carrefour	France
ST7	Ariel	Saudi Arabia
ST8	Noura	Syria
ST9	Active	Iran
ST10	Falcon	UAE
ST11	Tide	Saudi Arabia
ST12	ABC (red)	Turkey
ST13	Super royal	Iraq
ST14	Teobeby	Bulgaria
ST15	Ave	Iran
ST16	Alwazir	Jordan
ST17	Alwazir	Iraq
ST18	Persil	Turkey
ST19	Savex	Bulgaria
ST20	Barf	Iran
ST21	Mega	Thailand
ST22	ABC (black)	Turkey
ST23	Finish	Turkey
ST24	Peros	Turkey
ST25	Galgom	Turkey

2.2 Gamma Spectrometry

The specific activity of the primordial radionuclides in washing powder samples is determined using a high-efficiency gamma spectroscopy system with a low-background design. The system consists of a NaI(Tl) detector with lead castle shielding, a high-voltage power supply connected to a preamplifier, an amplifier, a multichannel analyzer (MCA), and a desktop computer.

The NaI(Tl) scintillation detector (SILENA model 3S3) used in this work, as shown in Fig. 1, has an active region of 3" × 3" and an energy resolution of 7.4% at the 662 KeV gamma-line of ^{137}Cs. Energy calibration for the NaI(Tl) gamma-ray spectrometry was performed using a point source of ^{226}Ra and its progeny ^{214}Pb (242, 295, and 352 KeV) and ^{214}Bi (609 and 1120 KeV), as shown in Fig. 1. In this study, efficiency calibration of the NaI(Tl) gamma-ray spectrometry was performed in a 1 L Marinelli beaker using a multi-nuclide standard source of ^{210}Pb, ^{241}Am, ^{109}Cd, ^{57}Co, ^{123m}Te, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y, and ^{60}Co prepared by the International Atomic Energy Agency (IAEA-315), covering the energy range of 25 KeV to 1500 KeV. The standard source was placed above the detector, maintaining an equal distance between the sample and the detector. Figure 2 shows a graph of efficiency versus gamma-ray energy.

Both ^{238}U and ^{232}Th are long-lived, so their concentrations were determined from the spectra using an indirect method. The concentration of ^{238}U was determined from the average concentrations of ^{214}Pb at 352 KeV and ^{214}Bi at 609 KeV in the detergent samples. The ^{232}Th concentration was determined from the average concentrations of the decay products of ^{208}Tl at 583 KeV and ^{228}Ac at 911 KeV. Finally, the ^{40}K concentration was determined directly from the 1460 KeV photopeak.

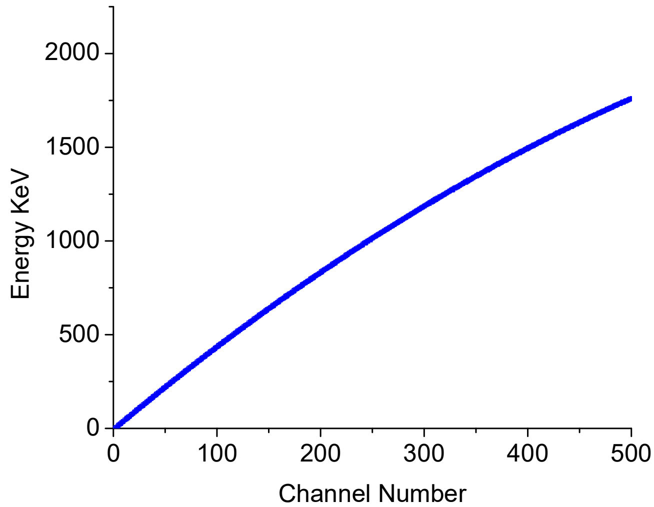

FIG. 1. Energy calibration for the NaI (Tl) scintillation detector.

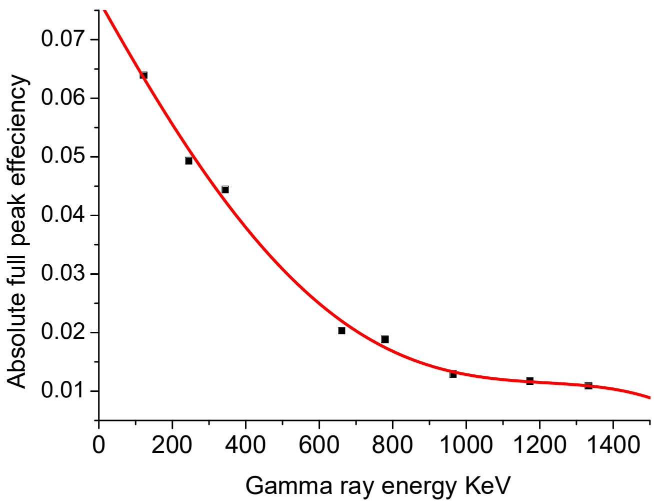

FIG. 2. Photopeak efficiency for gamma-ray energy of the NaI (Tl) detector.

2.3 Specific Activity Measurements

The radioactivity concentration ($Bq.kg^{-1}$) is defined as the activity per unit mass of the detergent samples. The specific activity of a radionuclide in detergent powder samples is given by the formula [10]:

$$A_s(Bq.kg^{-1}) = \frac{A_{net}}{\varepsilon \times I_\gamma \times m \times t} \quad (1)$$

where A_{net}, Iγ,m,t, and ε are the net count of the full range of photopeaks, the decay probability emission, the mass of the detergent sample, the time for running the samples, and the absolute efficiency of the photopeak at a certain energy, respectively.

2.4 Radium Equivalent (Ra_{eq})

To combine the specific activities of the elements and to assess the associated risks from materials containing different concentrations of natural radionuclides, such as ^{238}U, ^{232}Th, and ^{40}K, a single equivalent parameter is calculated based on the following equation [11]:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_U, A_{Th}, and A_K are the specific activities of ^{238}U, ^{232}Th, and ^{40}K (in Bq/kg), respectively. This equation defines Ra_{eq} as a single parameter, where 1Bq/kg of ^{238}U, 0.7 Bq/kg of ^{232}Th, and 13 Bq/kg of ^{40}K create a similar gamma-ray dose rate [12].

2.5 Outdoor and Indoor External Doses Rate

The D_{out} is calculated using gamma radiation from ^{238}U, ^{232}Th, and ^{40}K at a height of 1 meter above the Earth's surface. The radiation transfer factors for ^{238}U, ^{232}Th, and ^{40}K are 0.436 $nGy.h^{-1}$ per $Bq.kg^{-1}$, 0.599 $nGy.h^{-1}$ per $Bq.kg^{-1}$, and 0.0417 $nGy.h^{-1}$ per $Bq.kg^{-1}$, respectively.

D_{out} is calculated using the following equation [13, 14]:

$$D_{out}(\text{nGy}.h^{-1}) = 0.436A_U + 0.599A_{Th} + 0.0417A_K \quad (3)$$

The absorbed dose rate can be converted to the indoor effective dose rate using the following conversion factors: 0.92 $nGy.h^{-1}$ per $Bq.kg^{-1}$ for ^{238}U, 1.1 $nGy.h^{-1}$ per Bq.kg-1 for ^{232}Th, and 0.081 $nGy.h^{-1}$ per $Bq.kg^{-1}$ for ^{40}K. To calculate D_{in}, the following equation is utilized in conjunction with the previously stated conversion factors [15]:

$$D_{in}(\text{nGy}.h^{-1}) = 0.92A_U + 1.1A_{Th} + 0.081A_K \quad (4)$$

2.6 Annual Outdoor and Indoor External Effective Dose

The annual effective dose is divided into two categories: indoor annual effective dose (E_{in}) and outdoor annual effective dose (E_{out}). To calculate E_{out}, the occupancy dwelling factor (OF = 20% of 8760 h in a year) and the conversion factor (CF = 0.7 Sv Gy^{-1}) are applied. The following equations are used to determine E_{out}, which is used to convert the absorbed dose present in the atmosphere into an effective dose [1]:

$$E_{out} = D_{out}(nGyh^{-1}) \times 20\%\ of\ 8760h \times 0.7(Sv.Gy^{-1}) \quad (5)$$

$$= D_{out} \times 1.226\ \mu Sv.y^{-1} \quad (6)$$

The dose that a person receives indoors is known as E_{in}. The following equation can be used to derive the E_{in} from the indoor dose (D_{in}), which is the γ-ray dose within the building, the dose conversion factor (CF = 0.7 Sv Gy^{-1}), and the indoor occupancy factor (80% of a year) [16].

$$E_{in} = D_{in}(nGyh^{-1}) \times 80\%\ of\ 8760h \times 0.7(Sv.Gy^{-1}) \quad (7)$$

$$= D_{in} \times 4.905\ \mu Sv.y^{-1} \quad (8)$$

2.7 External Hazard Index (H_{ex})

The external hazard index is used to assess and quantify the risks associated with naturally occurring gamma radiation. It is calculated using the following equation [17]:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (9)$$

The H_{ex} values must be less than 1, which corresponds to the highest R_{eq} value (370 Bq/kg).

2.8 Internal Hazard Index (H_{in})

Radon is harmful to the respiratory system and is responsible for more than 50% of the total annual effective dose from natural radionuclides, making it a major factor in internal exposure [1]. The internal hazard index (H_{in}) is calculated thus:

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (10)$$

2.9 Excess Lifetime Cancer Risk (ELCR)

Using the annual effective gamma dose as a reference point, the following equations determine the indoor and outdoor ELCR [18]:

$$(\mathrm{ELCR})(\mathrm{Outdoor}) = (\mathrm{E_{out}}) \times \mathrm{LE} \times \mathrm{RF} \quad (11)$$

$$(\mathrm{ELCR})(\mathrm{Indoor}) = (\mathrm{E_{in}}) \times \mathrm{LE} \times \mathrm{RF} \quad (12)$$

where LE is the life expectancy (67 years) and RF (Sv^{-1}) is the fatal risk factor per Sievert, which is 0.05 [19].

3. Results and Discussion

Table 2 presents the calculated specific activity of ^{40}K, ^{232}Th, and ^{238}U found in the cleaning powder samples, while Fig. 3 depicts these results as a graph.

TABLE 2. The specific activity in $Bq.kg^{-1}$ of ^{238}U, ^{232}Th, and ^{40}K radionuclides in cleaning samples.

Sample code	Specific Activity in ($Bq.kg^{-1}$)		
	^{238}U	^{232}Th	^{40}K
ST1	1.148± 0.056	7.713± 0.303	70.279± 1.720
ST2	0.262± 0.027	0.142± 0.041	40.484± 1.305
ST3	0.011± 0.005	1.115± 0.115	46.754± 1.403
ST4	2.762± 0.086	9.256± 0.331	61.189± 1.605
ST5	0.143± 0.02	0.119± 0.038	28.027± 1.086
ST6	0.216± 0.024	1.59± 0.137	32.173± 1.164
ST7	ND	0.498± 0.077	29.269± 1.11
ST8	0.216± 0.024	0.985± 0.108	12.667± 0.73
ST9	ND	4.284± 0.225	11.068± 0.682
ST10	ND	1.24± 0.121	11.194± 0.686
ST11	0.227± 0.025	1.104± 0.114	21.862± 0.959
ST12	0.367± 0.031	0.403± 0.069	21.484± 0.951
ST13	0.189± 0.023	0.125± 0.038	15.234± 0.801
ST14	0.003± 0.003	1.75± 0.144	15.318± 0.803
ST15	0.317± 0.029	4.153± 0.222	5.892± 0.498
ST16	ND	0.819± 0.099	3.872± 0.404
ST17	0.005± 0.004	0.926± 0.105	8.438± 0.596
ST18	0.03± 0.009	3.643± 0.208	6.796± 0.535
ST19	0.111± 0.017	0.498± 0.077	22.599± 0.975
ST20	0.285± 0.028	0.237± 0.053	1.262± 0.230
ST21	ND	0.771± 0.096	1.515± 0.252
ST22	0.046± 0.011	1.258± 0.122	1.010± 0.206
ST23	0.123± 0.018	1.982± 0.153	2.399± 0.318
ST24	0.276± 0.027	1.394± 0.129	5.576± 0.484
ST25	0.011± 0.005	1.009± 0.109	3.956± 0.408

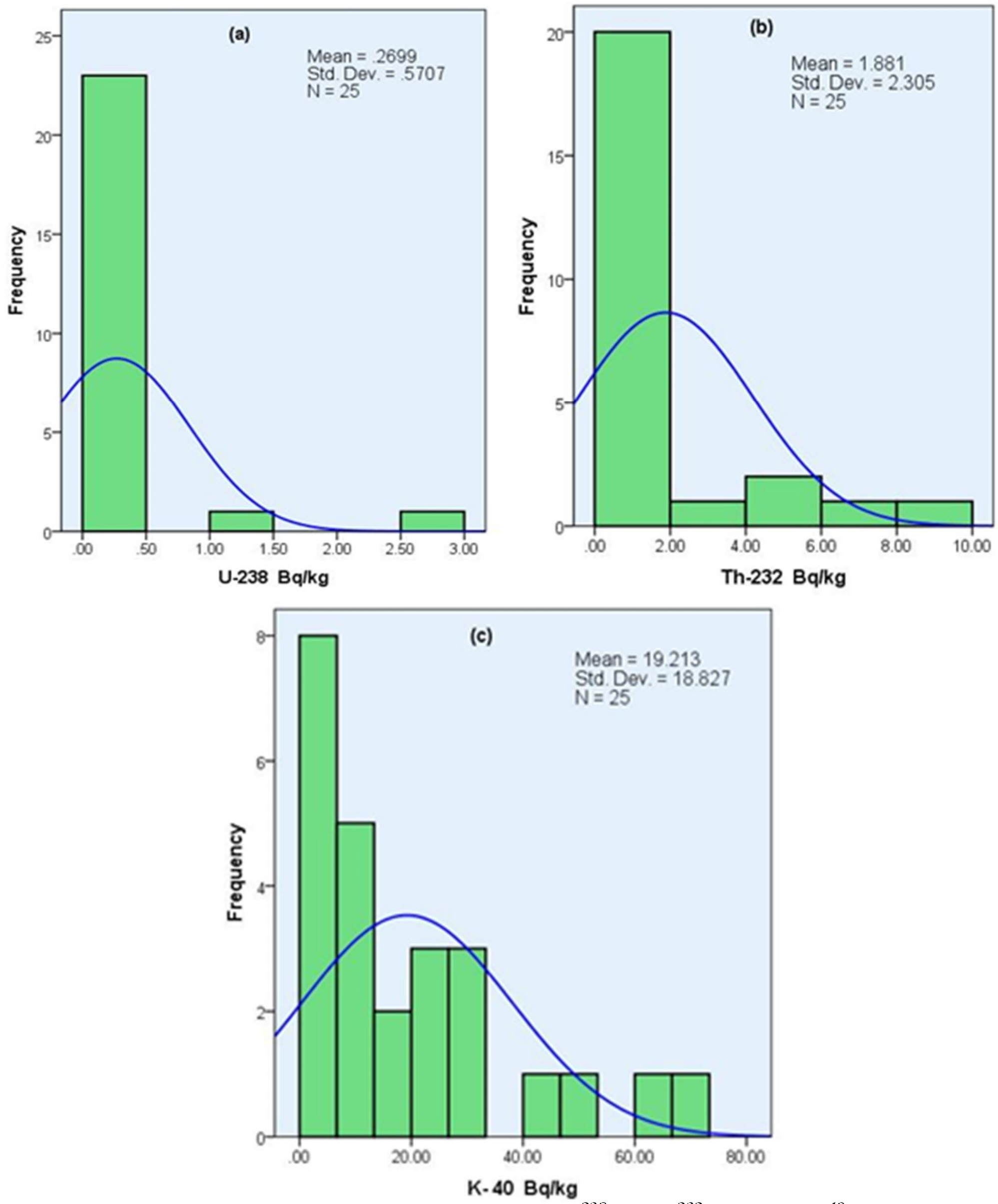

FIG. 3. The frequency distributions of (a) ^{238}U, (b) ^{232}Th, and (c) ^{40}K.

The specific activity of ^{238}U was detected in almost 80% of all samples, ranging from ND to 2.762±0.086 Bq/kg, with a mean value of 0.27±0.027 Bq/kg. For ^{232}Th, the specific activity varied from 1.115±0.115 Bq/kg to 9.256±0.331 Bq/kg with a mean value of 1.881±0.149 Bq/kg. Finally, the specific activity for ^{40}K ranged from 1.010± 0.206 Bq/kg to 70.279±1.720 Bq/kg with a mean value of 19.213±0.899 Bq/kg.

The highest specific activity for ^{238}U was detected in ST4 (Maria), which is lower than the value of 32 Bq/kg for raw materials declared by UNSCEAR [20]. ST4 (Maria) and ST1 (Bright) have the highest specific activity for ^{232}Th and ^{40}K, which are less than the limits of 45 and 412 Bq/kg, respectively, set by UNSCEAR [20].

Table 3 compares the results of the current investigation with values from previous studies obtained locally and in a neighboring country. The comparison reveals that, except for the activity concentration of ^{232}Th, the present analysis shows lower estimated activity concentrations of ^{238}U and ^{40}K radionuclides compared to those observed in previous studies [4-8].

TABLE 3. The measured activity concentrations compared to those of previous studies.

Country	Specific activities Bq/kg			References
	^{238}U	^{232}Th	^{40}K	
Iraq	22.342±6.984	4.664±2.438	45.642±30.637	[4]
Iraq	3.50 ± 0.60	1.77 ± 0.22	119.60 ± 7.27	[5]
Iraq	10.621±2.346	------	-----------	[6]
Iraq	4.80±0.87	1.34±0.43	108.76±15.11	[7]
Saudi Arabia	MDA-85.4±5.9	MDA-7.19±0.8	26.0±1.8-133±10	[8]
Iraq-Kurdistan	0.27± 0.570	1.881± 2.305	19.213± 18.827	Present study

Figure 4 shows the determined Ra_{eq}. activity values for the cleaning powder samples, derived from Eq. (2). The Ra_{eq} values across all samples ranged from 1.963 Bq/kg to 82.533 Bq/kg, with an average of 22.248 Bq/kg. Fortunately, the Ra_{eq} values for all detergent samples examined are below the accepted limit of 370 Bq/kg [1]. Thus, these cleaning agents available on the market do not present a radioactive risk when used as cleaning powders.

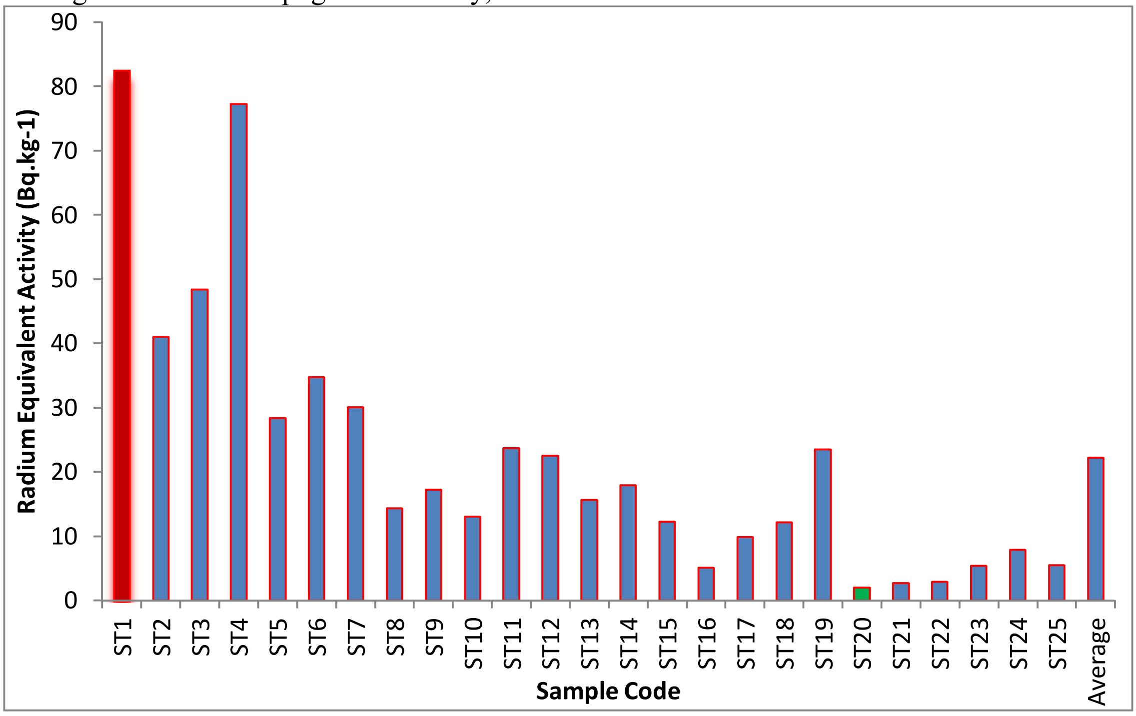

FIG. 4. Radium equivalent activity in cleaning powder samples.

The mean outdoor annual effective dose was 2.507 μSv y^{-1}, and the average indoor annual effective dose was 18.997μSv y^{-1}, both of which are lower than the global mean value of 410 μSv.y^{-1} [1]. As shown in column 6 of Table 4, the external hazard index (H_{ex}) values ranged from 0.002 (ST20) to 0.056 (ST4), with an average of 0.012. All H_{ex} values for the detergent samples were less than unity, indicating that using these detergent products for cleaning is safe in terms of radioactivity. The average H_{in} for the detergent samples was 0.013, with individual values ranging from 0.003 to 0.063, all of which were < 1 [21].

The (ELCR) for outdoor exposure, presented in column 8 of Table 4, ranged from 0.13×10^{-5} to 3.26×10^{-4}, with a mean value of 0.83×10^{-5}. For indoor exposure (last column of Table 4), the ELCR values ranged from 0.101×10^{-4} to 2.466×10^{-4}, with a mean of 0.627×10^{-4}. Consequently, the average ELCR value is less than the world's average value of 1.45×10^{-3} [16].

TABLE 4. The calculated radiological hazard indices for the studied detergent samples.

Sample code	D_{out} nGy.h-1	D_{in} nGy.h-1	E_{out} (μSv.y-1)	E_{in} (μSv.y-1)	H ex	Hin	ELCR (Outdoor)* 10^{-3}	ELCR (Indoor)* 10^{-3}
ST1	8.051	15.233	9.871	74.717	0.047	0.051	0.03257	0.24657
ST2	1.888	3.677	2.314	18.033	0.010	0.010	0.00764	0.05951
ST3	2.623	5.024	3.215	24.643	0.014	0.014	0.01061	0.08132
ST4	9.3	17.679	11.402	86.713	0.056	0.063	0.03763	0.28615
ST5	1.302	2.532	1.596	12.421	0.007	0.007	0.00527	0.04099
ST6	2.388	4.554	2.928	22.335	0.013	0.014	0.00966	0.07371
ST7	1.519	2.919	1.862	14.318	0.008	0.008	0.00615	0.04725
ST8	1.212	2.308	1.486	11.32	0.007	0.008	0.0049	0.03736
ST9	3.027	5.609	3.712	27.51	0.019	0.019	0.01225	0.09078
ST10	1.21	2.271	1.483	11.138	0.007	0.007	0.00489	0.03676
ST11	1.671	3.193	2.049	15.663	0.009	0.010	0.00676	0.05169
ST12	1.297	2.521	1.591	12.368	0.007	0.008	0.00525	0.04081
ST13	0.792	1.545	0.971	7.577	0.004	0.005	0.00321	0.025
ST14	1.688	3.169	2.07	15.542	0.010	0.010	0.00683	0.05129
ST15	2.872	5.337	3.521	26.179	0.018	0.019	0.01162	0.08639
ST16	0.652	1.214	0.799	5.956	0.004	0.004	0.00264	0.01965
ST17	0.909	1.707	1.114	8.371	0.005	0.005	0.00368	0.02762
ST18	2.478	4.585	3.039	22.49	0.016	0.016	0.01003	0.07422
ST19	1.289	2.48	1.58	12.167	0.007	0.007	0.00522	0.04015
ST20	0.319	0.625	0.391	3.066	0.002	0.003	0.00129	0.01012
ST21	0.525	0.971	0.644	4.764	0.003	0.003	0.00212	0.01572
ST22	0.816	1.508	1	7.395	0.005	0.005	0.0033	0.0244
ST23	1.341	2.487	1.644	12.199	0.008	0.009	0.00542	0.04026
ST24	1.188	2.24	1.457	10.986	0.007	0.008	0.00481	0.03625
ST25	0.774	1.44	0.949	7.062	0.005	0.005	0.00313	0.02331
Average	2.045	3.873	2.507	18.997	0.012	0.013	0.00827	0.06269

4. Conclusion

The study has provided data on the specific activity of primordial radionuclides in some of the common cleaning powders in the north-eastern Kurdistan region of Iraqi markets. The uptake of the natural radionuclides of ^{238}U, ^{232}Th, and ^{40}K is low in samples compared to the maximum values (32, 45, and 412 Bq/kg) declared by (UNSCEAR, 2008). All the samples contain a significant concentration of ^{40}K. However, the level of ^{40}K is relatively higher than that of ^{238}U and ^{232}Th.

The average annual external effective dose indoors and outdoors is less than the global average value of 70 μSv/y, and the obtained value of (ELCR) is less than the level 1.45 * 10^{-3} indicated by (National Cancer Institute, 2009). Therefore, there is no significant radiological risk to the general public from using the examined detergent formulations as cleaning agents

It has been determined that the amounts of natural radioactivity in the detergent powders available in Erbil-Iraq are well below the permissible ranges and do not present any radioactive risk to users.

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