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# Radiation Risk Among Children due to Natural Radioactivity in Breakfast Cereals

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## ABSTRACT

Breakfast cereal is one of the common foods for children's nutrition. It is made from sugar, barley, calcium carbonate, salt, maize, peanuts, molasses, and honey. Therefore, assessing the levels of radioactivity in breakfast cereal is essential for children's health. Gamma-ray spectrometry NaI(Tl) was used to measure the radiation hazard in ten samples collected from the Iraqi market. The corresponding radiation dose quantities and hazard indices were also calculated. The average concentrations of $^{226}Ra$, $^{232}Th$, and $^{40}K$ were found to be 18.195, 20.965, and 796.500 ($Bq.kg^{-1}$). The annual effective dose equivalent ($AEDE_{in}$), annual ingestion dose (AID), and the risk of cancer incidence (ELCR) were all seen to be within the accepted levels, except the annual gonadal equivalent dose (AGED). Radiation hazard index values (i.e., $I_\gamma$, $I_\alpha$, and $H_{in}$) were noticed to be lower than unity, except $I_\gamma$ was much higher than the internationally permissible limits for the samples of BGF5, BGF6, and BGF7 recommended by UNSCER2000. Therefore, the study findings reveal that this type of cereal can be considered a safe feeding material for children's health.

## INTRODUCTION

Natural radiation comes from many sources. One of these sources is natural radioactivity, divided into three main types: cosmic rays, radionuclides generated from cosmic rays, and radionuclides of terrestrial origin (Reedy et al. 1983). A second source is an artificial source. Ionizing radiation is a natural part of the environment in which we live, present in the Earth, buildings, food, and even in the bones of our bodies. Earth, water, air, plants, and animals contain over 40 natural radioactive elements, mainly in a non-active state. The number of artificial radioactive elements is much higher (Webber & Higbie 2003, Dolchinkov 2017). While radionuclides formed as a result of cosmic rays come from the interaction between the radionuclides of cosmic and the Earth's atmosphere. Nevertheless, the terrestrial source represents the dangerous part due to its radionuclides' direct contact with humans (Beer et al. 2012). In this context, Uranium-238 ($^{238}U$), Actinium-235 ($^{235}U$ ), and Thorium-232 ($^{232}Th$) are the largest naturally occurring radioactive elements in the Earth's crust that their half-lives are estimated to be at millions of years (Mernagh & Miezitis 2008).

The radioactive materials in nature differ according to location, height above sea level, the nature of the soil, and the type of dwelling. There are a large number of radionuclides that have decayed with time (Eisenbud & Gesell 1997). The radionuclides enter the body by ingestion or inhalation and emit either alpha or beta particles (Raabe 2010). Therefore, it is worth studying the radioactivity in commonly consumed foodstuffs and estimating the potential risk level to protect the consumer's health (Alhous et al. 2020). Cereal is a traditional product for evaluating cancer risk and the annual gonadal equivalent dose. Many studies have been conducted on this item of food, in which the radioactivity and risk factors were estimated. The latter may be due to the ease of preparation and storage, the long half-life, and the low cost (Changizi et al. 2013).

An example of the aforementioned studies is that the activity concentration of natural and anthropogenic radionuclides was measured for five different types of honey in Italy (Caridi et al. 2022). Another complete investigation was conducted to determine various radionuclide activities in foods ingested and evaluate dose levels in different foodstuffs in eight Sudanese states. Cereals, milk, and others for age groups 7–12 years and older than 17 years, the yearly effective dosage attributable to various foodstuffs was determined to be 2.78 $mSv.y^{-1}$ and 1.18 $mSv.y^{-1}$, respectively (Hemada 2009). A published relevant work examined the

Table 1: Information about the samples and their companies, origins, and the content of each sample.

| I.D. | The product | company | Origin | Content of each sample | Mass [g] |
|---|---|---|---|---|---|
| BGF1 | Gold corn flakes | Nestle | Turkey | Maize Semolina, sugar, Barley, Calcium Carbonate, and Salt. | 234 |
| BGF2 | Corn flakes hony and nuts | Kellogg's | Saudi Arabia | Maize, Sugar, Peanuts, Barley, Molasses, Honey, Salt. | 267 |
| BGF3 | Corn flakes | Temmy's | Egypt | Flour, Salt, Sugar, Barley, Vanillin, Calcium carbonatE170. | 287 |
| BGF4 | Semolina wheat | Alryad | U.A.E. | Soft white Semolina | 319 |
| BGF5 | Munchies cheese puff | Dena | Iraq | Wheat Flour, Sugar, vegetable, oil, cocoa powder, lecithin | 212 |
| BGF6 | Oat flakes | Skvira | Ukraine | Fat, Graisse, Carbohydrates, sugar, protein, Salt, Vitamins, Minerals | 259 |
| BGF7 | Supermi | Indomie | Indonesia | Wheat flour, edible vegetable oil, salt, acidity regulators, potassium carbonate, sodium carbonate. | 263 |
| BGF8 | Alafandi | Alfajr | Iraq | Peanut, Corn Starch, Salt, Olin, Oil Refined, Flavors, Food Allowed. | 55 |
| BGF9 | Corn flakes | Kellogg's | Turkey | Maize Semolina, sugar, Salt, Wheat Flour, blubbery, Vitamins, Minerals, | 265 |
| BGF10 | Nesquik | Nesquik | Turkey | Wheat, coco powder, Vitamins, protein | 314 |

long-lived gamma radiation emitters in the various types of pasta available in the Iraqi market. In another study, the measured $^{238}U$, $^{232}Th$, and $^{40}K$ concentrations were evaluated in 20 different types of pasta (Alaboodi et al. 2020). Therefore, it is necessary to investigate this food type and calculate some important transactions related directly and significantly to children's health. The current study aims to measure the radionuclides of $^{226}Ra$, $^{232}Th$, and $^{40}K$ and then evaluate the excess lifetime cancer risk and annual gonadal equivalent dose in breakfast cereals for children's food. It should be noted that this study was the first conducted to assess the radioactivity in children's breakfast cereal.

## MATERIALS AND METHODS

### Sample Collection and Preparation

Ten samples of breakfast cereals were collected from the local and imported breakfast cereals available in the Iraqi markets. The weight of each sample differs from the other due to the different sizes of breakfast cereals containers, as shown in Table 1. The samples were then ground into a powder and stored in special containers. The latter samples were held for a month to ensure the radioactive equilibrium between the uranium and thorium series and their short-lived progenies (Cochran & Masqué 2003). After that, the samples became ready for measurement. The elapsed time for measurement was determined to be 3 hours. Also, all sample measurements were conducted in the physics laboratory at the Faculty of Science, University of Kufa.

### Gamma-Ray Detection System

The radioactivity measurements were conducted using Sodium Iodide NaI (Tl) detector. Spectral data were collected and analyzed using MAESTRO-32 (A65- B32) software from ORTEC. The activity concentration of natural radionuclides $^{226}Ra$, $^{232}Th$, and $^{40}K$ was calculated utilizing equation (1) (Harb et al. 2008, Adhab & Alsabari 2020, Hamza et al. 2020, Salman et al. 2020).

$$A = \frac{N_{net}}{\varepsilon . I_G . m . t} \frac{\sqrt{N_{net}}}{\varepsilon . I_G . m . t} (Bq / Kg) \quad \ldots(1)$$

where $N_{net}$ represents the net count (area under the specified energy peak after background subtraction) in (c.s$^{-1}$), $\sqrt{N_{net}}$ is the random error in (c.s$^{-1}$), ε is the efficiency of the detector, $I_G$ is the transition probability of the emitted gamma ray, $t$ refers to the time of spectrum collection from the sample (3 h), and $m$ is the mass of the sample in kg units. Through the data obtained from the aforementioned system, many variables will be calculated, as shown below.

### Representative Gamma and Alpha Index ( $I_\gamma$, $I_\alpha$)

$I_\gamma$ was used to calculate the risk arising from gamma radiation associated with radioactive natural nuclei in the studied samples and was calculated using equation (3) which depends on the activity concentrations of $^{226}Ra$, $^{232}Th$, and $^{40}K$. Its value must be less than one in order not to cause any risk to human health. An alpha index was calculated for the breakfast cereal samples using the equation below (Ziqiang et al. 1988):

$$I_\alpha = \frac{A_{Ra}}{200} \quad \ldots(2)$$

### Internal Radiation Hazard Indices ($H_{in}$ )

Internal exposure to $^{222}Rn$ and its radioactive progeny, which are harmful to the respiratory system, can be estimated using the internal hazard index. They are derived from $^{226}Ra$, $^{232}Th$ and $^{40}K$ activity concentrations (Hussain et al. 2010, Kadhim et al. 2020, 2022).

### Annual Effective Dose Equivalent ($AEDE_{in}$)

The effective equivalent dose calculations are based on the absorbed dose rate level in the air. To perform these calculations, a conversion coefficient that relates the absorbed dose rate in the air to the effective dose equivalent and occupancy fraction must be considered. The value of the aforementioned two parameters varies in relation to climate conditions in the considered area and the mean age of the population taken in this work. Considering the UNSCEAR (2000a) report account, the conversion coefficient value was 0.7 $Sv.Gy^{-1}$ for male and female (indoor and outdoor), and a value of 0.8 for the outdoor occupancy fraction, then calculate Indoor absorbed dose $D_{in}$(nGy/h). (Absar 2014). As a result, the outdoor annual effective dose equivalent can be estimated as follows (UNSCEAR 2000a):

$$AEDE_{in}(\mu Sv.y^{-1}) = D_{in}(nGy.h^{-1}) \times 8760\ (h) \times 0.8 \times 0.7 (Sv.Gy^{-1}) \times 10^{-3} \quad \ldots(3)$$

### Annual Gonadal Equivalent Dose (AGED) and Annual Ingestion Dose (AID)

AGED was also calculated because the reproductive gland is important due to its high sensitivity to radiation (Alhous et al. 2020). The latter index is highly important in the UNSCEAR (2000b) publication (Vanmarcke 2002). Therefore, it is essential to calculate the annual gonadal equivalent dose (AGED) depending on the specific activities of $^{226}Ra$, $^{232}Th$, and $^{40}K$, in addition to the annual ingestion dose (AID.) using the following formulas, respectively (Changizi et al. 2013, Aswood et al. 2017):

$$AGED = 3.09 A_{Ra} + 4.18 A_{Th} + 0.314 A_K \quad \ldots(4)$$

$$AID = A_i \times C_R \times FDC_{ING} \quad \ldots(5)$$

where $A_i$ is the total activity concentration ($Bq.kg^{-1}$) of $^{226}Ra$, $^{232}Th$, and $^{40}K$, while the C.R. is the consumption rate (9.125 $kg.y^{-1}$) and $FDC_{ING}$ is the ingestion dose coefficient of the $^{226}Ra$, $^{232}Th$, and $^{40}K$, which are 0.28, 0.23 and 0.0062 in ($\mu Sv.Bq^{-1}$) respectively (Alhous et al. 2020, UNSCEAR 2000b).

### Excess Lifetime Cancer Risk (ELCR)

The excess lifetime cancer risk (ELCR) is significant, and it was done using the following equation (El-Arabi 2001, Hamza et al. 2020, Aswood et al. 2022):

$$ELCR = AID \times DL \times RF \quad \ldots(6)$$

DL is the mean children's lifespan of 10 years, and R.F. is the risk factor value of 0.055 per Sievert as recommended by the ICRP (Wrixon 2008).

## RESULTS AND DISCUSSION

Table 2 presents the activity concentrations of $^{226}Ra$, $^{232}Th$, and $^{40}K$ in the breakfast cereal samples, with an average value of 18.195, 20.965, and 796.500 ($Bq.kg^{-1}$), respectively. Depending on the internationally permissible limits, the concentrations of $^{226}Ra$, and $^{232}Th$ were seen to be lower than the values reported by UNSCEAR 2000, except the specific activity of $^{40}K$ was higher than the recommended level, as shown in Fig. 1 (BGF2 (Saudi Arabia), BGF3 (Egypt) and BGF8 (Iraq). From Table 3, the average values of $AEDE_{in}$, AID., and ELCR were 0.356 $mSv.y^{-1}$, 0.136 $mSv.y^{-1}$, and $0.068*10^{-3}$, respectively. All the latter results of dosemetric parameters were less than the global permissible value, where ELCR was less than the $2.5*10^{-3}$ recommended by ICRP and WHO.

The average AGED was $393.983*10^{-3}$ $\mu Sv.y^{-1}$, this means that it is higher than the internationally accepted limit, as reproductive organs are susceptible to radiation, and the reason may be because each sample is a mixture of a group of different materials in terms of origin, cultivation, preservatives, and storage method, which may affect this rise, as shown in Fig. 2.

The results have shown that the averages of all the radiometric parameters of the studied samples in this study were 0.862, 0.091, and 0.345 for $I_{\square}$, $I_{\square}$, and $H_{in}$, respectively. The relationship among radiation hazard indices for the radionuclides in the studied samples has also been drawn in Fig. 3. In this work, it has been noted that the average values of all radiation hazard indices were less than the global value (Nordic), except, $I_{\square}$ was greater than the internationally recommended limits for samples, BGF5 (Iraq), BGF6 (Ukraine), and BGF7 (Indonesia). Table 4 presents the ratio between $^{226}Ra$ to $^{232}Th$, $^{232}Th$ to $^{226}Ra$, $^{226}Ra$ to $^{40}K$, and $^{232}Th$ - $^{40}K$ for the studied samples, where the calculated average of the ratios was (0.869, 2.700, 0.026, and 0.030) respectively.

The studied data were statistically analyzed using SPSS program version 20, as shown in Table 5. The relationship between the specific activity of $^{226}Ra$ and $AEDE_{in}$ was moderately direct and had no statistical significance. At the same time, there was a positive, high, and statistically significant direct relationship between AID and ELCR. The specific activity of $^{232}Th$ is moderately positive and had no statistical significance with $AEDE_{in}$, AID, AGED, and ELCR, respectively. The specific activity of $^{40}K$ had a very

Table 2: Activity concentration (Bq.kg$^{-1}$) of $^{226}$Ra, $^{232}$Th and $^{40}$K.

| Code of sample | Activity Concentration | | | | | |
|---|---|---|---|---|---|---|
| | $^{226}$Ra | ±SD | $^{232}$Th | ±SD | $^{40}$K | ±SD |
| BGF1 | 4.385 | ± 3.205 | 13.682 | ± 2.549 | 943.901 | ± 20.962 |
| BGF2 | 40.503 | ± 1.922 | 24.216 | ± 2.116 | 416.826 | ± 11.959 |
| BGF3 | 3.025 | ± 1.650 | 15.639 | ± 1.476 | 345.857 | ± 13.705 |
| BGF4 | 29.818 | ± 3.588 | 13.972 | ± 2.115 | 973.671 | ± 14.942 |
| BGF5 | 29.787 | ± 4.654 | 25.169 | ± 2.813 | 1117.815 | ± 21.610 |
| BGF6 | 14.477 | ± 3.505 | 25.752 | ± 2.484 | 995.727 | ± 17.867 |
| BGF7 | 27.463 | ± 3.151 | 25.838 | ± 35.863 | 926.917 | ± 17.595 |
| BGF8 | 8.109 | ± 2.225 | 17.120 | ± 1.113 | 409.328 | ± 8.582 |
| BGF9 | 2.383 | ± 2.383 | 26.117 | ± 2.428 | 990.819 | ± 18.161 |
| BGF10 | 21.997 | ± 2.765 | 22.141 | ± 1.799 | 845.043 | ± 15.032 |
| Average | 18.195 | ± 2.905 | 20.965 | ± 5.476 | 796.590 | ± 16.042 |

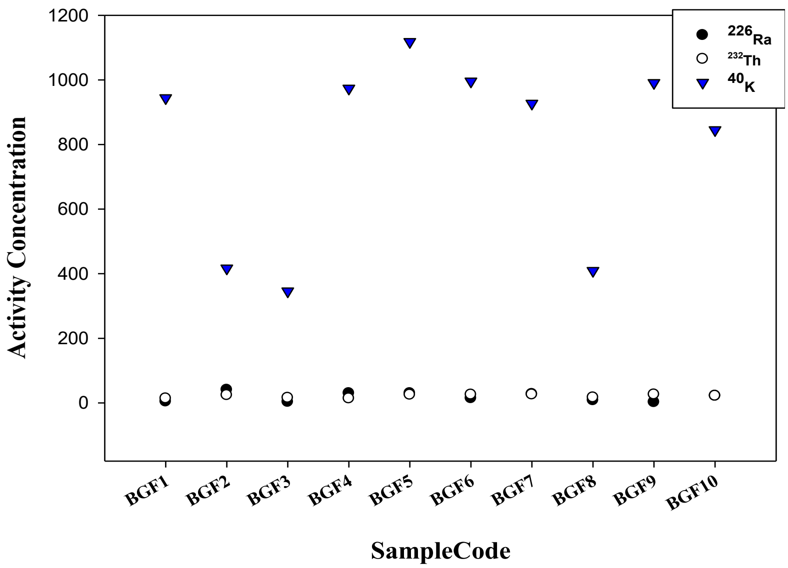


Fig. 1: Comparison of the specific activities (Bq.kg$^{-1}$) of the radionuclides in the studied samples.

Table 3: Radiological parameters dosemetric and radiation hazard indices of breakfast cereal samples.

| I.D. | AEDE [mSv.y$^{-1}$] | AID [mSv.y$^{-1}$] | ELCR*10$^{-3}$ | AGED*10$^{-3}$ [μSv.y$^{-1}$] | Radiation hazard indices < 1 | | |
|---|---|---|---|---|---|---|---|
| | | | | | $I_{\square}$ | $I_{\square}$ | $H_{in}$ |
| BGF1 | 0.329 | 0.093 | 0.047 | 367.125 | 0.795 | 0.022 | 0.273 |
| BGF2 | 0.327 | 0.178 | 0.089 | 357.262 | 0.790 | 0.203 | 0.399 |
| BGF3 | 0.169 | 0.060 | 0.030 | 183.319 | 0.407 | 0.015 | 0.149 |
| BGF4 | 0.407 | 0.161 | 0.080 | 456.271 | 0.988 | 0.149 | 0.418 |
| BGF5 | 0.494 | 0.192 | 0.096 | 548.244 | 1.195 | 0.149 | 0.491 |
| BGF6 | 0.421 | 0.147 | 0.074 | 465.035 | 1.018 | 0.072 | 0.385 |
| BGF7 | 0.438 | 0.177 | 0.088 | 483.914 | 1.059 | 0.137 | 0.441 |
| BGF8 | 0.207 | 0.080 | 0.040 | 225.149 | 0.498 | 0.041 | 0.195 |
| BGF9 | 0.388 | 0.117 | 0.058 | 427.648 | 0.938 | 0.012 | 0.320 |
| BGF10 | 0.385 | 0.150 | 0.075 | 425.863 | 0.931 | 0.110 | 0.380 |
| Average | 0.356 | 0.136 | 0.068 | 393.983 | 0.862 | 0.091 | 0.345 |

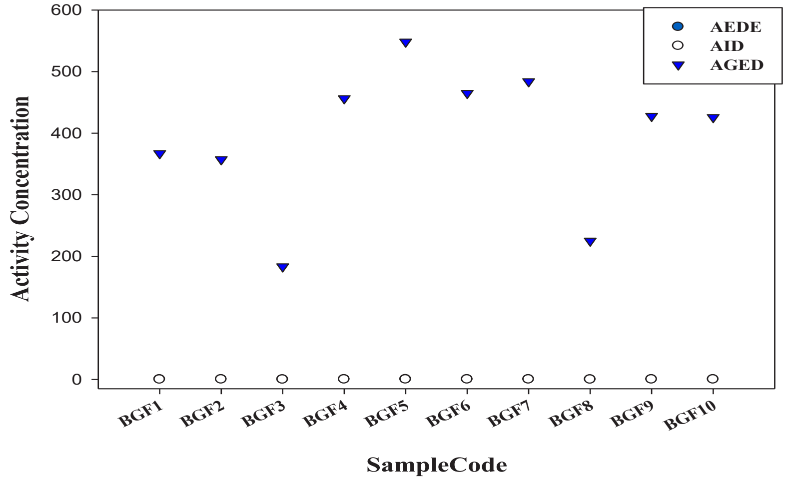


Fig. 2: Comparison of the radiation doses of radionuclides in the studied samples.

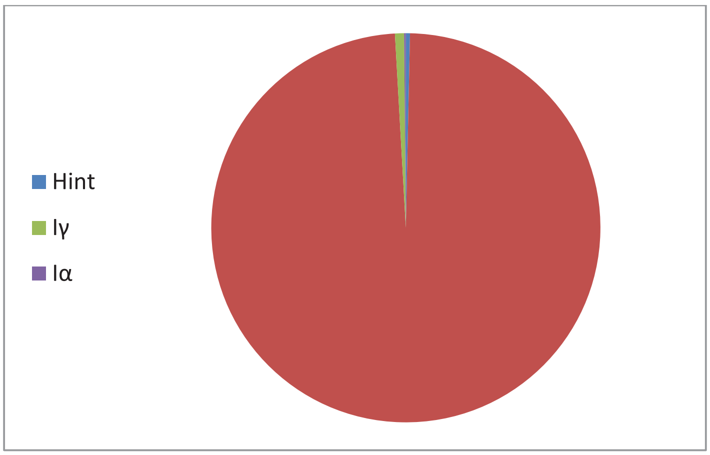


Fig. 3: Comparison of the coefficients of radiation hazard indices for the radionuclides in the studied samples.

Table 4: The ratio between the specific activity of $^{226}$Ra, $^{232}$Th, and $^{40}$K in the breakfast cereal samples.

| ID | $^{226}$Ra-$^{232}$Th | $^{232}$Th-$^{226}$Ra | $^{226}$Ra-$^{40}$K | $^{232}$Th-$^{40}$K |
|---|---|---|---|---|
| BGF1 | 0.321 | 3.120 | 0.005 | 0.014 |
| BGF2 | 1.673 | 0.598 | 0.097 | 0.058 |
| BGF3 | 0.193 | 5.169 | 0.009 | 0.045 |
| BGF4 | 2.134 | 0.469 | 0.031 | 0.014 |
| BGF5 | 1.183 | 0.845 | 0.027 | 0.023 |
| BGF6 | 0.562 | 1.779 | 0.015 | 0.026 |
| BGF7 | 1.063 | 0.941 | 0.030 | 0.028 |
| BGF8 | 0.474 | 2.111 | 0.020 | 0.042 |
| BGF9 | 0.091 | 10.960 | 0.002 | 0.026 |
| BGF10 | 0.993 | 1.007 | 0.026 | 0.026 |
| Average | 0.86 | 2.700 | 0.026 | 0.030 |
| Worldwide (Talab 2016) | 0.86 | 11.43 | - | - |

Table 5: Correlation among sample studies.

| | | $^{226}Ra$ [ppm] | $^{232}Th$ [ppm] | $^{40}K$ [ppm] | $AEDE_{in}$ | AID | ELCR | AGED |
|---|---|---|---|---|---|---|---|---|
| $^{226}Ra$ (ppm) | *P. C* | 1 | | | | | | |
| | Sig. (2-tailed) | | | | | | | |
| $^{232}Th$ (ppm) | *P. C* | 0.329 | 1 | | | | | |
| | Sig. (2-tailed) | 0.354 | | | | | | |
| $^{40}K$ (ppm) | *P. C* | 0.102 | 0.318 | 1 | | | | |
| | Sig. (2-tailed) | 0.779 | 0.370 | | | | | |
| $AEDE_{in}$ | P. C | 0.514 | 0.583 | 0.884** | 1 | | | |
| | Sig. (2-tailed) | 0.129 | 0.077 | 0.001 | | | | |
| AID | *P. C* | 0.879** | 0.605 | 0.512 | 0.849** | 1 | | |
| | Sig. (2-tailed) | 0.001 | 0.064 | 0.130 | 0.002 | | | |
| ELCR | *P. C* | 0.879** | 0.605 | 0.513 | 0.849** | 1.000** | 1 | |
| | Sig. (2-tailed) | 0.001 | 0.064 | 0.129 | 0.002 | .000 | | |
| AGED | *P. C* | 0.510 | 0.564 | 0.890** | 1.000** | .844** | .844** | 1 |
| | Sig. (2-tailed) | 0.132 | 0.089 | 0.001 | .000 | .002 | .002 | |

**Correlation is significant at the 0.01 level (2-tailed)

high positive relationship and was statistically significant with $AEDE_{in}$ and AGED.

In contrast, it had a moderate positive relationship without statistical significance with AID and ELCR. The annual effective dose equivalent $AEDE_{in}$ has a vital, positive, high statistical significance with AID and ELCR, with a direct relationship and very high statistical significance with AGED. The annual ingestion dose (AID) and ELCR have a direct relationship with high statistical significance, while AGED has a strong direct relationship with high statistical significance. Therefore, a solid positive direct relationship exists between ELCR and AGED with high statistical significance.

## CONCLUSIONS

In the current study, the samples demonstrate low specific activity values for radionuclides of $^{226}Ra$ and $^{232}Th$, thus contributing to the low-absorbed dose rates in the air. In general, the activity of the calculated radionuclide in terrestrial sources has given a lower value than the global permissible value, with the exception of $^{40}K$. The average values of $AEDE_{in}$, AID., and ELCR, together with the radiation hazard indices, were less than the average world value. Still, the AGED was higher than 0.29 $mSv.y^{-1,}$ as mentioned in UNSCEAR (2000a, 2000b). Finally, it is considered the first study at the level of Iraq, and it must be developed in the future by studying samples of other origins.

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