

ORIGINAL RESEARCH ARTICLE

Natural radioactivity and radiation risks of soils in Ali Al-Sharqi and Kumait, Iraq

Zahraa A. Ismail AL-Sudani^{1*}, Sawsan Sherif², and Mazin Mohammed³

¹Department of Physics, College of Science, University of Misan, Misan, Iraq

²Department of Physics, College of Education for Pure Sciences, University of Basrah, Basrah, Iraq

³Radiation Protection Center, Ministry of Environment, Baghdad, Iraq

*Corresponding author: Zahraa A. Ismail AL-Sudani (zahraaismail@uomisan.edu.iq)

Received: February 3, 2025; 1st revised: March 10, 2025; 2nd revised: March 23, 2025; 3rd revised: March 30, 2025; Accepted: March 31, 2025; Published online: April 16, 2025

Abstract: Humans are subjected to natural radiation from external sources, such as radionuclides on Earth and cosmic radiation, as well as internal radiation from radionuclides integrated into the body. Radionuclide intake occurs mostly through the ingestion of food and water, as well as inhalation. The natural radioactivity in the soils of Ali Al-Sharqi and Kumait, two cities in Misan province, Iraq, were measured. The soil samples were collected from 47 Ali Al-Sharqi and Kumait areas, and levels of natural radionuclide were analyzed using a high-purity germanium detector. The average activity concentrations of radionuclides, radium-226, thorium-232, and potassium-40, were found to be 15.1 ± 2.5 , 14.7 ± 2.4 , and 180.8 ± 7.9 Bq/kg, respectively, for Ali Al-Sharqi. In Kumait, the corresponding values were 13.6 ± 2.1 , 17.2 ± 2.4 , and 193.6 ± 8.6 Bq/kg, respectively. Radiation risk parameters were also evaluated for both cities. The average radium equivalent activities for Ali Al-Sharqi and Kumait were 50.2 Bq/kg and 53.2 Bq/kg, respectively. Internal and external hazard indices were 0.2 and 0.1, while the gamma level index was 0.2 in both cities. In Ali Al-Sharqi, the absorbed gamma dose rates in the air (D_{in} , D_{out} , and D_{tot}) were 44.8, 23.5, and 68.3 nGy/h, the annual effective dose equivalents (AEDE_{in}, AEDE_{out}, and AEDE_{tot}) were 0.2, 0.02, and 0.2 mSv/y, the excess lifetime cancer risks (ELCR_{in}, ELCR_{out}, and ELCR_{tot}) were 0.8×10^{-3} , 0.1×10^{-3} , and 0.9×10^{-3} , and the annual gonadal dose equivalent was 165.3 μSv/y. In Kumait, the corresponding values were 47.2, 24.8, and 72 nGy/h, 0.2, 0.03, and 0.3 mSv/y, 0.8×10^{-3} , 0.1×10^{-3} , and 0.9×10^{-3} , and 175 μSv/y, respectively. These findings indicate that the measured levels of radioactivity and health hazard parameters in both cities were below the global average values reported by the United Nations Scientific Committee on the Effects of Atomic Radiation. Therefore, the natural radioactivity in the soils of the investigated areas does not pose a health risk to the public.

Keywords: Soil; Radionuclides; High-purity germanium; Dose rate; Ali Al-Sharqi.

1. Introduction

Radiation in the environment originates from two sources: natural and artificial. Natural radiation includes both cosmic and terrestrial components, while artificial radiation arises from nuclear weapon testing

and nuclear accidents.¹ Cosmic radiation, which comes from cosmic rays, varies in intensity based on latitude and elevation. Natural terrestrial radiation in the Earth's crust is primarily caused by the decay of uranium-238, thorium-232 (²³²Th), and potassium-40 (⁴⁰K). The concentration of natural radioactive materials in the soils

is not uniform and varies according to the types of rocks from which they originate.²⁻⁴ Natural radiation accounts for roughly 87% of human radiation exposure, with the remaining exposure stemming from artificial sources.⁵ It is crucial for individuals to be aware of the radiation risks posed by both natural and artificial radioactive sources. For example, radon gas and its decay products in soil, sediment, and building materials can lead to internal radiation exposure that harms the respiratory system.⁶ Long-term exposure to both uranium and radium through inhalation can cause many health effects, including bone, cranial, and nasal tumors, due to radium exposure. On the other hand, exposure to thorium may lead to leukemia and hepatic, pancreatic, lung, skeletal, and kidney cancers.⁷ Consequently, quantitative information on the distribution of radioactive materials in various parts of the world is essential for protecting human life from radiation exposure.⁸ Numerous studies have been conducted worldwide to measure the levels of radionuclides in soil specimens and the radiation risks in Amman, Aqaba (Jordan),⁹ Rize (Turkey),¹⁰ Upper Egypt,¹¹ southwest of Nigeria,¹² North Lebanon,¹³ Sicily (Italy),¹⁴ Port Said (Egypt),¹⁵ Tongliao (China),¹⁶ Pshdar (Iraqi-Kurdistan),¹⁷ Shabwah and Hadramout (Yemen),¹⁸ Wassit (Iraq),¹⁹ Kirkuk (Iraq),²⁰ Mounana (Gabon),²¹ Rio de Janeiro (Brazil),²² Kuwait,²³ North Waziristan (Pakistan)²⁴; and (Taghdoua) Saudi Arabia.²⁵ However, the level of radioactivity in the cities of Ali Al-Sharqi and Kumait is unknown. This study is crucial as it aims to assess the radiation exposure levels in these cities. By measuring activity concentrations of radionuclides (radium-226 [²²⁶Ra], ²³²Th, and ⁴⁰K) in soil samples of Ali Al-Sharqi and Kumait cities using a high-purity germanium (HPGe) detector, the radiological hazard parameters were evaluated. These include radium equivalent activity (Ra_{eq}), internal and external hazard indices (H_{in} and H_{ex}), gamma level index ($I\gamma$), absorbed gamma dose rates (D_{in} , D_{out} , and D_{tot}), annual effective dose equivalents ($AEDE_{in}$, $AEDE_{out}$, and $AEDE_{tot}$), excess lifetime cancer risks ($ELCR_{in}$, $ELCR_{out}$, and $ELCR_{tot}$), and annual gonadal dose equivalent (AGDE). The results of this study will provide baseline data for Ali Al-Sharqi and Kumait, which can serve as a foundation for future research in the region.

2. Materials and methods

2.1. The study area

The study area included the cities of Ali Al-Sharqi and Kumait, located in Misan province, Iraq. Ali Al-Sharqi is situated in the northeastern and northwestern parts of

the Misan, between latitudes 32°4'0" and 32°16'0"N and longitudes 46°44'0" and 46°52'0"E. The city covers an area of 1,513 km² and had a population of 30,000, as of 2014. Kumait, located in the northwestern part of Misan province, lies between latitudes 31°56'00" and 32°4'0"N and longitudes 46°44'0" and 46°56'0"E. It has an area of 1,554 km², with a population of 46,000 as of 2014.

2.2. Collection and preparation of samples

A total of 47 soil samples were collected (24 samples from Ali Al-Sharqi and 23 samples from Kumait). Each sample was collected from a 0 to 5 cm depth of the soil's surface at a predetermined location, as shown in Figure 1. The location coordinates were determined using an eTrex Vista HCX Global Positioning System with part number 20233 (Garmin, United States), as listed in Tables 1 and 2 and shown in Figures 2 and 3. The collected soil samples were placed in clean zip-lock bags, each labeled with a distinct code for identification. The samples were then transported to the lab for preparation. The samples were thoroughly mixed and sieved through a 75- μ m mesh (200 mm \times 50 mm) with the part number 60132000075 and serial number 03008399 (Retsch, Germany). The sieved samples were dried in a Herfy-28L electric oven (Denik Company, Korea) at 80°C for 2 h to eliminate moisture from the soil, followed by weighing. The samples were transferred into 500 mL Marinelli polyethylene beakers (GA-MA, United States), sealed with plastic tape to avoid the leakage of airborne radionuclides, and left to rest for 4 weeks. This waiting period allowed the daughter products to reach radioactive secular equilibrium with their parent isotopes (²²⁶Ra and radon-222) before being analyzed using a gamma spectrometer.²⁶

2.3. Analyzing samples and assessment of activity concentrations

The naturally occurring radionuclides in the soils were measured utilizing a gamma spectrometer system



Figure 1. Soil samples collection

Table 1. Natural radioactivity in soil specimens of Ali Al-Sharqi

Sample code	Sample location	Coordinates of location (GPS)		Radionuclide activity concentrations (Bq/kg)		
		Latitude (N)	Longitude (E)	²²⁶ Ra±S.D.	²³² Th±S.D.	⁴⁰ K±S.D.
S ₁	Al-Saacidia	32° 14×48.9"	46° 43×58.6"	16.7±2.8	17.5±3	158.9±8
S ₂	Abd Al-Khan	32° 14×45.3"	46° 43×06.1"	8.7±1.6	14.6±1.9	198.1±8.3
S ₃	Al-Akhua	32° 14×20.8"	46° 42×39.1"	13.2±2.4	14.2±2.6	169.8±6.8
S ₄	Palestine	32° 13×48.5"	46° 41×57.4"	13.1±2.3	13.2±2.4	178.4±7.8
S ₅	Al-Shiyahina	32° 13×01.3"	46° 41×24.8"	12.9±2.5	17.2±2.8	193.4±8.8
S ₆	Al-Karima	32° 11×31.4"	46° 41×09.7"	16.1±3.3	17.5±2.6	175.7±7.4
S ₇	Al-Hikma	32° 11×10.1"	46° 43×04.4"	12.9±2.1	17.2±2.5	179.2±9.6
S ₈	Al-Shahid Hikma	32° 10×59.6"	46° 42×49.6"	13.4±2.8	12.4±2.4	178.5±5.8
S ₉	Al-Awadi	32° 10×25.7"	46° 43×40.0"	13.2±2.5	14.1±2.3	182.2±9.1
S ₁₀	Al-Duwayjat	32° 08×19.8"	46° 43×06.1"	15.1±2.7	16.8±2.3	189.6±7.9
S ₁₁	Al-Jabha (Jabbar Mankhi)	32° 07×30.7"	46° 43×24.3"	11.9±3.2	15.4±2.4	189.5±7.9
S ₁₂	Ramadan	32° 07×26.9"	46° 43×46.9"	13.5±2.7	14.8±1.6	179.7±8.6
S ₁₃	Al-Huda	32° 07×06.6"	46° 44×23.6"	15.9±1.8	15.4±2.9	172.8±7.9
S ₁₄	Al-Salam	32° 07×16.0"	46° 43×48.0"	33.9±3.4	17.4±2.7	163.2±8.4
S ₁₅	Al-Mucalimin	32° 07×05.8"	46° 44×17.9"	21.5±2.5	8.3±2.9	172.8±8.7
S ₁₆	Al-Sadrayn	32° 06×54.7"	46° 44×14.4"	18.6±2.1	13.1±1.8	169.4±8.7
S ₁₇	Fateh (Abu Amid Al-Husseini)	32° 06×43.2"	46° 43×52.3"	16.7±2.5	11.4±2.2	201.3±8.7
S ₁₈	Al-Banda	32° 06×03.8"	46° 45×19.6"	10.9±2.6	14.4±2.4	179.8±6.5
S ₁₉	Al-Muhsiniyyah	32° 05×37.6"	46° 46×14.2"	8.9±1.5	16.3±2.8	192.2±7.9
S ₂₀	Al-Madlul	32° 04×26.5"	46° 47×24.1"	11.9±1.9	16.3±2.4	179.8±6.7
S ₂₁	Al-Jayazina	32° 04×16.9"	46° 47×40.0"	17±2.1	11.8±1.9	201.6±8.3
S ₂₂	Zawiat Al-Eadala	32° 04×16.6"	46° 51×20.5"	13.2±2.4	13.8±2.1	181.6±8.2
S ₂₃	Al-Eadala	32° 04×48.0"	46° 51×57.5"	11.2±1.9	15.3±1.7	179.5±5.8
S ₂₄	Al-Shahmania	32° 04×13.1"	46° 52×30.2"	22.4±3.6	16.4±2.3	172.3±7.5
Minimum				8.7±1.6	8.3±2.9	158.9±8
Maximum				33.9±3.4	17.5±3	201.6±8.3
Mean value±standard deviation				15.1±2.5	14.7±2.4	180.8±7.9
World average (UNSCEAR ¹)				35	30	400

Abbreviations: GPS: Global positioning system; ⁴⁰K: Potassium-40; ²²⁶Ra: Radium-226; S.D.: Standard deviation; ²³²Th: Thorium-232; UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

consisting of a P-type HPGe coaxial detector, model GC4020, number 10025 (Canberra, United States). This detector has a constant relative efficiency of 40% and a resolution at full-width half maximum of 2 keV at the 1,332 keV gamma line of ⁶⁰Co. A crystal diameter of 62.2 mm was operated under a high voltage bias of +3,000 V (DC). The detector was covered with a 12 cm thick lead shield to minimize the background radioactivity from its surrounding environment. All samples' gamma spectra were analyzed using Canberra

Genie-2000 version 3.1 software, which includes peak search, nuclide identification and activity, and uncertainty calculation modules. The energy and relative efficiency calibrations of the detector were performed using a standard multi-gamma source with certificate number 1035-SE-40524-16, type CBSS 2, serial number 280616 – 1597016 (Czech Metrology Institute, Czech Republic). This source contains 12 radionuclides, including ²⁴¹Am (59.54 keV), ¹⁰⁹Cd (88.3 keV), ¹³⁹Ce (165.85 keV), ⁵⁷Co (122.06 and

Table 2. Natural radioactivity in soil specimens of Kumait

Sample code	Sample location	Coordinates of location (GPS)		Radionuclide activity concentrations (Bq/kg)		
		Latitude (N)	Longitude (E)	²²⁶ Ra±S.D.	²³² Th±S.D.	⁴⁰ K±S.D.
S ₁	Shaltag Aeur	32° 03'×58.4"	46° 48'×57.4"	19.5±2.8	19.7±2.8	197.4±8.3
S ₂	Hamid Mutashar	32° 03'×55.8"	46° 49'×10.7"	15.8±2.7	26.6±3.6	221.3±11.5
S ₃	Al-Makayin	32° 03'×51.5"	46° 47'×38.2"	11.7±2.2	17.3±1.9	194.7±11.2
S ₄	Manati-Syid	32° 03'×38.0"	46° 50'×39.5"	12.5±1.7	9.7±1.9	156.7±6.2
S ₅	Khalaf Al-Alwan	32° 03'×07.3"	46° 53'×20.4"	17.5±2.8	19.4±2.7	295.2±9.4
S ₆	Al- Bedouins	32° 02'×59.4"	46° 50'×01.1"	14.8±1.9	18.5±2.4	183.5±8.2
S ₇	Al- Ziyadat	32° 03'×22.3"	46° 47'×13.9"	17.2±2.7	7.2±1.6	185.7±9.4
S ₈	Al-Hussein	32° 02'×27.8"	46° 52'×13.6"	14.5±2.1	17.4±2.8	184.7±8.4
S ₉	Al-Buckmer	32° 02'×16.0"	46° 47'×13.3"	13.4±2.7	21.7±2.4	231.7±11.6
S ₁₀	Al-Shuhadaa	32° 01'×58.3"	46° 52'×07.2"	13.6±2.7	15.3±2.5	179.5±6.7
S ₁₁	Al-Zahraa	32° 01'×58.0"	46° 53'×04.6"	9.6±1.7	11.6±1.8	203.4±11.2
S ₁₂	Al-Bithunuan	32° 01'×34.9"	46° 48'×31.1"	7.8±1.9	17.7±2.8	188.5±8.3
S ₁₃	Al-Dujaila	32° 01'×17.2"	46° 44'×09.8"	11.2±1.3	14.6±2.2	185.7±7.5
S ₁₄	Al-Sumud	32° 01'×00.7"	46° 53'×51.3"	13.5±2.3	13.5±1.8	192.5±7.8
S ₁₅	Amer Shehaza	32° 00'×25.5"	46° 51'×07.5"	10.6±1.3	18.2±2.7	189.4±7.5
S ₁₆	Abd-Al	31° 59'×39.3"	46° 54'×39.2"	13.4±1.3	16.6±2.1	179.4±6.3
S ₁₇	Al-Jidiya	31° 58'×46.8"	46° 48'×58.2"	14.5±2.6	9.3±1.4	138.4±6.3
S ₁₈	Al- Suwaydiyyn	31° 58'×22.9"	46° 48'×34.8"	10.9±1.8	16.7±2.3	179.2±6
S ₁₉	Al-Kolbe	31° 57'×54.3"	46° 47'×43.5"	4.6±1.4	12.7±2.2	182.4±7.2
S ₂₀	Saad River	31° 57'×20.6"	46° 55'×50.5"	9.5±1.4	18.5±2.7	216.5±9.7
S ₂₁	Al-Bueli	31° 55'×40.1"	46° 54'×40.5"	12.8±2.1	16.9±2.5	179.4±6.9
S ₂₂	Al- Jaibeen	31° 54'×51.5"	46° 55'×38.5"	16.4±2.2	28.7±3.2	194.8±11.4
S ₂₃	Al-Safha	31° 54'×00.6"	46° 56'×31.2"	27.6±2.6	29.5±2.8	192.9±11.7
Minimum				4.6±1.4	7.2±1.6	138.4±6.3
Maximum				27.6±2.6	29.5±2.8	295.2±9.4
Mean value±standard deviation				13.6±2.1	17.2±2.4	193.6±8.6
World average (UNSCEAR ¹)				35	30	400

Abbreviations: GPS: Global positioning system; ⁴⁰K: Potassium-40; ²²⁶Ra: Radium-226; S.D.: Standard deviation; ²³²Th: Thorium-232; UNSCEAR: United nations scientific committee on the effects of atomic radiation.

136.47 keV), ⁶⁰Co (1,173.24 and 1,332.5) keV, ¹³⁷Cs (661.66 keV), ¹¹³Sn (391.69 keV), ⁸⁵Sr (514 keV), ⁸⁸Y (898.02 and 1,836.08 keV), ⁵¹Cr (320 keV), ⁵⁴Mn (834.8 keV), and ⁶⁵Zn (1,116 keV) in the energy range of 59.54 keV to 1,836.08 keV with a mass of 441.0 g, density of 0.98 ± 0.01 g/cm³, and a volume of 450.0 ± 4.5 cm³. For ²²⁶Ra activity calculation, the gamma-ray peaks of ²¹⁴Pb at 295.2 and 351.9 keV, and ²¹⁴Bi at 609.3, 1,120.3, and 1,764.5 keV were used under equilibrium conditions. For ²³²Th activities, the gamma-ray energy peaks of ²¹²Pb at 238.6 keV, ²²⁸Ac at 338.4, 463, 911.2, 964.6, and 969.0 keV, and ²⁰⁸Tl at 583.2 and 860.6 keV were analyzed. The peak energy of

1,460.80 keV was utilized to determine the concentration of ⁴⁰K.²⁷ The instrument MEFTRAN was selected to determine the true coincidence summing correction and self-absorption correction. The program uses Genie 2,000 to determine self-absorption and genuine chance summation corrections. The input data consist of the material composition of the detection, measuring instrument, and the sample. The bulk density of the material, the chemical formulations of any elements or compounds (e.g., SiO₂, Ge, H₂O), and the quantity of each (in weight percent) were inputted into the program. The tool generated a file containing the material attenuation coefficients for various gamma radiation

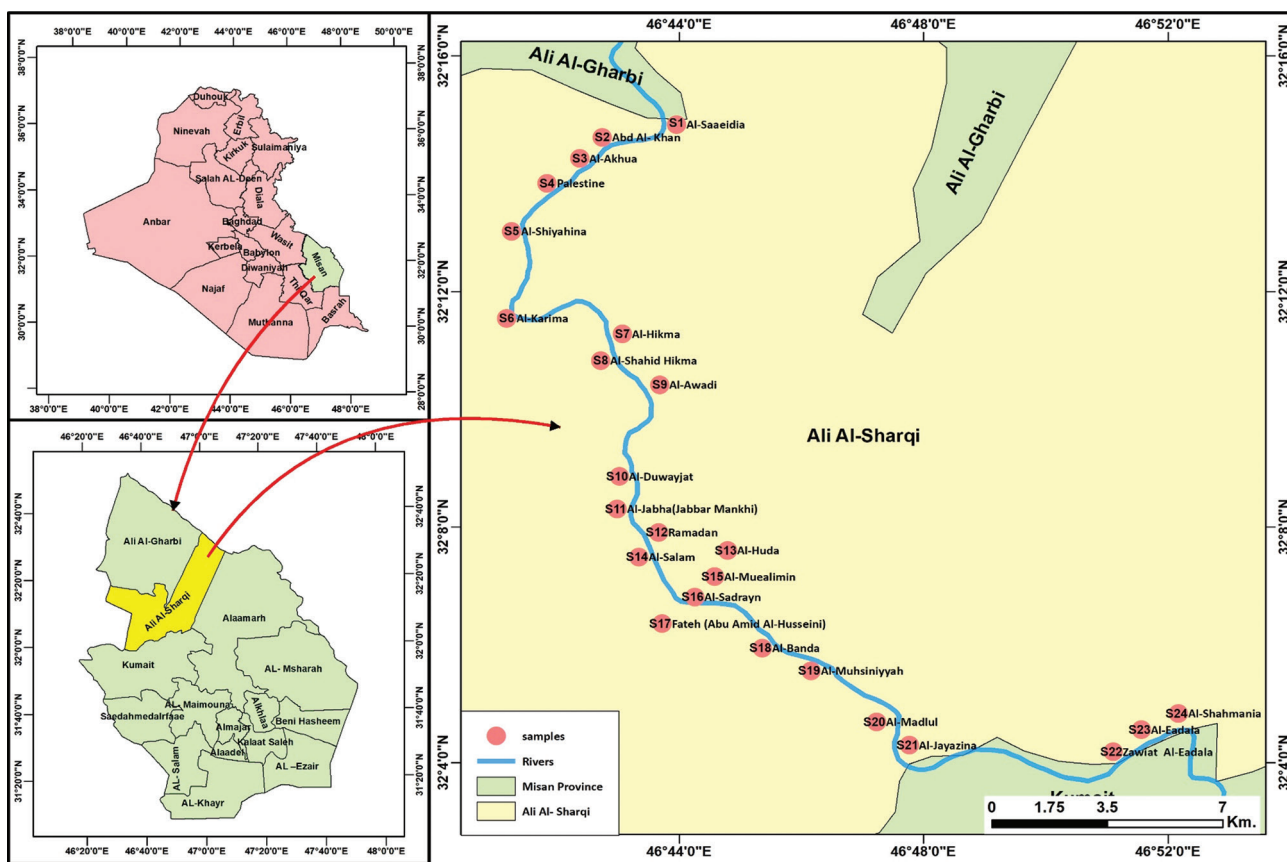


Figure 2. Soil sample locations in Ali Al-Sharqi city

energies and a file containing the parameters provided. In addition, the detector's parameters and the measuring geometry were established. The detector is composed of specific materials and has specific measurements, as indicated by the manufacturer's documentation. The shape of the measurement is determined by the position of the monitor and sample with one another, as well as the material and dimensions of the measuring vessel. A 0.5 L cylindrical polypropylene measure container was placed directly on the detector head. The efficiency of the detector, the material of the calibration reference, and the material of the tested sample are other factors considered when determining the amount of gamma radiation absorbed by the sample and how to account for self-absorption at specific radiation energies. Soil samples were placed sequentially on the detector and counted for 3,600 s. The efficiency and minimum detectable activity for radionuclides ^{226}Ra , ^{232}Th , and ^{40}K in soil were determined (Table 3).

The background distribution that resulted from natural radionuclides in the areas surrounding the detector was also measured by counting an empty Marinelli beaker the same way the samples were prepared in the laboratory. After calculating and

subtracting the background, activity concentrations (A) of ^{226}Ra , ^{232}Th , and ^{40}K in each sample were computed using Equation I,²⁷

$$A \left(\frac{\text{Bq}}{\text{kg}} \right) = \frac{A_n}{\epsilon p_{\gamma} M t} \quad (\text{I})$$

Where A_n is the net count rate under the full energy peaks, ϵ is the detector efficiency at the specified energy, p_{γ} is the absolute transition probability, M is the sample mass (kg), and t is the counting time (second).

2.4. Evaluation of radiation health risk parameters

Radiation risk parameters were evaluated to obtain relevant information on the radiation health status of the research areas.

2.4.1. Radium equivalent activity

The radium equivalent activity is a very useful guideline in organizing the safety standards in radiation protection for humans, and it was calculated using Equation II.^{28,29} It is assumed that 370 Bq/kg of ^{226}Ra , 259 Bq/kg of ^{232}Th , and 4,810 Bq/kg of ^{40}K produce the same gamma-ray dose rate,

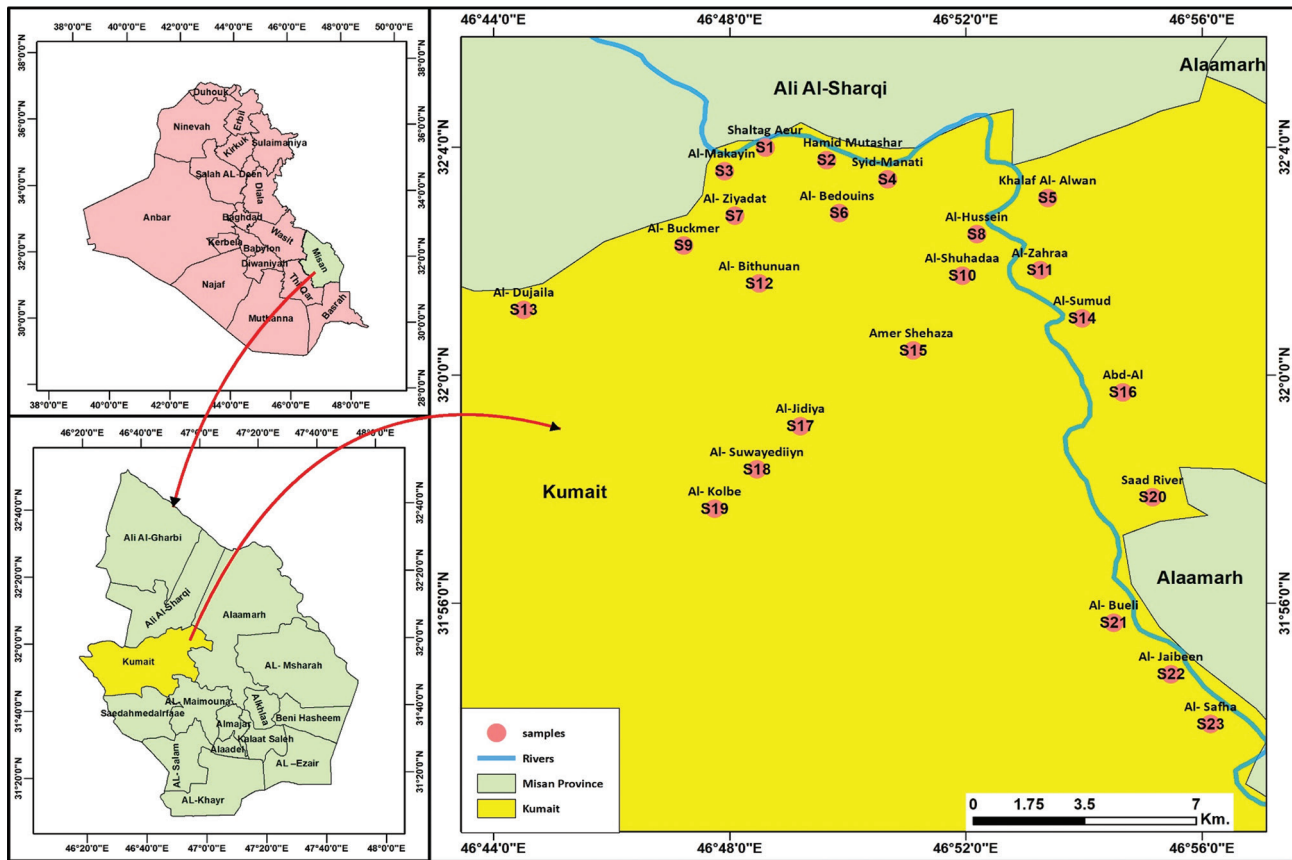


Figure 3. Soil sample locations in Kumait city

Table 3. The efficiency and minimum detectable activity for radium-226, thorium-232, and potassium-40

Nuclide	Efficiency	Minimum detectable activity (Bq/kg)
Radium-226	0.06103	1.831
Thorium-232	0.01142	2.632
Potassium-40	0.0113	2.79

$$Ra_{eq} = A_{Ra} + (1.43 \times A_{Th}) + (0.077 \times A_K) \quad (II)$$

Where A_{Ra} , A_{Th} , and A_K are the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in Bq/kg, respectively.

2.4.2. Hazard index

To account for the hazards associated with the external and internal exposure of the radiation emanating from ^{226}Ra , ^{232}Th , and ^{40}K in the studied soil samples, the internal hazard index (H_{in}) and external hazard index (H_{ex}) were determined using Equations III and IV.³⁰⁻³²

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

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

The prime objective of H_{in} and H_{ex} is to limit the radiation dose to a dose equivalent limit of 1 mSv/year. Thus, their values must be less than unity (i.e. ≤ 1) for the radiation hazards to be negligible.

2.4.3. Gamma index

The radioactivity level index (I_γ) can be used to estimate the gamma-radiation hazard levels, typically those associated with natural radionuclides, and it was evaluated using Equation V.^{33,34}

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (V)$$

The value of I_γ must be less than unity to keep the radiation hazard insignificant.

2.4.4. Absorbed dose rate

The absorbed dose rate in the air is measured one meter above the ground surface and is used to express the radiation dose received in the open air. This parameter is critical for evaluating radiation risk. The indoor,

outdoor, and total absorbed gamma dose rates (D_{in} , D_{out} , and D_{tot}) were computed using Equations VI-VIII.^{35,36}

$$D_{in} \left(\frac{nGy}{h} \right) = (0.92 \times A_{Ra}) + (1.1 \times A_{Th}) + (0.081 \times A_K) \quad (VI)$$

$$D_{out} \left(\frac{nGy}{h} \right) = (0.462 \times A_{Ra}) + (0.604 \times A_{Th}) + (0.0417 \times A_K) \quad (VII)$$

$$D_{tot} \left(\frac{nGy}{h} \right) = D_{in} + D_{out} \quad (VIII)$$

2.4.5. AEDE

To estimate the AEDE, one has to consider the conversion coefficient 0.7 Sv/Gy, which is used to convert the absorbed rate in the air to human effective dose equivalent with indoor and outdoor occupancy of 80 and 20%, respectively. The indoor, outdoor, and total annual effective dose rates ($AEDE_{in}$, $AEDE_{out}$, and $AEDE_{tot}$) were determined using Equations IX-XI,³⁷⁻³⁹

$$AEDE_{in} \left(\frac{mSv}{y} \right) = D_{in} \left(\frac{nGy}{h} \right) \times 0.7 \left(\frac{Sv}{Gy} \right) \times 0.8 \times 8760 \frac{h}{y} \times 10^{-6} \quad (IX)$$

$$AEDE_{out} \left(\frac{mSv}{y} \right) = D_{out} \left(\frac{nGy}{h} \right) \times 0.7 \left(\frac{Sv}{Gy} \right) \times 0.2 \times 8760 \frac{h}{y} \times 10^{-6} \quad (X)$$

$$AEDE_{tot} \left(\frac{mSv}{y} \right) = AEDE_{in} + AEDE_{out} \quad (XI)$$

2.4.6. ELCR

ELCR is used in radiation protection assessment to predict the probability of individuals' cancer development over a lifetime due to low radiation exposure levels. Based on the calculated values of annual effective dose rates, the indoor, outdoor, and total lifetime cancer risks ($ELCR_{in}$, $ELCR_{out}$, and $ELCR_{tot}$) were calculated using the Equations XII-XIV,^{7,40,41}

$$ELCR_{in} = AEDE_{in} \left(\frac{mSv}{y} \right) \times DL \times RF \quad (XII)$$

$$ELCR_{out} = AEDE_{out} \left(\frac{mSv}{y} \right) \times DL \times RF \quad (XIII)$$

$$ELCR_{tot} = ELCR_{in} + ELCR_{out} \quad (XIV)$$

Where DL is the duration of life (70 years), and RF is the risk factor (The International Commission on Radiological Protection 60 uses values of 0.05 Sv⁻¹ for the public).

2.4.7. AGDE

Radiation can have various effects on living organisms. These effects may kill a cell, cause it to change, or not affect the DNA. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) primarily focuses on the gonads, active bone marrow, and the cells on the bone surface when assessing radiation impacts. Equation XV was used to calculate the AGDE resulting from the radiation emitted by ²²⁶Ra, ²³²Th, and ⁴⁰K^{42,43} to determine the radiation risk to these tissues.

$$AGDE \left(\frac{\mu Sv}{y} \right) = (3.09 \times A_{Ra}) + (4.18 \times A_{Th}) + (0.314 \times A_K) \quad (XV)$$

3. Results and discussion

3.1. Activity concentrations of radionuclides

The results of activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in the soils of Ali Al-Sharqi and Kumait cities are presented in Tables 1 and 2.

The activity concentrations of ²²⁶Ra, ²³²Th, and ⁴⁰K in Ali Al-Sharqi varied from 8.7 ± 1.6 (S₂) to 33.9 ± 3.4 (S₁₄) Bq/kg, 8.3 ± 2.9 (S₁₅) to 17.5 ± 3 (S₁) Bq/kg, and 158.9 ± 8 (S₁) to 201.6 ± 8.3 (S₂₁) Bq/kg with an average value of 15.1 ± 2.5 Bq/kg, 14.7 ± 2.4 Bq/kg, and 180.8 ± 7.9 Bq/kg, respectively (Table 1). In Kumait, the activity concentrations of related radionuclides were varied from 4.6 ± 1.4 (S₁₉) to 27.6 ± 2.6 (S₂₃) Bq/kg, 7.2 ± 1.6 (S₇) to 29.5 ± 2.8 (S₂₃) Bq/kg, and 138.4 ± 6.3 (S₁₇) to 295.2 ± 9.4 (S₅) Bq/kg with an average value of 13.6 ± 2.1 Bq/kg, 17.2 ± 2.4 Bq/kg, and 193.6 ± 8.6 Bq/kg, respectively, for ²²⁶Ra, ²³²Th, and ⁴⁰K (Table 2).

It can be noted from Tables 1 and 2 that the mean activity concentrations of ²²⁶Ra in Ali Al-Sharqi soil were higher than in Kumait. In comparison, the mean activity concentrations of ²³²Th and ⁴⁰K in Kumait soil were higher than in Ali Al-Sharqi.

The findings indicate that average values of ²²⁶Ra, ²³²Th, and ⁴⁰K in Ali Al-Sharqi and Kumait soil samples are below the global average of 35, 30, and 400 Bq/kg, respectively.⁴⁴ For this study, a coverage

factor of $k = 2$ was selected for the uncertainty analysis, corresponding to a confidence level of approximately 95%.

3.2. Comparison of the natural radioactivity results

The average activity concentrations of natural radionuclides in soil specimens of the research areas (Ali Al-Sharqi and Kumait) were compared with identical measurements conducted in the world and Iraq, as demonstrated in Table 4.

The mean concentration of ^{226}Ra is lower than other reported values. The average activity of ^{232}Th is higher than China (Guangyao), Saudi Arabia (Dammam), and Kuwait and Iraq (Al-Sadr) but lower than Algeria (Setif), Nigeria (southwestern region), Malaysia (Peninsular Malaysia), Pakistan (Waziristan), Yemen (Sana'a), Iran (Ramsar and Mahallat), Turkey (Samsun), Jordan (northern highlands), Iraq (Erbil), Iraq (Wassit), Iraq (Thi-Qar), and Iraq (Abu Al Khasib).⁴⁵⁻⁵¹ Furthermore, the mean activity for ^{40}K is lower than in these previous studies.

3.3. Radiological hazard

Tables 5 and 6 show the radiological risk parameters obtained from soil samples in the study areas.

The levels of Ra_{eq} ranged from 44.8 (S_2) to 71.3 (S_{14}) Bq/kg with an average of 50.2 ± 5.7 Bq/kg in Ali Al-Sharqi (Table 5) and from 36.8 (S_{19}) to 84.6 (S_{23}) Bq/kg with an average of 53.2 ± 12.1 Bq/kg in Kumait (Table 6). All values of Ra_{eq} were lower than the worldwide average value of 370 Bq/kg.¹

The values of H_{in} varied from 0.1 (S_2) to 0.3 (S_{14}) with an average of 0.2 ± 0.02 in Ali Al-Sharqi (Table 5) and from 0.1 ($S_4, S_{11}, S_{12}, S_{17},$ and S_{19}) to 0.3 (S_{23}) with an average of 0.2 ± 0.04 in Kumait (Table 6). Whereas values of H_{ex} varied from 0.1 (S_{1-13} and S_{15-23}) to 0.2 (S_{14} and S_{24}) with an average of 0.1 ± 0.01 in Ali Al-Sharqi (Table 5) and from 0.09 (S_{19}) to 0.2 ($S_{15}, S_{22}, S_5,$ and S_9) with an average of 0.1 ± 0.03 in Kumait (Table 6). All these values of H_{in} and H_{ex} were less than the value of global values.¹

The levels of I_{γ} varied from 0.2 (S_{1-13} and S_{15-24}) to 0.3 (S_{14}) with an average of 0.2 ± 0.01 in Ali Al-Sharqi

Table 4. Mean activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in the present study compared to literature values

Country	Mean activity concentration (Bq/kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Guangyao, China	26.8	8.87	453.81	Wang and Ye ⁴²
Setif, Algeria	47	33	329	Boukhenfouf and Boucenna ⁴⁵
Southwestern region, Nigeria	54.5	91.1	286.5	Ajayi ¹²
Peninsular Malaysia	57	68	427	Almayahi <i>et al.</i> ⁴⁶
Waziristan, Pakistan	69.5	123.68	453.60	Khan <i>et al.</i> ²⁴
Sana'a, Yemen	48.2	41.7	939.1	Harb <i>et al.</i> ⁴⁷
Dammam, Saudi Arabia	16.73	10.40	419.78	Al-Ghamdi ⁴³
Kuwait	16.99	12.70	333.20	Bajoga <i>et al.</i> ²³
Ramsar and Mahallat, Iran	24.3	25.8	457.7	Kardan <i>et al.</i> ⁴⁸
Samsun, Turkey	19	22	521	Tufan and Bostancı ⁴⁹
Jordan	42.5	26.7	291.1	Al-Hamarneh and Awadallah ⁵⁰
Erbil, Iraq	25.61	20.15	326.64	Hussein ⁵¹
Al-Sadr, Iraq	15.35	13.31	351.39	Al-Alawy <i>et al.</i> ⁴⁴
Wassit, Iraq	19.420	18.487	204.266	Nafee <i>et al.</i> ¹⁸
Thi-Qar, Iraq	29.2	22.7	304.6	Najam <i>et al.</i> ¹⁹
Abu Al Khasib, Iraq	58.44	19.38	321.76	Mohammed and Ahmed ³⁹
World average	35	30	400	UNSCEAR ¹
Ali Al- Sharqi, Iraq	15.1	14.7	180.8	Present study
Kumait, Iraq	13.6	17.2	193.6	

Abbreviations: ^{40}K : Potassium-40; ^{226}Ra : Radium-226; ^{232}Th : Thorium-232; UNSCEAR: United nations scientific committee on the effects of atomic radiation.

Table 5. Radiological risk indices in Ali Al-Sharqi soil samples

Sample code	Radiation hazard indices														
	Ra _{sq} (Bq/kg)	H _{in}	H _{ex}	I _y	D _{in} (nGy/h)	D _{out} (nGy/h)	D _{tot} (nGy/h)	AED _{En} (mSv/y)	AEDE _{out} (mSv/y)	AEDE _{in} (mSv/y)	AEDE _{tot} (mSv/y)	ELCR _{in} (×10 ⁻³)	ELCR _{out} (×10 ⁻³)	ELCR _{tot} (×10 ⁻³)	AGDE (μSv/y)
S ₁	54	0.2	0.1	0.2	47.5	24.9	72.4	0.2	0.03	0.23	0.23	0.8	0.1	0.9	174.6
S ₂	44.8	0.1	0.1	0.2	40.1	21.1	61.2	0.2	0.02	0.22	0.22	0.7	0.09	0.79	150.1
S ₃	46.6	0.2	0.1	0.2	41.5	21.8	63.3	0.2	0.02	0.22	0.22	0.7	0.09	0.79	153.5
S ₄	45.7	0.2	0.1	0.2	41	21.5	62.5	0.2	0.02	0.22	0.22	0.7	0.09	0.79	151.7
S ₅	52.4	0.2	0.1	0.2	46.5	24.4	70.9	0.2	0.02	0.22	0.22	0.8	0.1	0.9	172.5
S ₆	54.7	0.2	0.1	0.2	48.3	25.3	73.6	0.2	0.03	0.23	0.23	0.8	0.1	0.9	178.1
S ₇	51.3	0.2	0.1	0.2	45.3	23.8	69.1	0.2	0.02	0.22	0.22	0.8	0.1	0.9	168
S ₈	44.9	0.2	0.1	0.2	40.4	21.1	61.5	0.2	0.02	0.22	0.22	0.7	0.09	0.79	149.3
S ₉	47.4	0.2	0.1	0.2	42.4	22.2	64.6	0.2	0.02	0.22	0.22	0.7	0.09	0.79	156.9
S ₁₀	53.7	0.2	0.1	0.2	47.7	25	72.7	0.2	0.03	0.23	0.23	0.8	0.1	0.9	176.4
S ₁₁	48.5	0.2	0.1	0.2	43.2	22.7	65.9	0.2	0.02	0.22	0.22	0.7	0.09	0.79	160.6
S ₁₂	48.5	0.2	0.1	0.2	43.3	22.7	66	0.2	0.02	0.22	0.22	0.7	0.09	0.79	160
S ₁₃	51.2	0.2	0.1	0.2	45.6	23.9	69.5	0.2	0.02	0.22	0.22	0.8	0.1	0.9	167.8
S ₁₄	71.3	0.3	0.2	0.3	63.5	33	96.5	0.3	0.04	0.34	0.34	1.1	0.14	1.24	228.7
S ₁₅	46.7	0.2	0.1	0.2	42.9	22.2	65.1	0.2	0.02	0.22	0.22	0.7	0.09	0.79	155.4
S ₁₆	50.4	0.2	0.1	0.2	45.2	23.6	68.8	0.2	0.02	0.22	0.22	0.8	0.1	0.9	165.4
S ₁₇	48.5	0.2	0.1	0.2	44.2	23	67.2	0.2	0.02	0.22	0.22	0.8	0.09	0.89	162.5
S ₁₈	45.3	0.2	0.1	0.2	40.4	21.2	61.6	0.2	0.02	0.22	0.22	0.7	0.09	0.79	150.3
S ₁₉	47	0.2	0.1	0.2	41.7	22	63.7	0.2	0.02	0.22	0.22	0.7	0.09	0.79	156
S ₂₀	49.1	0.2	0.1	0.2	43.4	22.8	66.2	0.2	0.02	0.22	0.22	0.7	0.09	0.79	161.4
S ₂₁	49.4	0.2	0.1	0.2	44.9	23.4	68.3	0.2	0.02	0.22	0.22	0.8	0.1	0.9	165.2
S ₂₂	46.9	0.2	0.1	0.2	42	22	64	0.2	0.02	0.22	0.22	0.7	0.09	0.79	155.5
S ₂₃	46.9	0.2	0.1	0.2	41.7	21.9	63.6	0.2	0.02	0.22	0.22	0.7	0.09	0.79	154.9
S ₂₄	59.1	0.2	0.2	0.2	52.6	27.4	80	0.3	0.03	0.33	0.33	0.9	0.11	1.01	191.9
Minimum	44.8	0.1	0.1	0.2	40.1	21.1	61.2	0.2	0.02	0.22	0.22	0.7	0.09	0.79	149.3
Maximum	71.3	0.3	0.2	0.3	63.5	33	96.5	0.3	0.04	0.34	0.34	1.1	0.14	1.24	228.7
Mean value±standard deviation	50.2±5.7	0.2±0.02	0.1±0.01	0.2±0.01	44.8±5	23.5±2.6	68.3±7.5	0.2±0.02	0.02±0.003	0.2±0.03	0.2±0.03	0.8±0.08	0.1±0.01	0.9±0.09	165.3±17.1
World average (UNSCEAR)	370	≤1	≤1	≤1	84	59	143	0.41	0.07	0.48	0.48	1.16	0.29	1.45	300

Abbreviations: AEDE: Annual effective dose equivalents; AGDE: Annual gonadal dose equivalent; D: Absorbed gamma dose rates; ECLR: Excess lifetime cancer risk; H_{ex}: External hazard index; H_{in}: Internal hazard index; I_y: Internal; I_{out}: External; Ra_{sq}: Radium equivalent activity; I_{tot}: Total; UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

Table 6. Radiological risk indices in Kumait soil samples

Sample code	Radiation hazard indices													
	R _{req} (Bq/kg)	H _{in}	H _{ex}	I _v	D _{in} (nGy/h)	D _{out} (nGy/h)	D _{tot} (nGy/h)	AEDE _{in} (mSv/y)	AEDE _{out} (mSv/y)	AEDE _{tot} (mSv/y)	ELCR _{in} (×10 ⁻³)	ELCR _{out} (×10 ⁻³)	ELCR _{tot} (×10 ⁻³)	AGDE (μSv/y)
S ₁	62.9	0.2	0.2	0.2	55.6	29.1	84.7	0.3	0.03	0.33	1	0.1	1.1	204.6
S ₂	70.9	0.2	0.2	0.3	61.7	32.6	94.3	0.3	0.03	0.33	1.1	0.1	1.2	229.5
S ₃	51.4	0.2	0.1	0.2	45.6	24	69.6	0.2	0.02	0.22	0.8	0.1	0.9	169.6
S ₄	38.4	0.1	0.1	0.1	34.9	18.2	53.1	0.2	0.02	0.22	0.6	0.07	0.67	128.4
S ₅	68	0.2	0.2	0.3	61.4	32.1	93.5	0.3	0.03	0.33	1.1	0.1	1.2	227.9
S ₆	55.4	0.2	0.1	0.2	48.8	25.7	74.5	0.2	0.03	0.23	0.8	0.1	0.9	180.7
S ₇	41.8	0.2	0.1	0.2	38.8	20	58.8	0.2	0.02	0.22	0.7	0.08	0.78	141.6
S ₈	53.6	0.2	0.1	0.2	47.4	24.9	72.3	0.2	0.03	0.23	0.8	0.1	0.9	175.5
S ₉	62.3	0.2	0.2	0.2	55	29	84	0.3	0.03	0.33	0.9	0.1	1	204.9
S ₁₀	49.3	0.2	0.1	0.2	43.9	23	66.9	0.2	0.02	0.22	0.8	0.09	0.89	162.3
S ₁₁	41.8	0.1	0.1	0.2	38.1	19.9	58	0.2	0.02	0.22	0.7	0.08	0.78	142
S ₁₂	47.6	0.1	0.1	0.2	41.9	22.2	64.1	0.2	0.02	0.22	0.7	0.09	0.79	157.3
S ₁₃	46.4	0.2	0.1	0.2	41.4	21.7	63.1	0.2	0.02	0.22	0.7	0.09	0.79	153.9
S ₁₄	47.6	0.2	0.1	0.2	42.9	22.4	65.3	0.2	0.02	0.22	0.7	0.09	0.79	158.6
S ₁₅	51.2	0.2	0.1	0.2	45.1	23.8	68.9	0.2	0.02	0.22	0.8	0.1	0.9	168.3
S ₁₆	51	0.2	0.1	0.2	45.1	23.7	68.8	0.2	0.02	0.22	0.8	0.1	0.9	167.1
S ₁₇	38.5	0.1	0.1	0.1	34.8	18.1	52.9	0.2	0.02	0.22	0.6	0.07	0.67	127.1
S ₁₈	48.6	0.2	0.1	0.2	42.9	22.6	65.5	0.2	0.02	0.22	0.7	0.09	0.79	159.8
S ₁₉	36.8	0.1	0.09	0.1	33	17.4	50.4	0.2	0.02	0.22	0.6	0.07	0.67	124.6
S ₂₀	52.6	0.2	0.1	0.2	46.6	24.6	71.2	0.2	0.03	0.23	0.8	0.1	0.9	174.7
S ₂₁	50.8	0.2	0.1	0.2	44.9	23.6	68.5	0.2	0.02	0.22	0.8	0.1	0.9	166.5
S ₂₂	72.4	0.2	0.2	0.3	62.4	33	95.4	0.3	0.04	0.34	1.1	0.1	1.2	231.8
S ₂₃	84.6	0.3	0.2	0.3	73.5	38.6	112.1	0.4	0.04	0.44	1.3	0.2	1.5	269.2
Minimum	36.8	0.1	0.09	0.1	33	17.4	50.4	0.2	0.02	0.22	0.6	0.07	0.67	124.6
Maximum	84.6	0.3	0.2	0.3	73.5	38.6	112.1	0.4	0.04	0.44	1.3	0.2	1.5	269.2
Mean	53.2±12.1	0.2±0.04	0.1±0.03	0.2±0.04	47.2±10.1	24.8±5.4	72±15.5	0.2±0.04	0.03±0.006	0.3±0.06	0.8±0.2	0.1±0.02	0.9±0.2	175±37.2
value±standard deviation														
World average (UNSCEAR)	370	≤1	≤1	≤1	84	59	143	0.41	0.07	0.48	1.16	0.29	1.45	300

Abbreviations: AEDE: Annual effective dose equivalents; AGDE: Annual gonadal dose equivalent; D: Absorbed gamma dose rates; ECLR: Excess lifetime cancer risk; H_{ex}: External hazard index; H_{in}: Internal hazard index; I_v: Internal; D_{out}: External; Ra_{eq}: Radium equivalent activity; I_{tot}: Total; UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

Table 7. Radiological hazard indices in the investigated soil samples compared to literature values

Country	Radiological hazard indices										References	
	R_{req} (Bq/kg)	H_{in}	H_{ex}	I_{γ}	D_{in} (nGy/h)	D_{out} (nGy/h)	$AEDE_{\text{in}}$ (mSv/y)	$AEDE_{\text{out}}$ (mSv/y)	$ELCR_{\text{in}}$ ($\times 10^{-3}$)	$ELCR_{\text{out}}$ ($\times 10^{-3}$)		AGDE ($\mu\text{Sv/y}$)
Sicily, Italy	72	-	-	-	-	34	0.32	0.04	-	-	-	Lanzo <i>et al.</i> ¹⁴
Mounana, Gabon	2,928.75	15.51	7.92	-	-	1,352.76	9.30	1.66	-	-	-	Mouandza <i>et al.</i> ²¹
Uttara Kannada, India	140.74	0.48	0.38	0.51	-	64.84	0.32	0.08	-	1.59	478.8	Suresh <i>et al.</i> ³²
Punjab, Pakistan	179.26	0.642	0.482	-	-	85.045	0.417	0.105	-	-	-	Rahman <i>et al.</i> ⁴
Shabwah and Hadramout, Yemen	94.73	-	0.26	0.36	-	46.50	-	0.031	-	-	-	Nafee <i>et al.</i> ¹⁸
Taghdoua, Saudi Arabia	-	-	-	-	70	37	0.3	0.1	1.3	0.2	-	Aydarous <i>et al.</i> ²⁵
Fars, Iran	-	-	-	-	-	32.6	0.189	0.039	-	-	-	Faghghi <i>et al.</i> ⁵³
Bolu, Turkey	62.8	-	0.2	0.2	-	29.9	-	0.036	-	0.13	209.7	Dizman <i>et al.</i> ²⁷
Ma'an, Jordan	94.21	0.41	0.25	-	-	37.15	-	0.045	-	-	-	Saleh and Shaye ⁵⁵
Tulkarem, Palestine	72	0.3	0.21	0.55	-	35.5	-	0.044	-	-	-	Thabaynehxx
Pshdar, Iraq	69.83	0.227	0.200	-	-	33.26	-	0.040	-	-	-	Muhammad <i>et al.</i> ⁵⁴
Kirkuk, Iraq	81.182	0.286	0.210	0.603	-	38.618	0.189	0.048	-	-	-	Taqi <i>et al.</i> ²⁰
Baghdad, Iraq	74.383	0.248	0.206	0.577	-	36.320	0.178	0.045	-	-	-	Mohammed <i>et al.</i> ³⁹
Al-Sadr, Iraq	61.434	0.208	0.166	-	57.974	29.535	0.285	0.037	0.997	0.128	-	Al-Alawy <i>et al.</i> ⁴⁴
Ad Dayr, Iraq	-	-	-	-	91.72	46.16	0.45	0.06	1.48	0.19	-	Mohammed and Ahmed ³⁸
World average	370	$1 \geq$	$1 \geq$	≤ 1	84	59	0.41	0.07	1.16	0.29	300	UNSCEAR ¹
Ali Al- Sharqi, Iraq	50.2	0.2	0.1	0.2	44.8	23.5	0.2	0.02	0.8	0.1	165.3	Present study
Kumait, Iraq	53.2	0.2	0.1	0.2	47.2	24.8	0.2	0.03	0.8	0.1	175	

Note: Refers to not available.

Abbreviations: AEDE: Annual effective dose equivalents; AGDE: Annual gonadal dose equivalent; D: Absorbed gamma dose rates; ECLR: Excess lifetime cancer risk;

H_{ex} : External hazard index; H_{in} : Internal hazard index; I_{in} : Internal; I_{out} : External; Raecq: Radium equivalent activity; tot: Total; UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation.

(Table 5) and from 0.1 (S_4 , S_{17} , and S_{19}) to 0.3 (S_2 , S_5 , S_{22} , and S_{23}) with an average of 0.2 ± 0.04 in Kumait (Table 6). The determined values of $I\gamma$ were below global values.¹

The levels of D_{in} ranged from 40.1 (S_2) to 63.5 (S_{14}) nGy/h with an average of 44.8 ± 5 nGy/h in Ali Al-Sharqi (Table 5) and from 33 (S_{19}) to 73.5 (S_{23}) nGy/h with an average of 47.2 ± 10.1 nGy/h in Kumait (Table 6). D_{out} values ranged from 21.1 (S_2 and S_8) to 33 (S_{14}) nGy/h with an average of 23.5 ± 2.6 nGy/h in Ali Al-Sharqi (Table 5) and from 17.4 (S_{19}) to 38.6 (S_{23}) nGy/h with an average of 24.8 ± 5.4 nGy/h in Kumait (Table 6). Furthermore, the values of D_{tot} ranged from 61.2 (S_2) to 96.5 (S_{14}) nGy/h with an average of 68.3 ± 7.5 nGy/h in Ali Al-Sharqi (Table 5) and from 50.4 (S_{19}) to 112.1 (S_{23}) nGy/h with an average of 72 ± 15.5 nGy/h in Kumait (Table 6). These computed air-absorbed dose rates were below the world average of 84 nGy/h, 59 nGy/h, and 143 nGy/h, respectively, for D_{in} , D_{out} , and D_{tot} .¹

The $AEDE_{in}$ values varied from 0.2 (S_{1-13} and S_{15-23}) to 0.3 (S_{14} and S_{24}) mSv/y with a mean of 0.2 ± 0.02 mSv/y in Ali Al-Sharqi (Table 5) and from 0.2 (S_3 , S_4 , S_{6-8} , and S_{10-21}) to 0.4 (S_{23}) mSv/y with a mean value of 0.2 ± 0.04 mSv/y in Kumait (Table 6). $AEDE_{out}$ values varied from 0.02 (S_{2-5} , S_{7-9} , S_{11-13} , and S_{15-23}) to 0.04 (S_{14}) mSv/y with a mean value of 0.02 ± 0.003 mSv/y in Ali Al-Sharqi (Table 5) and from 0.02 (S_3 , S_4 , S_7 , S_{10-20} , and S_{21}) to 0.04 (S_{22} and S_{23}) mSv/y with a mean value of 0.03 ± 0.006 mSv/y in Kumait (Table 6). In addition, $AEDE_{tot}$ values varied from 0.22 (S_{2-5} , S_{7-9} , S_{11-13} , and S_{15-23}) to 0.34 (S_{14}) mSv/y with a mean value of 0.2 ± 0.03 mSv/y in Ali Al-Sharqi (Table 5) and from 0.22 (S_3 , S_4 , S_7 , S_{10-19} , and S_{21}) to 0.44 (S_{23}) mSv/y with a mean value of 0.3 ± 0.06 mSv/y in Kumait (Table 6). The estimated values of AEDE were lower than the worldwide average values of 0.41 mSv/y, 0.07 mSv/y, and 0.48 mSv/y, respectively, for $AEDE_{in}$, $AEDE_{out}$, and $AEDE_{tot}$.¹

The levels of $ELCR_{in}$ ranged from 0.7×10^{-3} (S_{2-4} , S_8 , S_9 , S_{11} , S_{12} , S_{15} , S_{18-20} , S_{22} , and S_{23}) to 1.1×10^{-3} (S_{14}) with an average of $(0.8 \pm 0.08) \times 10^{-3}$ in Ali Al-Sharqi (Table 5) and from 0.6×10^{-3} (S_4 , S_{17} , and S_{19}) to 1.3×10^{-3} (S_{23}) with an average of $(0.8 \pm 0.2) \times 10^{-3}$ in Kumait (Table 6). $ELCR_{out}$ values ranged from 0.09×10^{-3} (S_{2-4} , S_8 , S_9 , S_{11} , S_{12} , S_{15} , S_{17-20} , S_{22} , and S_{23}) to 0.14×10^{-3} (S_{14}) with an average of $(0.1 \pm 0.01) \times 10^{-3}$ in Ali Al-Sharqi (Table 5) and from 0.07×10^{-3} (S_4 , S_{17} , and S_{19}) to 0.2×10^{-3} (S_{23}) with an average of $(0.1 \pm 0.02) \times 10^{-3}$ in Kumait (Table 6). Moreover, $ELCR_{tot}$ values varied from 0.79×10^{-3} (S_{2-4} , S_8 , S_9 , S_{11} , S_{12} , S_{14} , S_{15} , S_{18-20} , S_{22} , and S_{23}) to 1.24×10^{-3} (S_{14}) with an average of

$(0.9 \pm 0.09) \times 10^{-3}$ in Ali Al-Sharqi (Table 5) and from 0.67×10^{-3} (S_4 , S_{17} , and S_{19}) to 1.5×10^{-3} (S_{23}) with an average of $(0.9 \pm 0.2) \times 10^{-3}$ in Kumait (Table 6). The evaluated values of ELCRs were below the worldwide average of 1.16×10^{-3} , 0.29×10^{-3} , and 1.45×10^{-3} , respectively, for $ELCR_{in}$, $ELCR_{out}$, and $ELCR_{tot}$.¹

The levels of AGDE varied from 149.3 (S_8) to 228.7 (S_{14}) μ Sv/y with a mean value of 165.3 ± 17.1 μ Sv/y in Ali Al-Sharqi (Table 5) and from 124.6 (S_{19}) to 269.2 (S_{23}) μ Sv/y with a mean value of 175 ± 37.2 μ Sv/y in Kumait (Table 6). These AGDE values were less than the worldwide average value of 300 μ Sv/y.¹

Based on the above outcomes, it can be concluded that the mean values of the radiological risk parameters in the soil of the research areas were below the globally recommended levels. Therefore, there are no potential health risks to the general public in Ali Al-Sharqi and Kumait, and the radiation levels remain in normal ranges.

3.4. Comparison of radiological hazard indices of the soil of the current study with identical research

The average radiological risk indices obtained from the soils of the research areas were compared with those obtained from other regions in the world and Iraq, as shown in Table 7.

The mean values for Ra_{eq} , H_{in} , H_{ex} , $I\gamma$, D_{in} , D_{out} , $AEDE_{in}$, $AEDE_{out}$, $ELCR_{in}$, $ELCR_{out}$, and AGDE in the present study are generally lower than those reported in previous studies. However, the mean value of $AEDE_{in}$ in Ali Al-Sharqi and Kumait exceeds that observed in Iran (Fars),¹⁹ Iraq (Kirkuk),¹⁹ and Iraq (Baghdad).⁵³ In addition, the mean value of $I\gamma$ in Ali Al-Sharqi and Kumait is comparable to those observed in Turkey (Bolu).⁵²

4. Conclusion

Natural radionuclides of ^{226}Ra , ^{232}Th , and ^{40}K were measured in soil specimens from two cities, Ali Al-Sharqi and Kumait, utilizing an HPGe detector. The average concentrations of these radionuclides for Ali Al-Sharqi were 15.1 Bq/kg for ^{226}Ra , 14.7 Bq/kg for ^{232}Th , and 180.8 Bq/kg for ^{40}K . In Kumait, the respective concentrations were 13.6, 17.2, and 193.6 Bq/kg for ^{226}Ra , ^{232}Th , and ^{40}K , respectively. These concentrations were all below the internationally recommended limits reported by UNSCEAR in 2,000. Based on the measured activity concentrations in soil, the radiological parameters, including Ra_{eq} , H_{in} and H_{ex} , $I\gamma$, D_{in} , D_{out} , and D_{tot} , $AEDE_{in}$, $AEDE_{out}$, and $AEDE_{tot}$, $ELCR_{in}$, $ELCR_{out}$,

and $ELCR_{tot}$, and AGDE were calculated. The mean values for radiological risk parameters in the study areas were below the globally recommended safety values reported by UNSCEAR in 2,000.

Consequently, natural radioactivity measurements indicate that Ali Al-Sharqi and Kumait soils are considered radiologically safe and do not pose any health risks to the public. Furthermore, the findings of this study provide valuable baseline data that can support the development of maps for naturally occurring radioactivity, aiding in future soil radiological environmental monitoring effects.

Acknowledgments

The authors would like to thank the Iraqi Ministry of Environment for their continuous support.

Funding

None.

Conflict of interest

The authors declare that they have no competing interests.

Author contributions

Conceptualization: Zahraa A. Ismail AL-Sudani

Formal analysis: All authors

Investigation: Zahraa A. Ismail AL-Sudani, Sawsan Sherif

Methodology: All authors

Writing – original draft: Zahraa A. Ismail AL-Sudani, Sawsan Sherif

Writing – review & editing: Zahraa A. Ismail AL-Sudani

Availability of data

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

References

1. UNSCEAR. Effects of Ionizing Radiation. New York: United Nations; 2000. p. 453-487.
2. Banerjee KS, Guin R, Gutierrez-Villanueva JL, Charro ME, Sengupta D. Variation in u-238 and th-232 enrichment in u-mineralized zone and geological controls on their spatial distribution, Singhbhum shear zone of India. *J Environ Earth Sci.* 2012;65:2103-2110. doi: 10.1007/s12665-011-1191-9
3. Otansev P, Karahan G, Kam E, Barut I, Taskin H. Assessment of natural radioactivity concentrations and gamma dose rate levels in Kayseri, Turkey. *Radiat Prot Dosimetry.* 2012;148(2):227-236. doi: 10.1093/rpd/ncr023
4. Rahman S, Matiullah MF, Rafique M, Anwar J, Ziafat M. Measurement of naturally occurring/fallout radioactive elements and assessment of annual effective dose in soil samples collected from four districts of the Punjab province, Pakistan. *J Radioanal Nucl Chem.* 2011;287(2):647-655. doi: 10.1007/s10967-010-0819-7
5. Kassa MK, Deressu TT. Measurement of natural radioactivity levels and evaluation of radiological hazard risks in areas of eastern coastline sediments of Lake Hawassa in Ethiopia's Sidama Region. *J Phys.* 2023;9(4):1819-1837. doi: 10.22059/poll.2023.357027.1843
6. Hameed PS, Pillai GS, Satheeshkumar G, Mathiyarasu R. Measurement of gamma radiation from rocks used as building material in Tiruchirappalli District, Tamil Nadu, India. *J Radiat Nucl Chem.* 2014;300:1081-1088. doi: 10.1007/s10967-014-3033-1
7. Ramasamy V, Suresh G, Meenakshisundaram V, Ponnusamy V. Horizontal and vertical characterization of radionuclides and minerals in river sediments. *Appl Radiat Isot.* 2011;69(1):184-195. doi: 10.1016/j.apradiso.2010.07.020
8. Rani A, Singh S. Natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ -ray spectrometry. *Atmos Environ.* 2005;39(34):6306-6314. doi: 10.1016/j.atmosenv.2005.07.050
9. Al-Jundi J, Al-Bataina B, Abu-Rukah Y, Shehadeh HM. Natural radioactivity concentrations in soil samples along the Amman Aqaba Highway, Jordan. *Radiol Meas.* 2003;36(1-6):555-560. doi: 10.1016/S1350-4487(03)00202-6
10. Kurnaz A, Küçükömeroğlu B, Keser R, et al. Determination of radioactivity levels and hazards of soil and sediment samples in Fırtına Valley (Rize, Turkey). *Appl Radiat Isot.* 2007;65(11):1281-1289. doi: 10.1016/j.apradiso.2007.06.001
11. Harb SRM, Din KS, Abbady AE, Mohamed AEE, Michel R. Measurements of natural radionuclides in soil samples from Upper Egypt. *Nucl Sci Technol.* 2008;19(5):302-307. doi: 10.1016/S1001-8042(09)60008-7
12. Ajayi OS. Measurement of activity concentrations of ^{40}K , ^{226}Ra and ^{232}Th for assessment of radiation hazards from soils of the SouthWestern region of Nigeria. *Radiat Environ Biophys.* 2009;48:323-332. doi: 10.1007/s00411-009-0225-0

13. El Samad O, Baydoun R, Nsouli B, Darwish T. Determination of natural and artificial radioactivity in soil at North Lebanon province. *J Environ Radioact.* 2013;125:36-39.
doi: 10.1016/j.jenvrad.2013.02.010
14. Lanzo G, Rizzo S, Tomarchio E. A radiometric and petrographic approach to risk assessment at alte madonie mounts region (Sicily, Italy). *Radiat Prot Dosimetry.* 2014;158(4):427-434.
doi: 10.1093/rpd/nct245
15. Attia TE, Shendi EH, Shehata MA. Assessment of natural and artificial radioactivity levels and radiation hazards and their relation to heavy metals in the industrial area of port said city, Egypt. *Environ Sci Pollut Res Int.* 2015;22:3082-3097.
doi: 10.1007/s11356-014-3453-z
16. Haribala, Hu B, Wang C, et al. Assessment of radioactive materials and heavy metals in the surface soil around uranium mining area of Tongliao, China. *Ecotoxicol Environ Saf.* 2016;130:185-192.
doi: 10.1016/j.ecoenv.2016.04.002
17. Mustafa MI, Yazici NA, Mangur PH. The investigation of terrestrial radioactivity in soil samples around pshdar region in Iraqi-Kurdistan. *Zanco J Pure Appl Sci.* 2016;28(6):13-20.
doi: 10.21271/ZJPAS.28.6.3
18. Nafee S, Al-Othmany D, Hamidalddin S, Al-Zahrani J, Alharbi W, Barashed H. Measurement of gamma emitting radionuclides for assessment, environmental hazards of radiation in rock and soil samples of Shabwah and Hadramout regions, Yemen. *J Geosci Environ Protect.* 2017;5(5):66-75.
doi: 10.4236/gep.2017.55005
19. Najam LA, Salim KM, Khalid HT. Evaluation of natural radioactivity of soil samples from different regions of wassit governorate. *Pollution.* 2017;3(1):47-53.
doi: 10.7508/pj.2017.01.006
20. Taqi AH, Shaker AM, Battawy AA. Natural radioactivity assessment in soil samples from Kirkuk city of Iraq using HPGe detector. *Int J Radiat Res.* 2018;16(4):455-463.
doi: 10.18869/acadpub.ijrr.16.4.455
21. Mouandza SYL, Moubissi AB, Abiama PE, Ekogo TB, Ben-Bolie GH. Study of natural radioactivity to assess of radiation hazards from soil samples collected from Mounana in South-East of Gabon. *Int J Radiat Res.* 2018;16(4):443-453.
doi: 10.18869/acadpub.ijrr.16.4.443
22. Ribeiro FCA, Silva JIR, Lima ESA, Do Amaral Sobrinho NMB, Perez DV, Lauria DC. Natural radioactivity in soils of the state of Rio de Janeiro (Brazil): Radiological characterization and relationships to geological formation, soil types and soil properties. *J Environ Res.* 2018;182:34-43.
doi: 10.1016/j.jenvrad.2017.11.017
23. Bajoga AD, Al-Dabbous AN, Abdullahi AS, Alazemi NA, Bachama YD, Alaswad SO. Evaluation of elemental concentrations of uranium, thorium and potassium in top soils from Kuwait. *Nucl Eng Environ Technol.* 2019;51(6):1638-1649.
doi: 10.1016/j.net.2019.04.021
24. Khan UI, Qin Z, Xie T, et al. Evaluation of health hazards from radionuclides in soil and rocks of North Waziristan, Pakistan. *Int J Radiat Res.* 2020;18(2):243-253.
doi: 10.18869/acadpub.ijrr.18.2.243
25. Aydarous AS, Zeghib S, Abdullahi S, Al-Subaie H. Radiological hazard assessment and sensitivity analysis for soil samples in Taghdoua area of Ranyah, Saudi Arabia. *J Radiol Res Appl Sci.* 2022;15(2):119-128.
doi: 10.1016/j.jrras.2022.05.006
26. De Regge P, Burns K, Danesi PR. The IAEA programme and perspectives for environmental radionuclide monitoring and preparation of reference materials. *Czech J Phys.* 1999;49:237-245.
doi: 10.1007/s10582-999-0032-5
27. Dizman S, Görür FK, Keser R, Görür O. The assessment of radioactivity and radiological hazards in soils of Bolu province, Turkey. *Environ Forensics.* 2019;20(3):211-218.
doi: 10.1080/15275922.2019.1629129
28. Beretka J, Mathew PJ. Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Phys.* 1985;48(1):87-95.
doi: 10.1097/00004032-198501000-00007
29. Smail JM, Ahmad ST, Mansour HH. Estimation of the natural radioactivity levels in the soil along the Little Zab River, Kurdistan Region in Iraq. *J Radiol Nucl Chem.* 2022;331(1-10):119-128.
doi: 10.1007/s10967-021-08064-5
30. Krieger RJ. Radioactivity of construction materials. *World J Nucl Sci Technol.* 1981;47(8):468-473.
doi: 10.1016/S0160-3450(16)31258-2
31. Yadav M, Rawat M, Dangwal A, Prasad M, Gusain GS, Ramola RC. Levels and effects of natural radionuclides in soil samples of Garhwal Himalaya. *J Radioanal Nucl Chem.* 2014;302:869-873.
doi: 10.1007/s10967-014-3277-9
32. Mountford PJ, Temperton DH. Recommendations of the international commission on radiological protection (ICRP) 1990. *Eur J Nucl Med.* 1992;19:77-79.
doi: 10.1007/BF00184120
33. Suresh S, Rangaswamy DR, Sannappa J, Dongre S, Srinivasa E, Rajesh S. Estimation of natural radioactivity and assessment of radiation hazard indices in soil samples of Uttara Kannada district, Karnataka, India. *J Radiat Nucl Chem.* 2022;331(4):1869-1879.
doi: 10.1007/s10967-021-08145-5
34. European Commission. *Radiological Protection Principles Concerning the Natural Radioactivity of Building Materials.* Radiation Protection No. 112. Luxembourg: Publications of the European

- Communities; 1999.
35. Temelli UE. Determination of natural radioactivity levels of concrete core and cements in Eskisehir Area. *Fresenius Environ Bull.* 2018;27:2717-2723.
 36. Asaduzzaman K, Khandaker MU, Amin YM, Bradley DA. Natural radioactivity levels and radiological assessment of decorative building materials in Bangladesh. *Indoor Built Environ.* 2016;25(3):541-550. doi: 10.1177/1420326X14562048
 37. Ravisankar R, Chandramohan J, Chandrasekaran A, et al. Assessments of radioactivity concentration of natural radionuclides and radiological hazard indices in sediment samples from the East coast of Tamilnadu, India with statistical approach. *Mar Pollut Bull.* 2015;97(1-2):419-430. doi: 10.1016/j.marpolbul.2015.05.058
 38. Sukumaran Chettiar Rajamma S, Abraham S, Panakal John J. Gamma radiation profile of the high background radiation area along southwest coastal India and its neighbourhood. *Pollution.* 2023;9(4):1867-1879. doi: 10.22059/poll.2023.360416.1937
 39. Mohammed RS, Ahmed RS. Estimation of excess lifetime cancer risk and radiation hazard indices in Southern Iraq. *Environ Earth Sci.* 2017;76:303. doi: 10.1007/s12665-017-6616-7
 40. Ugbede FO, Okoye ONN, Akpolile AF, Oladele BB. Baseline radioactivity in the soil of evangel take-off campus, evangel university, Nigeria, and its associated health risks. *Chem Africa.* 2021;4(3):703-713. doi: 10.1007/s42250-021-00254-8
 41. Agar O, Boztosun I, Korkmaz ME, Özmen SF. Measurement of radioactivity levels and assessment of radioactivity hazards of soil samples in Karaman, Turkey. *Radiat Prot Dosimetry.* 2014;162(4):630-637. doi: 10.1093/rpd/ncu027
 42. Wang Z, Ye Y. Assessment of soil radioactivity levels and radiation hazards in Guangyao Village, South China. *J Radiochem Nucl Chem.* 2021;329:679-693. doi: 10.1007/s10967-021-07818-5
 43. Al-Ghamdi AH. Health risk assessment of natural background radiation in the soil of Eastern Province, Saudi Arabia. *J Radiat Res Sci.* 2019;12(1):219-225. doi: 10.1080/16878507.2019.1637045
 44. Al-Alawy IT, Taher WI, Mzher OA. Soil radioactivity levels, radiation hazard assessment and cancer risk in Al-Sadr City, Baghdad Governorate, Iraq. *Int J Radiat Res.* 2023;21(2):293-298.
 45. Boukhenfouf W, Boucenna A. The radioactivity measurements in soils and fertilizers using gamma spectrometry technique. *J Environ Radioact.* 2011;102(4):336-339. doi: 10.1016/j.jenvrad.2011.01.006
 46. Almayahi BA, Tajuddin AA, Jaafar MS. Radiation hazard indices of soil and water samples in Northern Malaysian Peninsula. *Appl Radiat Isot.* 2012;70(11):2652-2660. doi: 10.1016/j.apradiso.2012.07.021
 47. Harb S, El-Kamel AEH, Abbady AEB, Saleh EE, El-Mageed AI. Specific activities of natural rocks and soils at quaternary intraplate volcanism north of Sana'a, Yemen. *J Med Pharmacol.* 2012;37(1):54-60. doi: 10.4103/0971-6203.92721
 48. Kardan MR, Fathabdi N, Attarilar A, et al. A national survey of natural radionuclides in soils and terrestrial radiation exposure in Iran. *J Environ Radioact.* 2017;178:168-176. doi: 10.1016/j.jenvrad.2017.08.010
 49. Tufan MÇ, Bostancı S. Radioactivity concentrations in soil and dose assessment for Samsun City Centre, Turkey. *Radiat Prot Dosimetry.* 2012;151(3):532-536. doi: 10.1093/rpd/ncs034
 50. Al-Hamarneh IF, Awadallah MI. Soil radioactivity levels and radiation hazard assessment in the highlands of northern Jordan. *Radiat Meas.* 2009;44(1):102-110. doi: 10.1016/j.radmeas.2008.11.005
 51. Hussein ZA. Assessment of natural radioactivity levels and radiation hazards for soil samples used in Erbil Governorate, Iraqi Kurdistan. *ARO Sci J Koya Univ.* 2019;7(1):34-39. doi: 10.14500/aro.10471
 52. Mohammed NA, Ebrahiem SA. Radioactivity levels of ²³⁸U, ²³⁴Th, ⁴⁰K and ¹³⁷C in the soil surface of selected regions from Baghdad Governorate. *J Nucl Eng Sci.* 2020;14(1):15-27. doi: 10.1504/ijnest.2020.108794
 53. Faghihi R, Mehdizadeh S, Sina S. Natural and artificial radioactivity distribution in soil of Fars Province, Iran. *Radiat Prot Dosimetry.* 2011;145(1):66-74. doi: 10.1093/rpd/ncq367
 54. Muhammed MI, Najim Y, Mangur P. The Investigation of Terrestrial Radioactivity in Soil Samples around Pshdar Region in Iraqi-Kurdistan. *ZANCO J Pure and Appl Sci.* 2016;28(6):13-20.
 55. Saleh, H, Shayeb MA. Natural radioactivity distribution of southern part of Jordan (Maan) Soil. *Ann Nucl Energy.* 2014;65:184-9. doi: 10.1016/j.anucene.2013.10.042