Long-lived gamma-ray measurement in soil samples collected from city central of Al-Diwaniyah, Iraq

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Abstract. Activity concentrations of 20 soil samples were collected randomly from the city central of Al-Diwaniyah, Iraq were measured using NaI (Tl) detector. Estimation of average concentrations of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ were 15.22, 18.84 and 97.66 Bq kg$^{-1}$ respectively. The results showed the average value of activity concentrations for $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ were lower than the level reported by United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). The radiological hazards of the soil samples were calculated using various models written by UNSCEAR. The radium equivalent activity was found below the permissible limit as reported in Organization for Economic Cooperation and Development (OECD), on the other hand the values of other hazard indices were also lower their limit values. The results have been compared with other location in world.

1. Introduction
Natural Occurring Radionuclides Materials (NORMs), such as $^{238}\text{U}$, $^{232}\text{Th}$, $^{235}\text{U}$, and $^{40}\text{K}$ have very long half- lived (up to $10^8$ years), their presence in soil, water, food and rock can simply be considered as permanent. The radionuclides of $^{238}\text{U}$, $^{232}\text{Th}$ series and $^{40}\text{K}$ are the main source of natural radioactivity in soil [1-4]. Soil is important to human and their health. It provides a resource that can be used as a shelter and for food production. The geological and geographical conditions are the major factors effects on the levels of environmental radioactivity from natural. The specific levels for the radioactivity of various soils are related to the nature of the parent rock [5].Therefore, these radiation levels appeared at different levels in the soil of each region in the world [6]. The presence of radioactivity in the environment is known to be responsible for a large radiation exposure against humankind. The radionuclides may emit either alpha or beta particles, may be taken into the body through ingestion or inhalation. This can lead to an increment in the internal exposures. Some of these nuclear species are responsible for the emission of gamma rays which represents the main source of external exposures to humans as mentioned in UNSCEAR [7, 15]. Measurements of natural radioactivity in soils have been carried out in different countries to establish baseline data from the natural radiation levels [8-12]. Al-Diwaniyah is the city in Iraq. The population was estimated one million and half. The area around Al-Diwaniyah city, which is well irrigated from the nearby Euphrates River, is often considered to be one on the most fertile parts of Iraq, and is heavily
cultivated. The town is located on the main rail transport corridor between Baghdad and Basra. Al-Diwaniyah consists of vast agricultural areas, wetlands, arid zones, and semi-desert areas. The town is the site of a tire manufacturing plant that once provided tires for much of Iraq. The main goal of this research is to assess the concentration of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ and estimated the radiological impact on the human population in soil samples collected from Al-Diwaniyah city using NaI (Tl) detector.

2. Material and methods

2.1. Study area
Al-Diwaniyah is one of the governorates of Iraq. It is located in the center of Iraq. It is approximately 190 km from Baghdad, the capital of Iraq. Al-Diwaniyah borders with Babylon in the north, Kut from west, Samawah in the south and Najaf from East. Al-Diwaniyah city having an area of 8153 km$^2$ located on Euphrates river between latitudes 31.17 - 32.24 °N and longitudes 44.24 - 45.49 °E with population about million and a half million people was estimated according to the census of 2014. The samples were collected from city center of Al-Diwaniyah as shown in figure 1.

![Figure 1. Map of Al-Diwaniyah, Iraq with sampling sites](image)

2.2. Collection and preparation of Samples
Twenty of soil samples are collected to study either the total deposition or the possible availability of radionuclides in the crops grown in the cultured agricultural land. In this study, soil samples were collected to determine the availability of radionuclides in the crops based on the IAEA standards. The samples were taken in crop areas with a hand drill to the depth from 5 to 15 cm. One kg of soil was taken from each location and kept in polyethylene bags. The soil samples were then marked with the time, collection location and date for each sample (IAEA 1989) [13]. The one kg of soil samples was oven-dried at 110 °C for 24 h. After that, grinded and then screened using a 2 mm diameter borehole to obtain homogeneous. All the samples were left in containers at least one month to confirm the equilibrium between the long lived of series with their short-lived progenies.

2.3. Sodium Iodide NaI (Tl) detector
Quantitative radioactivity of gamma-based nodules for \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\), was measured using the electronic counting and analysis system used to detect the nuclear radiation of the Sodium Iodide NaI (Tl) detector (3” x 3”), equipped with a multichannel analyzer (ORTEC-Digi Base) with 4096 channels connected to a unit called ADC (Analog to Digital Convertor). It helps the analyst to convert the next pulse into numerical numbers, and the analyses are done by computer program called (MAESTRO - 32). The IAEA, set no. 34 were used to calibrate energy and determined the absolute efficiency using mixed radionuclides with ten \(\gamma\)-ray lines emitted from \(^{22}\text{Na},^{137}\text{Cs},^{60}\text{Co},^{133}\text{Ba}\) and \(^{152}\text{Eu}\) [14-15]. Each sample was counted for 6 hour. The activity concentrations were calculated from the progenies of \(^{238}\text{U}\) (at gamma line 1765 keV for \(^{214}\text{Bi}\)), \(^{232}\text{Th}\) (at gamma line 2614 keV for \(^{208}\text{Tl}\)) and \(^{40}\text{K}\) was estimated directly by gamma line at 1460 keV. In order to measure the natural radioactivity in soil samples from the city center of Al-Diwaniyah. The activity concentration with a gamma energy transition could be expressed using the following equation [14].

\[
A = \frac{N_{net}}{\varepsilon \cdot I_{\gamma} \cdot m \cdot t} \pm \sqrt{\frac{N_{net}}{\varepsilon \cdot I_{\gamma} \cdot m \cdot t}} \quad [\text{Bq kg}^{-1}]
\]

where \(N_{net}\) represent the net count (area under the specified energy peak after back ground subtraction) in (c/s), \(\sqrt{N_{net}}\) is the random error in (c/s), \(\varepsilon\) is the efficiency of the detector, \(I_{\gamma}\) is the transition probability of the emitted gamma ray, \(t\) is the time (6 hours) for spectrum collected and \(m\) is the sample weight (in kg).

3. Calculation of Radiological Hazards
Depending on the activity concentrations of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\), the following risk factors were calculated [7, 15].

3.1. Radium equivalent activity (Ra\text{eq})
Distribution of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\) in environment is not uniform, so that with respect to exposure to radiation, the radioactivity has been defined in terms of radium equivalent activity in Bq kg\(^{-1}\).

\[
Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K
\]

where \(A_U\), \(A_{Th}\) and \(A_K\) are represented the activity concentration in Bq kg\(^{-1}\) of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\), respectively. The index is useful to compare the specific activity of materials containing different concentrations of \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\).

3.2. Gamma Dose Rate (D)
The total dose rate \(D\) in the air due to uniform distribution of all the \(^{238}\text{U},^{232}\text{Th}\) and \(^{40}\text{K}\) in the soil samples at 3.28 ft above the ground surface was estimated by:

\[
D = 0.427A_U + 0.662A_{Th} + 0.043A_K
\]
3.3. Annual Effective Dose Equivalent (AEDE)

In order to estimate the outdoor annual effective dose rate in air the conversion coefficient from absorbed dose in air to effective dose received by an adult had to be taken into consideration. The annual effective dose equivalent was given by the following equation:

\[
AEDE (\mu Sv/\text{y}) = D(nGyh^{-1}) \times N_h \times O \times F
\]

where \( N_h \) is the number of hours in one year (8766 h), \( O \) is the outdoor occupancy factor (0.2), and \( F \) is the conversion coefficient from the absorbed dose in the air to effective dose received by adults (0.7 Sv Gy^{-1}).

3.4. External and internal hazard index \((H_{ex}, H_{in})\)

The external hazard index \((H_{ex})\) and the internal hazard index \((H_{in})\) were given by the following equation.

\[
H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}
\]

\[
H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}
\]

For the safe use of a material in the construction of dwellings the internal hazard index should be less than unity.

4. Results and Discussions

Minimum and maximum in mean as well as range values of activity concentrations for \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) in 20 soil samples collected from city centre of Al-Diwaniyah are presented in table 1. The activity concentrations of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) range from 8.89 to 23.02 with a mean value of 15.22, from 13.23 to 29.10 with a mean value of 18.85 and from 65.14 to 136.80 with a mean value of 97.66 Bq kg\(^{-1}\), respectively. The activity concentrations of natural radioactivity in the earth crust are varied with half-lives of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\). The amount of \(^{232}\text{Th}\) is almost higher than the amount of \(^{238}\text{U}\) in all the study sites. In this case, the \(^{40}\text{K}\) is higher than the amount of \(^{238}\text{U}\) and \(^{232}\text{Th}\) as shown in figure 2. The result showed that all the activity concentrations of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) in soil sample are lower than worldwide average as reported 35 Bq kg\(^{-1}\) for \(^{238}\text{U}\), 30 Bq kg\(^{-1}\) for \(^{232}\text{Th}\) and 400 Bq kg\(^{-1}\) for \(^{40}\text{K}\) [7].

Table 1. The activity concentrations of natural radioactivity in soil samples collected from Al-Diwaniyah.

| Sample No. | \(^{238}\text{U}\) (Bq kg\(^{-1}\)) | \(^{232}\text{Th}\) (Bq kg\(^{-1}\)) | \(^{40}\text{K}\) (Bq kg\(^{-1}\)) |
|-----------|-------------------------------|-------------------------------|-------------------------------|
| S1        | 20.40 ± 3.26                  | 15.21 ± 3.17                  | 91.20 ± 4.45                  |
| S2        | 17.26 ± 3.00                  | 26.46 ± 4.18                  | 82.52 ± 4.23                  |
| S3        | 13.08 ± 2.61                  | 15.87 ± 3.24                  | 65.14 ± 3.76                  |
| S4        | 9.94 ± 2.82                   | 14.55 ± 3.10                  | 88.60 ± 4.38                  |
| S5        | 18.31 ± 3.09                  | 20.50 ± 3.68                  | 69.49 ± 3.86                  |
| S6        | 23.02 ± 3.47                  | 23.81 ± 3.96                  | 108.57 ± 4.85                 |
| S7        | 11.51 ± 2.45                  | 21.16 ± 3.74                  | 115.09 ± 4.99                 |
| S8        | 14.13 ± 2.71                  | 14.55 ± 3.10                  | 119.43 ± 5.09                 |
| S9        | 10.46 ± 2.33                  | 15.21 ± 3.17                  | 87.51 ± 4.35                  |
| S10       | 18.83 ± 3.13                  | 19.84 ± 3.62                  | 125.95 ± 5.22                 |
| S11       | 15.70 ± 2.86                  | 14.55 ± 3.10                  | 95.55 ± 4.55                  |
| S12       | 9.42 ± 2.21                   | 19.18 ± 3.56                  | 89.47 ± 4.40                  |
| S13       | 11.51 ± 2.45                  | 26.46 ± 4.18                  | 76.01 ± 4.06                  |
| S14       | 18.31 ± 3.09                  | 13.23 ± 2.95                  | 80.35 ± 4.17                  |
| S15       | 17.79 ± 3.05                  | 29.10 ± 4.38                  | 129.86 ± 5.31                 |
| S16       | 9.42 ± 2.21                   | 20.50 ± 3.68                  | 130.72 ± 5.32                 |
The radium equivalent activity ($Ra_{eq}$), dose rate (D), internal hazard indices ($H_{in}$), external hazard indices ($H_{ex}$) and annual outdoor effective dose equivalent (AEDE) were computed and tabulated in table 2, the mean values of $Ra_{eq}$, D, AEDE, $H_{in}$, and $H_{ex}$ were found to be 49.70 Bq kg$^{-1}$, 23.18 nGy h$^{-1}$, 0.028 mSv y$^{-1}$, 0.030 and 0.134, respectively. The radiological hazards of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in soil samples of radium equivalent activity, dose rate in air, outdoor annual effective dose and hazard indices (external and internal) were determined. The term, radium equivalent activity in Bq kg$^{-1}$, is normally used to compare the uniformity in radiation of a material containing different amounts of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$. The value of $Ra_{eq}$ is lower than 370 Bq kg$^{-1}$, which is the level of safety limit reported by OECD [16]. While, the result of D is 23.18 nGy h$^{-1}$, which is the lower than the safety level as presented in UNSCEAR [7], the D in air from the terrestrial gamma rays in normal circumstances is about 59.0 nGy h$^{-1}$ and the national average is ranged from 20 to 1100 nGy h$^{-1}$. Thus, the D is within the range of safety limit. The AEDE is 0.028 mSv y$^{-1}$ in soil samples, while the world wide average annual effective dose is at approximately 0.5 mSv y$^{-1}$ as well as the results for individual countries being generally within the range 0.3 - 0.6 mSv y$^{-1}$ [7]. Furthermore, the AEDE is within the permissible dose equivalent limit which is 1.0 mSv (ICRP, 1990). The values of $H_{in}$ and $H_{ex}$ were 0.03 and 0.13 in soil samples. Based on the UNSCEAR all these values are lower than unity. Therefore, according to the International Commission on Radiological Protection (1990) and UNSCEAR [7], the soil of these regions is safe and can be used as a construction material without posing any significant radiological threat to the population.
Table 2. Radium equivalent activity (Ra\textsubscript{eq}), dose rate (D), annual outdoor effective dose equivalent (AEDE), internal hazard indices (H\textsubscript{in}), external hazard indices (H\textsubscript{ex}), for the soil samples.

| Sample No. | Ra\textsubscript{eq} (Bq kg\textsuperscript{-1}) | D (nGy h\textsuperscript{-1}) | AEDE (mSv y\textsuperscript{-1}) | H\textsubscript{in} | H\textsubscript{ex} |
|------------|---------------------|------------------|-------------------|----------|----------|
| S1         | 49.17               | 22.71            | 0.028             | 0.031    | 0.133    |
| S2         | 61.45               | 28.43            | 0.035             | 0.033    | 0.166    |
| S3         | 40.79               | 18.89            | 0.023             | 0.027    | 0.110    |
| S4         | 37.57               | 17.69            | 0.022             | 0.025    | 0.101    |
| S5         | 52.98               | 24.38            | 0.030             | 0.031    | 0.143    |
| S6         | 65.43               | 30.26            | 0.037             | 0.035    | 0.177    |
| S7         | 50.64               | 23.87            | 0.029             | 0.029    | 0.137    |
| S8         | 44.13               | 20.80            | 0.026             | 0.028    | 0.119    |
| S9         | 38.95               | 18.30            | 0.022             | 0.026    | 0.105    |
| S10        | 56.91               | 26.59            | 0.033             | 0.032    | 0.154    |
| S11        | 43.86               | 20.44            | 0.025             | 0.028    | 0.118    |
| S12        | 43.73               | 20.57            | 0.025             | 0.027    | 0.118    |
| S13        | 55.19               | 25.70            | 0.032             | 0.030    | 0.149    |
| S14        | 43.41               | 20.03            | 0.025             | 0.029    | 0.117    |
| S15        | 69.40               | 32.44            | 0.039             | 0.035    | 0.187    |
| S16        | 48.80               | 23.21            | 0.028             | 0.027    | 0.132    |
| S17        | 49.09               | 22.79            | 0.028             | 0.030    | 0.132    |
| S18        | 35.15               | 16.47            | 0.020             | 0.024    | 0.095    |
| S19        | 51.26               | 23.79            | 0.029             | 0.031    | 0.138    |
| S20        | 56.05               | 26.20            | 0.032             | 0.032    | 0.151    |
| Min.       | 35.15               | 16.47            | 0.020             | 0.024    | 0.095    |
| Max.       | 69.40               | 32.44            | 0.039             | 0.035    | 0.187    |
| Average    | 49.70               | 23.18            | 0.028             | 0.030    | 0.134    |

The concentration of $^{238}$U, $^{232}$Th and $^{40}$K in soil samples are compared with other values reported in other countries as shown in table 3. The comparisons are indicated the activity concentration of $^{238}$U was found to be lower than in other countries, except for India, Malaysia and Kuwait. On the other hand, the activity concentration of $^{232}$Th was observed to be lower than in other countries, except Pakistan, India and Malaysia. Whilst, the activity concentration of $^{40}$K was found to be lower than in other countries, except for Cyprus. The results indicated that the concentration varied from country to country due to the differences in the geological nature of the soil.

Table 3. A comparison of the concentrations (Bq kg\textsuperscript{-1}) of soil samples with the values reported for other countries.

| Country     | $^{238}$U | $^{232}$Th | $^{40}$K | References |
|-------------|-----------|------------|----------|------------|
| Pakistan    | 20.9      | 42.6       | 550      | 8          |
| Cyprus      | 7.1       | 5          | 104.6    | 12         |
| India       | 56.7      | 87.4       | 143      | 18         |
| Malaysia    | 178       | 353        | 296      | 11         |
| Kuwait      | 36        | 6          | 227      | 10         |
| Saudi Arabia| 14.5      | 11.2       | 225      | 17         |
| Iraq        | 23.02     | 29.10      | 136.80   | Present study |
5- Conclusions

The study of natural radioactivity levels of $^{238}$U, $^{232}$Th and $^{40}$K in soil samples has provided baseline data in the areas of study. The results of natural radionuclides in a soil samples collected from the areas of study varied significantly from place to place. Based on the UNSCEAR all these values are lower than unity. Therefore, according to the International Commission on Radiological Protection (1990) and UNSCEAR (2000), the soil of these regions is safe and can be used as a construction material without posing any significant radiological threat to the population.

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