MEASUREMENTS OF NATURAL RADIOACTIVITY AND ASSOCIATED RADIOLOGICAL HAZARDS IN SAND AND GRAVEL QUARRIES IN ASSIUT, EGYPT

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This study contains 70 samples and covered a total of 36 different sand and gravel quarries in Assiut, Egypt. Activity concentration of 226Ra, 232Th and 40K were measured using γ-ray spectrometry (NaI (Tl) 3" x 3"). The average values of specific activity for 226Ra, 232Th and 40K in sand samples are 4.74, 4.10 and 109.82 Bq kg\(^{-1}\), respectively, and in gravel samples these values are 6.01, 1.82 and 31.6 Bq kg\(^{-1}\), respectively. These values are smaller than the world average values that reported by UNSCEAR 2000. Some radiological indices such as Radium equivalent activity, Absorbed dose rate, Annual Effective Dose Equivalent and Annual Gonadal Dose Equivalent, were calculated, to estimate the radiological hazards arising from using these row building materials in Assiut governorate, and found that, all the investigated quarries are safe from radiological view for use in building construction.

Keywords: γ-ray spectrometry, Natural radioactivity, Annual Effective Dose Equivalent, 226Ra, 232Th and 40K and Excess Lifetime Cancer Risk.

INTRODUCTION

All building materials contain various amounts of natural radioactive nuclides. Materials derived from rock and soil contains mainly natural radionuclides i.e. uranium (238U), thorium (232Th) and potassium (40K). The members of the radioactive decay chains of 232Th (14%), 235U and 238U (55.8%), along with 40K (13.8%) are
responsible for the main contributions to the dose from natural radiation [1]. The knowledge of the radioactivity present in construction materials helps to: (a) assess the possible radiological hazards to human health, and (b) develop the standards and guidelines for the use and management of these materials [2]. Generally, the specific activities of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in raw building materials and their products depend on geological and geographical conditions as well as the geochemical features of those materials [3]. Knowing the amount of natural radioactivity in building materials will determine their use in construction affairs and set national guidelines based on scientific recommendations.

MATERIALS AND METHODS

Samples Collection and Preparation

In this study we investigated two types of raw building materials, Sand and Gravel, which are the commonly used building materials in Egypt. Seventy samples are collected from thirty six different quarries in Assiut; twenty one sand quarries and fifteen Gravel quarries. Figure 1 and Table 1 contain complete description for the position of the investigated samples. The samples were crushed, homogenized, sieved through a 200 μm mesh, which is the optimum size enriched in heavy minerals, dried in an oven at 110 °C for 48 hours to ensure that moisture is completely removed, weighted and placed in beakers. The beakers were completely sealed for four weeks, to reach radioactive secular equilibrium between $^{226}\text{Ra}$ and $^{232}\text{Th}$ and their short-lived daughters [4].

Figure 1. Sand and Gravel quarries Locations in Assiut governorate, Egypt.
Table 1. A complete description of samples map.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Coordinates</th>
<th>Type</th>
<th>No. of quarries</th>
<th>Codes</th>
<th>No. of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dashlout</td>
<td>27° 34’ 7.71” North, 30° 42’ 18.24” East</td>
<td>Sand</td>
<td>1</td>
<td>S₁</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Muharraq Monastery area</td>
<td>27° 22’ 51.02” North, 30° 46’ 47.26” East</td>
<td>Sand</td>
<td>1</td>
<td>S₂, G₁</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Al Atamma</td>
<td>27° 17’ 10.80” North, 30° 53’ 43.26” East</td>
<td>Sand</td>
<td>1</td>
<td>S₂</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>Beni Ady</td>
<td>27° 15’ 10.46” North, 30° 55’ 26.11” East</td>
<td>Sand</td>
<td>3</td>
<td>S₃, S₄, S₅, G₂</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>Al-Ezza</td>
<td>27° 13’ 21.34” North, 30° 59’ 25.82” East</td>
<td>Gravel</td>
<td>2</td>
<td>G₃, G₄</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>Al Taher Alexandria</td>
<td>27° 10’ 42.27” North, 31° 5’ 11.82” East</td>
<td>Sand</td>
<td>1</td>
<td>S₆</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Assiut cement company</td>
<td>27° 10’ 19.79” North, 31° 1’ 11.03” East</td>
<td>Sand</td>
<td>1</td>
<td>S₇</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Arab Al-Kalabat</td>
<td>27° 11’ 27.84” North, 31° 15’ 38.09” East</td>
<td>Sand</td>
<td>1</td>
<td>S₁₆</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Sheikh Suief</td>
<td>27° 13’ 11.58” North, 31° 15’ 35.64” East</td>
<td>Sand</td>
<td>1</td>
<td>Sₓ</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>New Assiut</td>
<td>27° 15’ 38.69” North, 31° 18’ 6.88” East</td>
<td>Sand</td>
<td>2</td>
<td>Sₓ, Sₓ₁, Gₓ, Gₓ₁</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Al-Ghoraieb</td>
<td>27° 7’ 53.81” North, 31° 19’ 2.04” East</td>
<td>Sand</td>
<td>4</td>
<td>Sₓ₁, Sₓ₂, Sₓ₃, Sₓ₄</td>
<td>8</td>
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<tr>
<td>12</td>
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<td>26° 54’ 24.81” North, 31° 18’ 39.19” East</td>
<td>Sand</td>
<td>1</td>
<td>Sₓ₇</td>
<td>2</td>
</tr>
<tr>
<td>13</td>
<td>Dikran</td>
<td>26° 58’ 7.47” North, 31° 16’ 45.84” East</td>
<td>Sand</td>
<td>1</td>
<td>Sₓ₈</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>Al-Nawwrah</td>
<td>26° 51’ 5.49” North, 31° 30’ 41.08” East</td>
<td>Sand</td>
<td>3</td>
<td>Sₓ₁₆, Sₓ₂₀, Sₓ₂₁</td>
<td>4</td>
</tr>
<tr>
<td>15</td>
<td>Al-Etmaniah</td>
<td>26° 53’ 47.31” North, 31° 51’ 0.46” East</td>
<td>Gravel</td>
<td>2</td>
<td>Gₓ₁₆, Gₓ₁₃</td>
<td>3</td>
</tr>
</tbody>
</table>

Measuring System and Calibration

The samples were analyzed using 3×3 inch NaI (Tl) gamma-ray spectrometric system with a 2048 multi-channel pulse height analyzer and Genie 2000 software [5]. To reduce gamma ray background, a cylindrical lead shield (100 mm thick) with a fixed bottom and movable cover shielded the detector. The lead shield contained an inner concentric cylinder of copper (0.3 mm thick) in order to absorb X rays generated in the lead. The efficiency calibration curve was made using IAEA-314 reference material [6].

Detection Limit

Detection limit is the lowest amount of activity of a specific gamma-emitting radionuclide that can be detected at the time of measurement. A generally accepted expression for estimating the Minimum Detectable Activity (MDA) which contains a
preselected risk of 5 % of concluding falsely that activity is present and a 95 % degree of confidence for detecting the presence of activity is as follows:

\[ MDA = \frac{4.66 \sqrt{S_b}}{\eta I_\gamma \times t \times m} \]  

(1)

where \( S_b \) the mean number of background counts at specific gamma line, \( \eta \) the measured efficiency for gamma line, \( I_\gamma \) the intensity of gamma line, \( t \) the time of counting and \( m \) the mass of the sample. To obtain low detection limits the efficiency should be high, the sample should be as large as practicable, the counting time should be as long as practicable, and the background should be as low as attainable [7]. The calculated MDA for the collected samples are listed in table 2.

**Table 2. Minimum Detectable Activity for different samples.**

<table>
<thead>
<tr>
<th>Type</th>
<th>MDA (Bq kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-238</td>
<td>1.78</td>
</tr>
<tr>
<td>Th-232</td>
<td>1.58</td>
</tr>
<tr>
<td>K-40</td>
<td>7.69</td>
</tr>
</tbody>
</table>

**Measurements of Specific Activity Concentration**

\(^{226}\)Ra concentration was estimated from the average concentration of 609.3 keV (46.1%) \( \gamma \)-peak of \(^{214}\)Bi, 351.9 keV (37.1%), 1120.3 keV (15%), 1729.6 keV (3.05%) and 1764.5 keV (15.9%) \( \gamma \)-peak of \(^{214}\)Pb. \(^{232}\)Th concentration was estimated from the average concentration of 911.1 keV (29%) \( \gamma \)-peak of \(^{228}\)Ac, 238.6 keV (43.6%) \( \gamma \)-peak of \(^{212}\)Pb and 2614.5 keV (35.8%) \( \gamma \) peak of \(^{208}\)Tl. \(^{40}\)K radionuclide was estimated using the 1460.83 keV (10.7%) \( \gamma \) peak from \(^{40}\)K itself. [8] The activity concentration (A) in Bq kg⁻¹ was obtained as from the equation:

\[ A = \frac{N_p \times 100}{\eta \times I_\gamma \times t \times m} \]  

(2)

where \( N_p \) is the [count/s of sample minus count/s of back ground], \( \eta \) is the measured efficiency for gamma line, \( I_\gamma \) is the intensity of gamma line, \( t \) is the counting time and \( m \) is the mass of the sample in kilograms [9]. By using Eq. (1) we can calculate the uncertainty of specific activity \( u \) (A) by using the following equation:

\[ \left( \frac{u(A)}{A} \right)^2 = \left( \frac{u(N_p)}{N_p} \right)^2 + \left( \frac{u(\eta)}{\eta} \right)^2 + \left( \frac{u(I_\gamma)}{I_\gamma} \right)^2 + \left( \frac{u(t)}{t} \right)^2 + \left( \frac{u(m)}{m} \right)^2 \]  

(3)

where \( u(N_p) \) was obtained from the code Genie 2000 [5]. And \( u(I_\gamma) \) were taken from the compilation of Reus and Westmeier [10].

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Evaluation of Radiological Hazard Effects

Radium Equivalent Activity $Ra_{eq}$

This index is used to describe the radiation hazard from different radionuclide mixture in a material. Assuming that 370 Bq/kg of $^{226}$Ra, 259 Bq/kg of $^{232}$Th and 4810 Bq/kg of $^{40}$K produce the same gamma-ray dose rate [11], $Ra_{eq}$ is calculated using the following relation:

$$Ra_{eq} (Bqkg^{-1}) = A_{Ra} + 1.34A_{Th} + 0.077A_K$$  \hspace{1cm} (4)

where $A_{Ra}$, $A_{Th}$ and $A_K$ are the specific activity of $^{226}$Ra, $^{232}$Th and $^{40}$K in (Bq kg$^{-1}$), respectively. The recommended maximum value for the safe use of materials in the construction of buildings is 370 Bq kg$^{-1}$ [12].

Absorbed Gamma Dose Rate ($D$)

The conversion factors used to compute absorbed gamma dose rate ($D$) in air per unit activity concentration in Bq kg$^{-1}$ (dry weight) corresponds to 0.462 nGyh$^{-1}$ for $^{226}$Ra, 0.604 nGyh$^{-1}$ for $^{232}$Th and 0.042 nGyh$^{-1}$ for $^{40}$K. Therefore $D$ can calculate as follows:

$$D(nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K$$  \hspace{1cm} (5)

where $A_{Ra}$, $A_{Th}$ and $A_K$ are the specific activity of $^{226}$Ra, $^{232}$Th and $^{40}$K in (Bq kg$^{-1}$), respectively [13]. The world average value of $D$ is 57 nGyh$^{-1}$ [14].

Annual Effective Dose Equivalent (AEDE)

A value of 0.7 Sv Gy$^{-1}$ was used for the conversion coefficient from absorbed dose in air to effective dose received by adults, and 0.8 for the indoor occupancy factor, implying that 20% of time is spent outdoor, on average, around the world. The annual effective dose is determined using the following equations:

$$AEDE_{out} (\mu Sv y^{-1}) = D(nGyh^{-1}) \times 8760(h) \times 0.7(SvGy^{-1}) \times 0.2 \times 10^{-3}$$  \hspace{1cm} (6)

$$AEDE_{in} (\mu Sv y^{-1}) = D(nGyh^{-1}) \times 8760(h) \times 0.7(SvGy^{-1}) \times 0.8 \times 10^{-3}$$  \hspace{1cm} (7)

The world average value of indoor AEDE is (450 $\mu$Sv y$^{-1}$) and for outdoor AEDE is (70 $\mu$Sv y$^{-1}$) [8].

External and Internal Radiation Hazard Indices ($H_{ex}, H_{in}$)

Beretka and Mathew (1985) defined 2 indices that represent external and internal radiation hazards. The prime objective of these indices is to limit the radiation dose to
A dose equivalent limit of 1 mSv y$^{-1}$ has been set. These external hazard indices are calculated using the given equations:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}$$  \hspace{1cm} (8)

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}$$  \hspace{1cm} (9)

The values of $H_{ex}$ and $H_{in}$ must not exceed the limit of unity for the radiation hazard to be negligible [15], [14].

**Gamma Index ($I_{\gamma}$)**

The gamma activity concentration index ($I_{\gamma}$) has been defined by the European Commission and correlated with the annual dose rate. Materials with $I_{\gamma} > 6$ should be avoided since these values correspond to dose rates higher than 1 mSv y$^{-1}$ which is the highest value of the dose rates recommended for humans [16].

$$I_{\gamma} = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_{K}}{4000}$$  \hspace{1cm} (10)

**Annual Gonadal Dose Equivalent (AGDE)**

The annual gonadal dose equivalent (AGDE) due to the specific activities of $^{226}$Ra, $^{232}$Th, and $^{40}$K was calculated using the following formula: [8]

$$AGDE(\mu Sv y^{-1}) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_{K}$$  \hspace{1cm} (11)

**Excess Lifetime Cancer Risk (ELCR)**

Excess lifetime cancer risk (ELCR) was calculated by using the equation:

$$ELCR = AEDE \times DL \times RF$$  \hspace{1cm} (12)

where DL is duration of life (70 year) and RF is risk factor. For stochastic effects, [ICRP, 1991] uses values of 0.05 for the public [13].
RESULTS AND DISCUSSION

A. Radioactivity in Sand Samples

Specific Activity Concentration (Bq kg$^{-1}$)

Figure 2 shows the minimum, maximum and mean values of activity concentration (Bq kg$^{-1}$) of $^{226}$Ra, $^{232}$Th and $^{40}$K for sand samples in graphical form. These values are smaller than the world average values which are 35, 30 and 400 Bq kg$^{-1}$ for $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively [2].

![Figure 2](image)

**Figure 2.** Minimum, maximum and mean values of activity concentration (Bq kg$^{-1}$) of $^{226}$Ra, $^{232}$Th and $^{40}$K for sand samples.

The contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to the total activity for all sand samples can be seen in Figure 3. From it we can find that, the contribution of $^{226}$Ra to the total activity is between 2.42 % in ($S_{12}$) to 11.9 % in ($S_{7}$) and for $^{232}$Th is between 2.38 % in ($S_{4}$) to 5.45 % in ($S_{8}$) and for $^{40}$K is between 82.74 % in ($S_{7}$) to 94.25 % in ($S_{12}$), Which indicates that the specific activity due to $^{40}$K is the largest contributor to the total activity for all samples. Table 3 shows a comparison between the specific activities of $^{226}$Ra, $^{232}$Th and $^{40}$K for sand samples of this work and other regions of the world.
Figure 3. The relative concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K to the total activity in sand samples.

Table 3. Comparison between the specific activity (Bq kg$^{-1}$) for sand samples and other regions of the world.

<table>
<thead>
<tr>
<th>Country</th>
<th>$^{226}$Ra</th>
<th>$^{232}$Th</th>
<th>$^{40}$K</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greece</td>
<td>12 ±3</td>
<td>2.6 ± 3.6</td>
<td>–</td>
<td>[17]</td>
</tr>
<tr>
<td>Previous work</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>20.8±1</td>
<td>22.5±1.2</td>
<td>148.8±13.3</td>
<td>[18]</td>
</tr>
<tr>
<td>Yemen, Juban</td>
<td>32.1</td>
<td>22.3</td>
<td>190.9</td>
<td>[19]</td>
</tr>
<tr>
<td>Pakistan</td>
<td>20 ±9</td>
<td>29± 8</td>
<td>383 ± 142</td>
<td>[20]</td>
</tr>
<tr>
<td>Australia</td>
<td>3.7</td>
<td>40</td>
<td>44.4</td>
<td>[15]</td>
</tr>
<tr>
<td>Brazil</td>
<td>14.3</td>
<td>18</td>
<td>807</td>
<td>[21]</td>
</tr>
<tr>
<td>Netherland</td>
<td>8.1</td>
<td>10.6</td>
<td>200</td>
<td>[22]</td>
</tr>
<tr>
<td>USA</td>
<td>37</td>
<td>33.3</td>
<td>18.5</td>
<td>[23]</td>
</tr>
<tr>
<td>Algeria</td>
<td>12±1</td>
<td>7±1</td>
<td>74±7</td>
<td>[24]</td>
</tr>
<tr>
<td>Egypt, Assiut</td>
<td>4.74</td>
<td>4.10</td>
<td>109.82</td>
<td>Present work</td>
</tr>
</tbody>
</table>

Radiological Hazards

Radium Equivalent Activities ($Ra_{eq}$)

Figure 4 shows the values of radium equivalent activity $Ra_{eq}$ in graphical form. As shown from this figure the calculated values of $Ra_{eq}$ are varied from 8.04 ($S_1$) to 29.87 ($S_4$) Bq kg$^{-1}$ with an average of 19.05 Bq kg$^{-1}$. All values of $Ra_{eq}$ in sand samples are lower than the criterion limit of 370 Bq kg$^{-1}$ [12]. The contribution of $^{226}$Ra, $^{232}$Th and
$^{40}$K to the radium equivalent activity $\text{Ra}_{\text{eq}}$ is shown in Figure 5. $^{40}$K is the main contributor to $\text{Ra}_{\text{eq}}$ in all samples, except in ($S_i$) the main contributor to $\text{Ra}_{\text{eq}}$ is $^{232}$Th and in ($S_7$) the main contributor to $\text{Ra}_{\text{eq}}$ is $^{226}$Ra.

Figure 4. Radium equivalent activity $\text{Ra}_{\text{eq}}$ of sand samples.

Figure 5. Contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to the radium equivalent activity $\text{Ra}_{\text{eq}}$ in sand samples.

Absorbed Dose Rate ($D$)

From Figure 6 we can see that the values of absorbed dose rate $D$ is ranged from 3.8 ($S_1$) to 14.69 (nGy h$^{-1}$) in ($S_2$) with average value 9.24 (nGy h$^{-1}$). These values are clearly smaller than the world average value of $D$ (57 nGy h$^{-1}$) [11]. Figure 7 shows that $^{40}$K is the main contributor to absorbed dose rate in all samples, except in ($S_7$), the main contributor to absorbed dose rate is $^{226}$Ra.

Figure 6. Absorbed dose rate $D$ of sand samples.

Figure 7. Contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to the absorbed dose rate ($D$) in sand samples.

Indoor Annual Effective Dose Equivalent ($E_{\text{in}}$)

The values of indoor Annual effective dose equivalent are vary between 18.66 in ($S_1$) to 72.08 in ($S_4$), as shown in Figure 8, with average value 45.34 µSv y$^{-1}$. These values are smaller than the world average value of indoor AEDE that is (450 µSv y$^{-1}$) [11]. The relative contributions of $^{226}$Ra, $^{232}$Th and $^{40}$K to indoor annual effective dose equivalent are the same to absorbed dose rate.

Outdoor Annual Effective Dose Equivalent ($E_{\text{out}}$)

Values of outdoor Annual effective dose equivalent vary between 4.67 in ($S_1$) to 18.02 in ($S_4$), as shown in Figure 9, with average value 11.34 µSv y$^{-1}$. These values are
smaller than the world average value of outdoor AEDE that is (70 μSv y⁻¹) [11]. The relative contributions of ²²⁶Ra, ²³²Th and ⁴⁰K to outdoor annual effective dose equivalent are the same to absorbed dose rate.

**Figure 8.** Indoor annual effective dose equivalent for sand samples.

**Figure 9.** Outdoor annual effective dose equivalent for sand samples.

**External Hazard Index (H_ex)**

As shown in figure 10, the values of H_ex are ranged from 0.022 (S₁) to 0.081 (S₄) with average value 0.05. These values are clearly smaller than unity that is the limit for the radiation hazard to be negligible. From figure 11 it is clear that ⁴⁰K is the main contributor to the external hazard in all samples, except in (S₇), the main contributor is ²²⁶Ra and (S₁) where the main contributor is ²³²Th.

**Figure 10.** External hazard index for sand samples.

**Figure 11.** Contribution of ²²⁶Ra, ²³²Th and ⁴⁰K to the external hazard index in sand samples.

**Internal Hazard Index (H_in)**

The values of H_in are clearly smaller than unity and is ranged from 0.028 (S₂) to 0.103 (S₄) with average value 0.06, as shown in figure 12. Figure 13 shows that ²²⁶Ra is the main contributor to the internal hazard in all samples, except in (S₈ - S₁₃, S₁₅, S₁₆, S₁₉, S₂₀), the main contributor to the internal hazard is ⁴⁰K.
Figure 12. Internal hazard index for sand samples.

Figure 13. Contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to the internal hazard index in sand samples.

### Gamma Index ($I_\gamma$)

The values of gamma index $I_\gamma$ vary between 0.027 ($S_1$) and 0.099 in ($S_4$) with an average of 0.06. Therefore, these samples can be used as building materials without radiological hazard. Figure 14 shows the values of $I_\gamma$ in graphical form. The relative contributions of $^{226}$Ra, $^{232}$Th and $^{40}$K to gamma index are looks like external hazard index.

### Excess Lifetime Cancer Risk (ELCR)

The values of ELCR vary between $81.66 \times 10^{-6}$ in ($S_1$) and $315.34 \times 10^{-6}$ in ($S_4$) with an average of $198.37 \times 10^{-6}$. Figure 15 shows the values of excess lifetime cancer risk (ELCR) in graphical form. The relative contributions of $^{226}$Ra, $^{232}$Th and $^{40}$K to Excess lifetime cancer risk are the same to absorbed dose rate.

### Annual Gonadal Dose Equivalent (AGDE)

As appear in Figure 16, the values of annual gonadal dose equivalent (AGDE) vary between 26.94 in ($S_1$) and $105.54 \mu$Sv y$^{-1}$ in ($S_4$), with an average of $66.25 \mu$Sv y$^{-1}$.
The relative contributions of $^{226}$Ra, $^{232}$Th and $^{40}$K to annual gonadal dose equivalent are the same to absorbed dose rate.

**Figure 16.** Annual gonadal dose equivalent (AGDE) for sand samples.

**Figure 17.** Minimum, maximum and mean values of the activity concentration (Bq kg$^{-1}$) of $^{226}$Ra, $^{232}$Th and $^{40}$K in gravel samples.

**Figure 18.** Contribution of $^{226}$Ra to the total activity is between 5.3 % in (G$_3$) to 81.55 % in (G$_{15}$), and for $^{232}$Th, is between 2.58 % in (G$_7$) to 18.45 % in (G$_{13}$), and for $^{40}$K, the values are between 65.2 % in (G$_2$) to 91.87 % in (G$_5$), as shown in figure 18.
Figure 18  The relative concentration of $^{226}$Ra, $^{232}$Th and $^{40}$K to the total activity in gravel samples.

Table 4 shows a comparison between the specific activity of $^{226}$Ra, $^{232}$Th and $^{40}$K for gravel samples of this work and other regions of the world.

Table 4. Comparison between the specific activity (Bq Kg$^{-1}$) for gravel samples of this work and other regions of the world.

<table>
<thead>
<tr>
<th>Country</th>
<th>$^{226}$Ra</th>
<th>$^{232}$Th</th>
<th>$^{40}$K</th>
<th>Reference</th>
</tr>
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<td>Austria</td>
<td>13.9</td>
<td>14.8</td>
<td>171</td>
<td>[25]</td>
</tr>
<tr>
<td>Brazil</td>
<td>10.3</td>
<td>-</td>
<td>933</td>
<td>[21]</td>
</tr>
<tr>
<td>Iran</td>
<td>20.4 ± 1.2</td>
<td>6.3 ± 0.3</td>
<td>450.7 ± 14</td>
<td>[26]</td>
</tr>
<tr>
<td>Cuba</td>
<td>20</td>
<td>13</td>
<td>134</td>
<td>[27]</td>
</tr>
<tr>
<td>Greece</td>
<td>11</td>
<td>12</td>
<td>140</td>
<td>[28]</td>
</tr>
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<td>6.8</td>
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<td>1.82</td>
<td>31.60</td>
<td>Present work</td>
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Radiological Hazards

Radium Equivalent Activities ($Ra_{eq}$)

Figure 19 shows the values of radium equivalent activity $Ra_{eq}$ in graphical form. As is shown from this figure the calculated values of $Ra_{eq}$ are varied from 6.40 (G1) to 16.44 (G14) Bq kg$^{-1}$ with an average of 10.61 Bq kg$^{-1}$. All values of $Ra_{eq}$ in gravel samples are lower than the criterion limit of 370 Bq kg$^{-1}$ [12]. The contributions of $^{226}$Ra, $^{232}$Th and $^{40}$K to the radium equivalent activity $Ra_{eq}$ are shown in figure 20. As is shown in this figure, $^{226}$Ra is the main contributor to $Ra_{eq}$ in all samples except in (G1), the main contributor to $Ra_{eq}$ is $^{40}$K.

Figure 19. Radium equivalent activity $Ra_{eq}$ of gravel samples.  
Figure 20. Contribution of $^{226}$Ra, $^{232}$Th and $^{40}$K to the radium equivalent activity $Ra_{eq}$ in gravel s.
Absorbed Dose Rate (D)

From figure 21, it is shown that, the values of D is ranged from 3.04 (G₁) to 7.78 (nGy h⁻¹) in (G₁₄) with average value 4.98 (nGy h⁻¹). These values are clearly smaller than the world average value of D (57 nGy h⁻¹). [11] The main contributor to absorbed dose rate in all samples is ²²⁶Ra, except in (G₃), the main contributor is ⁴⁰K, as shown in figure 22.

![Figure 21](image1.png)  ![Figure 22](image2.png)

**Figure 21.** Absorbed dose rate D of gravel samples.  **Figure 22.** Contribution of ²²⁶Ra, ²³²Th and ⁴⁰K to the absorbed dose rate (D) in gravel samples.

Indoor Annual Effective Dose Equivalent ($E_{in}$)

The values of indoor Annual effective dose equivalent are vary between 14.91 in (G₁) to 38.16 in (G₁₄) with average value 24.42 µSv y⁻¹, as shown in figure 23. These values are smaller than the world average value of indoor AEDE that is (450 µSv y⁻¹) [11]. The relative contributions of ²²⁶Ra, ²³²Th and ⁴⁰K to indoor annual effective dose equivalent are the same to absorbed dose rate.

Outdoor Annual Effective Dose Equivalent ($E_{out}$)

As is shown in figure 24, values of outdoor Annual effective dose equivalent vary between 3.73 in (G₁) to 9.54 in (G₁₄) with average value 6.11 µSv y⁻¹. These values are smaller than the world average value of outdoor AEDE that is (70 µSv y⁻¹) [11]. The relative contributions of ²²⁶Ra, ²³²Th and ⁴⁰K to outdoor annual effective dose equivalent are the same to absorbed dose rate.
Figure 23. Indoor annual effective dose equivalent for gravel samples.

Figure 24. Outdoor annual effective dose equivalent for gravel samples.

External Hazard Index ($H_{ex}$)

The values of $H_{ex}$, that shown in figure 25, is ranged from 0.017 ($G_1$) to 0.044 ($G_{14}$) with average value 0.029. These values are clearly smaller than unity that is the limit for the radiation hazard to be negligible. The main contributor to the external hazard index in all samples is $^{226}\text{Ra}$, except in ($G_3$), the main contributor is $^{40}\text{K}$ as shown in figure 26.

Figure 25. External hazard index for gravel samples.

Figure 26. Contribution of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ to the external hazard in gravel samples.

Internal Hazard Index ($H_{in}$)

The values of $H_{in}$ are clearly smaller than unity and is ranged from 0.0319 ($G_1$) to 0.068 ($G_{14}$) with average value 0.045, as shown in figure 27. $^{226}\text{Ra}$ is the main contributor to the internal hazard index in all samples as shown in figure 28.
The values of gamma index $I_\gamma$ vary between 0.021 (G1) and 0.055 in (G14) with an average of 0.036. Therefore, these samples can be used as building materials without radiological hazard. Figure 29 shows the values of $I_\gamma$ in graphical form. The relative contributions of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ to gamma index are the same to external hazard index.

**Excess Lifetime Cancer Risk (ELCR)**

The values of ELCR vary between 65.24E-6 in (G1) and 166.95E-6 in (G14) with an average of 106.85E-6. Figure 30 shows the values of Excess lifetime cancer risk (ELCR) in graphical form.

As appear in Figure 31, the values of annual gonadal dose equivalent (AGDE) vary between 20.79 in (G1) and 54.35 µSv y$^{-1}$ in (G14) with an average 34.53 µSv y$^{-1}$. The relative contributions of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ to Excess lifetime cancer risk and annual gonadal dose equivalent are the same to absorbed dose rate.
CONCLUSION

The specific activity of natural radionuclides $^{238}$U ($^{226}$Ra), $^{232}$Th and $^{40}$K in row building material samples extracted from sand and gravel quarries in Assiut, Egypt have been measured by using gamma spectrometry (NaI (Tl) 3” x 3”)and found that The mean specific activity of $^{226}$Ra in gravel are greater than its value in sand samples, But the mean specific activity of $^{232}$Th and $^{40}$K in sand samples are greater, and all values are smaller than the world average values which are 35, 30 and 400 Bq kg$^{-1}$ for $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively, that reported by the UNSCEAR 2000.

Values including Radium equivalent ($\text{Ra}_{eq}$), Absorbed dose rate ($D$), External and Internal hazard indices ($H_{\text{ex}}$ and $H_{\text{in}}$), Gamma index ($I_{\gamma}$), the indoor and outdoor Annual Effective Dose Equivalent (AEDE), Excess Lifetime Cancer Risk (ELCR) and the Annual Gonadal Dose Equivalent (AGDE), were calculated, to estimate the radiological hazards arising from using these row building materials in Assiut governorate and found that all sand and gravel quarries in Assiut governorate are safe from radiological view for use in building construction.

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REFERENCES

materials used in the Tiruvannamalai District, Tamilnadu, India, using a statistical approach, Jtusci 11, 523–533 (2017).


