Natural Radioactivity Measurements for Assessment Radiation from soils of Hadhramout Region, Yemen

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Abstract. Measurements of gamma-emitting radionuclides were performed on soil samples collected at various depth levels from different locations in the Hadhramout region, Yemen. The activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$, $^{40}\text{K}$, and $^{137}\text{Cs}$ were determined by gamma spectrometry detector. The measurement concentrations of $^{238}\text{U}$, $^{232}\text{Th}$, $^{40}\text{K}$ in the soil samples ranged from 9.25 to 423.84 Bq/kg, 7.85 to 667.23 Bq/kg, and from 31.54 to 373.12 Bq/kg, respectively. The concentrations of these radionuclides are compared with the recommended values. According to the present lower concentration levels of $^{137}\text{Cs}$, it does not pose any radiological complication. However, this data may provide a general background level for the area studied and may also serve as a guideline for future measurement and assessment of possible radiological risks to human health in this region.

1. Introduction
Natural radioactive $\gamma$ emitters as $^{40}\text{K}$, $^{232}\text{Th}$, and $^{238}\text{U}$ are essential nuclides in the crust of the earth. The world is exposed to pollutants which are naturally radioactive. Naturally, radionuclides and almost 82% of human species absorb radiation [1]. The most common radionuclides in the crust of the Earth are Uranium-234 ($^{234}\text{U}$) and Uranium-238 ($^{238}\text{U}$). In addition, environmental isotopes are radon-222 ($^{222}\text{Rn}$), radium-226 ($^{226}\text{Ra}$), and radium-228 ($^{228}\text{Ra}$), and that are formed as the radioactive decay of thorium and uranium present in rock and soil is the result of [2]. These radioactive nuclides pose risks due to external exposure to emissions of $\gamma$ radiation and radon and its progeny internally. Radon is called the second main cause of lung disease and is a human carcinogen [3]. For a good understanding of differences in the background of natural radiations, the starting point must be knowing the wide differing radioactivity content of naturally happing radionuclides in soils. [4,5]

The most important key for detecting the radioactive natural background in the soil is measuring of radioactive concentration of the radioactive isotopes [6]. In soil, the natural radioactivity levels change according to the geological nature and geographical structure.

The natural presence of the radon gases which are radioactive and the presence of other naturally occurred radionuclides and their radioactive daughters in the soil provide exposures to humans [7]. Natural-Occurrence radioactivity depends on the type of soil; soil radioactivity sources other than
those present in natural foundation are primarily because of the widespread use for agricultural purposes of phosphate-wealthy fertilizers [8]. Thus this study aims to detect the radioactivity per unit mass of 40K, 137Cs, 232Th, and 238U in the soil of the Hadhramout region and to calculate the radium equivalent dose rate, representative index, external hazard index, annual effective dose and absorbed dose rate. A measurement of terrestrial γ dose rates is fundamental since γ radiation gives information relating to excess lifetime cancer risks (CR). So, lifetime measured and exhibited hither. The outcomes will appear as a baseline information group, which will allow calculating the exposure of the population. Radiation happens in nature and comes from sources, from our bodies, everywhere. Radiation is often mistaken, but it helps to cure diseases and save lives [9].

1.1 Location of Study Area
Hadhramout region is located on the Arab sea in the east part of Yemen, which lies at Longitude 49° 30 east and latitude 16° 40 north. It is populated by approximately more than 1 million people. Sampling points and studied area are shown in Figure 1.

2. Materials and Methods
Soil samples have been taken randomly among selected locations of the Hadhramout region (As sufale site) in Yemen at varying depths as, surface (0-5), (5-50), (50-60), and (60-70) cm. The strange material like plant roots, stones were taken away from the mix. The samples were handled as they dried in the sun, one-hole day drying inside an oven of one hundred °C, crushed, ground to a soft powder, and homogenized by blending before the test [10]. Then a combined sample of about 500 gm was sealed and kept for about four weeks duration to let the equilibrium of radioactive [11]. The activity concentrations were measured for the 40K, 232Th, 226Ra The γ – spectrometer used for analyzing all samples is High purity Germanium (HPGe) detector with a 25% of relative efficiency, coaxial-type. The resolution (FWHM) is from 3 to 3.5 keV for 1332.5 keV γ-ray peak of 60Co, and Compton peak ratio is 41:1. In our study, the background was estimated each week under the same circumstances as a measurement of the sample. The elapsed time of measurement was 82800 s. The specific activity of 226Ra was estimated from γ-ray lines of 214Bi at 609.3, 1120.3 & 1764.49 keV, and 214Pb at 351 keV, while the specific activity of 232Th was decided from γ-ray lines of 228Ac at 911.16 & 968.9 keV, 212Pb at 238.58 Kev and 212Bi at 727. 25. 40K was defined by measuring its single peak at 1460.8 Kev. The reference decay for detecting 137Cs is the decay of 137Ba.

Activity calculations in each sample were estimated utilizing the next equation [12,13].

\[ Ac \text{ (Bq/kg)} = \frac{N_c}{\varepsilon \beta M} \]  
(1)

Where: Nc represents counting rate of gamma, \( \varepsilon \) represents the efficiency of detector, \( \beta \) represents the absolute transition probability of γ–decay, M represents the sample’s mass in kilograms.
3. Results and discussions

3.1 Activity concentration

Twenty soil samples were taken from five different locations of the Hadhramout region at different depths: 5, 50, 60, and 70 cm underground. The results of the $^{40}$K, $^{137}$Cs, $^{226}$Ra, and $^{232}$Th activity concentrations taken from all measured samples in addition to their corresponding total uncertainties are abstracted in the table (1).

The radioactivity of $^{226}$Ra was from 9.25 Bq/kg for sample S5 (no.18) at depth (5-50) cm to 423.84 Bq/kg for sample S1 (no.2) at depth (5-50) cm. Comparing these values with the reported world range of $^{226}$Ra activity concentrations which varies from 10 to 50 Bq/kg as reported by UNSCEAR2000, it can be seen that the upper value in the current work is 7 times more than the reported upper-value concentration of 60 Bq/kg.

The activity concentration for $^{232}$Th ranges from 7.85 Bq/kg for sample S5 (no.20) at a depth (60-70) cm to 667.23 Bq/kg in sample S1 (no.2) at a depth (5-50) cm. The reported world values of $^{232}$Th range from 16 to 110 Bq/kg (UNSCEAR2000). So, the measured upper value in the current research is ten times as much as the upper limit world values. The $^{40}$K activity concentration was determined are within the range from 31.54 Bq/kg in sample S2 (no.8) at a depth (60-70) cm to 373.12 Bq/kg in sample S5 (no.18) at a depth (5-50) cm. The scope of activity concentration values of $^{40}$K is beneath the world range in soil (140 to 850 Bq/kg) UNSCEAR2000.

Also from Table 1, it can be seen that the samples S1, S2, S3, and S4 at depths (0-5) cm and (5-50) cm have much lower values of $^{40}$K activity concentrations and greater values for $^{226}$Ra and $^{232}$Th in comparison with the present soil samples and the reported range values [7]. The higher values of $^{226}$Ra and $^{232}$Th for these samples may be attributed to their graphical locations under investigation from which the samples were collected, where, these samples were located in the vicinity of the sea and exposed to rapidly spreading water due to the crack of wavefronts at the shore. Consequently, radionuclides are deposited from those transports with seawater during high tide and then pass downward through the porous sandy soil surface. According to the findings of this research, exceptional samples (S1, S2, S3 and S4) at depths (0-5) and (5-50) cm denote the U enrichment in this area needs a very good uranium prospect with economic potential is high.

The concentration results of the samples S5 (no.17, no.18, no.19, and no.20) at all depths are lower than the worldwide average. Also, the results in table (1) indicate that no significant variations are depending on soil depth for these samples (S5) at various depths, this may be referred to the location...

![Figure 1. Location of soil samples in Hadhramout region (As sufal site)](image-url)
of the soil samples lies away from the sea and may be due to the absence of igneous rocks. The difference in the soil radioactivity content may be recognized from one location to the other depending on the soil type, soil formation, soil transport method.

The man-made radionuclide concentrations of $^{137}$Cs in the samples of the Hadhramout region have been observed only in samples S1 (no. 1, no. 2, no. 4), S2 (no 5, no 6), S3 (no. 9), S4 (no. 13) and S5 (no. 17) as presented in the table (1) and varies from 0.64 Bq/kg in sample S5 (no 17) at a depth (0-5) cm to 5.80 Bq/kg in sample S1 (no 2) at depth (5-50) cm. These values of measurements are usual measurements of fallout in the global atmospheric and comparable to the information summarized in different places, 5.4 Bq/kg in Turkey [14], 2.5 Bq/kg in Belgrade [15], and 0.9 Bq/kg in Sudan [16]. However, the lower concentration levels of $^{137}$Cs determined in the present study for soil samples in table 1 are not posing any radiological complication.

### 3.2 Hazard indices

#### 3.2.1 Radium equivalent activity (Ra$_{eq}$)

This index was determined through the next relation [17]:

$$Ra_{eq} (Bq/kg) = ARa + 1.429ATh + 0.077AK$$

The last equation is based on the presumption 481 Bq/kg of $^{40}$K, 370 Bq/kg of $^{226}$Ra, 259 Bq/kg of $^{232}$Th gives the same γ-ray dose rate [18].

As presented in table 2, radium equivalent Ra$_{eq}$ for all soil samples vary from 39.08 Bq/kg in sample S1 (no.3) at a depth (50-60) cm to 1384.23 Bq/kg in sample S1 (no.2) at a depth (5-50) cm. Radium equivalent values for the samples S1 (no. 1 & no.2) at depths (0-5) & (5-50) cm and sample S2 (no.6) at a depth (5-50) cm are 1068.27, 1384.23, and 1151.61 Bq/kg, where these values are more than three times the limit value 370 Bq/kg. Fig. 2. Represents a comparison between the measured radium equivalent for samples S1, S2, S3, S4 & S5 at different depths and the reported value in (UNSCEAR, 2000).

### Table 1. Natural radionuclides radioactivity ($^{40}$K, $^{226}$Ra, and $^{232}$Th) and $^{137}$Cs the fallout nuclide in samples of soil (Bq/kg) of Hadhramout region in Yemen and reported mean values in (UNSCEAR, 2000).

| Sample No. | Code of Sample and depth (cm) | Activity concentrations Bq/kg |
|------------|-------------------------------|-------------------------------|
|            | $^{226}$Ra                    | $^{232}$Th                    | $^{40}$K                      | $^{137}$Cs |                      |
| 1          | S1 (0-5)                      | 315.40 ±0.00013               | 523.93 ±0.00050               | 47.38 ±0.00050 | 2.61 ±0.00001  |
| 2          | S1 (5-50)                     | 423.84 ±0.00011               | 667.23 ±0.00046               | 81.22 ±0.00009 | 5.80 ±0.0002  |
| 3          | S1 (50-60)                    | 16.77 ±0.00014                | 13.69 ±0.00165                | 35.51 ±0.00003 | L.D.L |
| 4          | S1 (60-70)                    | 24.00 ±0.000016               | 28.41 ±0.00015                | 50.16 ±0.00004 | 0.59 ±0.00000 |
| 5          | S2 (0-5)                      | 99.59 ±0.00019                | 144.78 ±0.00096               | 39.59 ±0.00004 | 1.10 ±0.0001  |
| 6          | S2 (5-50)                     | 344.05 ±0.00015               | 561.17 ±0.00053               | 66.01 ±0.00007 | 5.21 ±0.0001  |
| 7          | S2 (50-60)                    | 31.78 ±0.00025                | 44.51 ±0.00079                | 39.96 ±0.00004 | L.D.L |
| 8          | S2 (60-70)                    | 37.61 ±0.00024                | 45.31 ±0.00023                | 31.54 ±0.00003 | L.D.L |
3.2.2 External hazard index

For reference value of external γ-ray dose of 1.5 mSv per year, Hex calculated using the following equation [17]:

\[ \text{Hex} = \frac{A_{Ra}}{370 \text{ Bq/kg}} + \frac{A_{Th}}{259 \text{ Bq/kg}} + \frac{A_{K}}{4810 \text{ Bq/kg}} \] (3)

Where: AK, ARa, and ATh are the activity concentrations (Bq/kg) of the specific radiation. The highest value of Hex to be less than unity agrees to the top limit of Raeq (370 Bq/kg).

As presented in table 2, the highest values of the outdoor radiation hazard index (Hex) are present in the sample S1 (no. 1 & no. 2) as 2.89 & 3.74 and in the sample S2 (no. 6) as 3.11, where these values are more than three times the critical limit reported by UNSCEAR 2000. External index values for the other samples are smaller than the unity of critical value.

3.2.3. Representative level index

The equation is as follows used to estimate Iγ for soil samples under investigation.

\[ I_{\gamma} = \left( \frac{1}{300} \right) A_{Ra} + \left( \frac{1}{200} \right) A_{Th} + \left( \frac{1}{3000} \right) A_{K} \] (4)

Where ARa, ATh, and AK are the specific activities of $^{226}\text{Ra}$, $^{232}\text{Th}$, and $^{40}\text{K}$ in Bq/kg, respectively. As observed in table 2, Iγ differs from 0.14 to 4.78 with an average value of 0.98. The values of Iγ for the samples S1, S2 at depths (0-5) cm and (5-50) cm and the samples S3&S4 at the surface only are higher than the standard value.
3.2.4 Absorbed $\gamma$ dose rates $D$

"The absorbed $\gamma$ dose rates in the air at 1m over the ground were measured using UNSCEAR 2000 guidelines:

$$D (\text{nG per hour}) = 0.427A_{\text{Ra}} + 0.623A_{\text{Th}} + 0.043A_{\text{K}}$$

Where: $A_{\text{K}}$, $A_{\text{Ra}}$, and $A_{\text{Th}}$ are radioactivities (Bq/kg) of $^{40}\text{K}$, $^{226}\text{Ra}$, and $^{232}\text{Th}$, respectively.

As present in table 2, the total absorbed dose rate range between the lowest value 17.22 nGy/h in the sample S1 (no. 3) at a depth (50-60) cm to the highest value 600.16 nGy/h in the sample S1 (no. 2) at a depth (5-10) cm. The absorbed dose can be seen in the group samples S1 (no.1 & no.2), S2 (no.5 & no.6), S3 (no.9) and S4 (no.13 & no.14) are 463.12, 600.16, 134.43, 499.36, 144.55, 136.55 and 123.29 nGy/h, respectively. These values are significantly higher than the global average value 57 nGy/h listed by UNSCEAR 2000. Whereas, the absorbed dose values of the other soil samples at different depths are lower than the global average value.

3.2.5 Annual effective dose equivalent ($AED_{\text{outdoor}}$)

It was determined from the absorbed dose by using the dose conversion factor of 0.7 Sv/Gy with an outdoor occupancy factor of 0.2 [7]:

$$D_{\text{eff}} (\text{mSv/Y}) = D (\text{nGy/h}) \times 8766 \text{ h/y} \times 0.7(\text{Sv/Gy}) \times 0.2 \times 10^{-6}$$

Table 2 shows the effective dose equivalent per year, from 0.021 mSv/Y in sample S1 (no.3) to 0.736 mSv/Y in sample S1 (no.2). The annual effective dose for samples S1 (no.1 & no.2), S2 (no.5) is higher than the global average value of 0.48 mSv/Y for outdoor terrestrial radiation for the region of normal radiation background UNSCEAR (2000). Whereas, the effective dose of the other samples at different depths is less than the global average value reported in UNSCEAR2000.

According to the analysis of the soil samples S1, S2, S3, S4 at depths (0-50) cm, we can say that the housing construction of the housing in these regions is not safe for human habitation. Whereas, analysis of the soil sample S5 at all depths showed that no health hazards. And so, we can say that samples from S1 to S4 at depths greater than 50 cm and samples from S5 for all depths are secure and can be utilized as frame materials, with no major radiological hazards to on population.
Table 2. Raeq, Iγ, and Hex for samples from the Hadhramout region, Yemen

| Sample No. | Sample code & depth (cm) | Raeq (Bq/kg) | Iγ (Bq/kg) | Hex (D/nGy/h) | Deff (mSv/Y) | ELCR (Out) *10^4 |
|------------|--------------------------|--------------|------------|---------------|-------------|-----------------|
| 1          | S1 (0-5)                 | 1068.27      | 3.69       | 2.89          | 463.12      | 0.568           |
| 2          | S1 (5-50)                | 1384.23      | 4.78       | 3.74          | 600.16      | 0.736           |
| 3          | S1 (50-60)               | 39.08        | 0.14       | 0.11          | 17.22       | 0.027           |
| 4          | S1 (60-70)               | 68.49        | 0.24       | 0.19          | 30.10       | 0.037           |
| 5          | S2 (0-5)                 | 309.67       | 1.07       | 0.84          | 134.43      | 0.165           |
| 6          | S2 (5-50)                | 1151.61      | 3.97       | 3.11          | 499.36      | 0.612           |
| 7          | S2 (50-60)               | 98.51        | 0.34       | 0.27          | 43.02       | 0.052           |
| 8          | S2 (60-70)               | 104.83       | 0.36       | 0.28          | 45.64       | 0.056           |
| 9          | S3 (0-5)                 | 332.43       | 1.15       | 0.90          | 144.55      | 0.177           |
| 10         | S3 (5-50)                | 50.15        | 0.185      | 0.14          | 22.65       | 0.028           |
| 11         | S3 (50-60)               | 75.41        | 0.27       | 0.20          | 34.75       | 0.043           |
| 12         | S3 (60-70)               | 63.34        | 0.23       | 0.17          | 29.52       | 0.036           |
| 13         | S4 (0-5)                 | 314.74       | 1.09       | 0.85          | 136.55      | 0.167           |
| 14         | S4 (5-50)                | 583.07       | 0.98       | 0.77          | 123.29      | 0.151           |
| 15         | S4 (50-60)               | 57.35        | 0.20       | 0.16          | 25.79       | 0.032           |
| 16         | S4 (60-70)               | 45.32        | 0.16       | 0.12          | 19.99       | 0.025           |
| 17         | S5 (0-5)                 | 39.60        | 0.15       | 0.11          | 18.12       | 0.022           |
| 18         | S5 (5-50)                | 51.26        | 0.21       | 0.14          | 25.78       | 0.032           |
| 19         | S5 (50-60)               | 42.58        | 0.16       | 0.12          | 20.66       | 0.025           |
| 20         | S5 (60-70)               | 42.34        | 0.17       | 0.11          | 20.87       | 0.026           |
| Range      |                          | 39.08-1384.23| 0.14-4.78 | 0.11-3.74    | 17.22-600.16| 0.021-0.736     |
| Average    |                          | 281.15       | 0.98       | 0.76          | 463.12      | 0.15            |
| UNSCEAR 2000|                        | 370          | ≤ 1        | ≤ 1           | 57          | 0.48            |

3.2.6 Excess lifetime cancer risk outdoors (CR)

It was measured as follows [13]:

\[
CR = \text{Deff} \times T \times RF \tag{7}
\]

Where: T is the life duration (70 years) and RF is a risk factor (Sv⁻¹), fatal cancer risk per Sever. To calculate the damage-adjusted cancer risk of $5.52 \times 10^{-2}$ Sv⁻¹ for the entire people. The excess lifetime cancer risk ranges from $0.88 \times 10^{-4}$ to $29.51 \times 10^{-4}$. The present average is significantly higher than the global average ($0.29 \times 10^{-3}$) [7]. As shown in Table 2 all the samples have a risk value higher than the recommended value.

4. Conclusion

We used γ - spectrometry to calculate radioactivity per kg at different depths of 20 samples of soil were taken from the Hadramout area, Yemen. The findings reveal that the radioactivity per unit mass for $^{40}$K, $^{226}$Ra, and $^{232}$Th range (31.54 to 373.12 Bq/kg), (9.25 to 423.84 Bq/kg), and (7.85 to 667.23 Bq/kg) respectively. Also, the average value of the whole absorbed dose rate is 463.12 nGy/h, and it is significantly higher than the identical global average value which is 57 nGy/h.

Because of the high values of Hazard indices of the samples S1, S2, S3, and S4 at the surface and at depth (5-50) cm, we can conclude that the use of these soil samples for the construction of the housing is not secure for people occupancy. Whereas, it says there isn't a health risk of Hadramout region from the soil samples of S5 at all depths and the samples S1, S2, S3, and S4 at depths greater than 50 cm underground. However, these results may give a public knowledge level for the region studied and
may also provide a future calculation guideline and evaluation of likely radiological risks to personal health in this area.

![Graph](image)

**Figure 2.** Comparison between the measured radium equivalent for samples S1, S2, S3, S4 & S5, and the reported value in (UNSCEAR, 2000).

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