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Measurement of Gamma Emitting Radionuclides for Assessment, Environmental Hazards of Radiation in Rock and Soil Samples of Shabwah and Hadramout Regions, Yemen

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Abstract

The natural radioactivity of ^{226}Ra, ^{232}Th and ^{40}K and the fallout of ^{137}Cs in soils and granite rocks of two regions in Yemen (Shabwah and Hadramout) were measured by using gamma-ray spectrometry (HPGe) detector. The average values of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the soil samples are 14.34, 25.78 and 566.05 Bq/kg respectively. For rock samples, the average activity concentration for ^{226}Ra, ^{232}Th and ^{40}K are 45, 106 and 1235 Bq/kg respectively. Low concentration values of ^{137}Cs in soil and rock samples under investigation, are not radiologically important. The radium equivalent activity (Raeq) and external hazard index (Hex) of all samples are less than the limits of 370 Bq·kg^{-1} and unity, respectively. The average values of total absorbed dose rate due to three primordial radionuclides in soil and rock samples are 46.5 nGy/h and 138.36 nGy/h, respectively, where the absorbed average value of the granite is higher than the permitted limit. So, the local people must avoid using these granite samples as the interior decorative materials of dwelling without radioactivity control.

Keywords

Gamma Spectrometry, Annual Effective Dose, External Hazard Index

1. Introduction

The natural radioactivity of soil and rock samples is usually determined from the

^{226}Ra, ^{232}Th and 40 K contents [1]. A significant amount of man-made radionuclides ^{137}Cs, may also present in the environment as a result of testing of nuclear weapons in the atmosphere, accidents and the routine discharge of radionuclides from nuclear installations [2]. The specific level radiation in the crust varies from one region to another as the concentrations of these natural radioactive elements vary due to their non-uniform nature in soils and the types of rock from which the soil originates [3]. The knowledge of radiation levels in the environment is an important for assessing the effects of radiation exposure. So, the aim of the present study is to measure the natural radioactivity levels for estimating the radiogecal hazard indices in soils and granite rocks. This work can be used as a baseline guideline for assessing the exposure of the natural radiation in the study region, especially, in this area, the rocks and soils are used as building materials. The studied regions located in southwestern Yemen (**Figure 1**).

2. Material and Methods

2.1. Samples Collection and Preparation

A total of twenty soil sample at depths (0 - 5, 5 - 50, 50 - 60 and 60 - 70 cm) underground and 6 granite rock samples were collected from different locations in Shabwah and Hadramout regions, Yemen, respectively. The sampling locations were chosen mostly in a wide area that we believe that it's representative of the important region. All soil samples collected from undisturbed sites located away from buildings, trees and roads to ensure that there was no influence of man-made structures and anthropogenic activities.The collected samples (soil and

Figure 1. Location map of studying regions.

granite) were first sundried and then oven dried at 110˚C to constant weight. The samples were pulverized, homogenized and sieved through 1-mm mesh [4]. 500 gm of each meshed sample was replaced in Marinelli beaker and then was stored for four weeks to reach the equilibrium state between radium and its decay products [5]. Radioactivity measurements were performed by using High purity Germanium (HPGe) detector (25% relative efficiency). The measurement time of activity or background was 82800 seconds. The radioactivity concentration of ^{226}Ra was determined from the photopeaks of 295.09, 351.87 Kev (^{214}Pb), 609.31 Kev & 1120.27 keV & 1764.49 keV (^{214}Bi). ^{232}Th radioactivity was determined from 238.58 Kev (^{212}Pb), 727.25 Kev (^{212}Bi) and 911.16 keV & 968.97 Kev (^{228}Ac) while the ^{40}K radioactivity was determined from 1460.8 Kev and finally, ^{137}Cs was determined from the decay of ^{40}Ar and ^{137}Ba [4].

2.2. Calculations

The activity concentrations (Bq/kg) for the natural radionuclides in the measured samples were calculated after decay correction using the equation:

$$A_c = Nc/\left(m\beta\varepsilon_{abs}\right) \quad (1)$$

where A_c is the activity concentration (Bq/kg) in the sample, Nc is the net area under the corresponding peak/second, m the dry weight sample mass (kg), β the branching ratio, and ε_{abs} is the detection absolute efficiency of a specific energy.

The radium equivalent activity is a very useful guideline in organization the safety standards in radiation protection for humans. The index calculated by the following relation [6].

$$Ra_{eq} = A_{Ra} + (A_{Th} \times 1.43) + (A_K \times 0.077) \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq/kg, The formula is based on the assumption that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 481 Bq/kg of ^{40}K produce the same gamma-ray dose rate [7].

The representative level index, I_γ is used to estimate gamma radiation associated with the natural radionuclides in soil and calculated by the following equation [1]:

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (3)$$

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

The external hazard index Hex can be calculated by the following equation [8]:

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The maximum value of H_{ex} to be less than unity [8].

The absorbed gamma dose rates D(nGy/h) in air at 1m above the Earth's surface for the uniform distribution of radionuclides were calculated based on guidelines given by [8]:

$$D(nG/h) = 0.427A_{Ra} + 0.623A_{Th} + 0.043A_{K} \quad (5)$$

where, A_{Ra}, A_{Th} and A_{K} are the activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The annual effective dose rate was calculated from the absorbed dose through the application of dose conversion factor of 0.7 Sv/Gy with occupancy in the outdoor factor 0.2. [8]

$$D_{eff}\,(mSv/y) = Dr(nG/h) \times 8760\ h \times 0.7(SvG/y) \times 0.2 \times 10^{-6} \quad (6)$$

where 8,760 h is the number of hours in 1 year. 10^{-6} is a conversion factor of nano and Milli.

3. Results and Discussion

3.1. Activity Concentrations

The results of the measured values of activity concentrations for ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs obtained from the samples are presented in Table 1. From this table, the average values, concentrations of ^{226}Ra, ^{232}Th, in soil and are less than the world average values [8]. ^{40}K activity concentrations are in the range between 510.92 in the sample (S3) to 600.75 Bq/kg in sample (S5) with an average value is

Table 1. Activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and the fallout nuclide ^{137}Cs (Bq/kg) in soil and granite samples.

Sample type	Sample code	Activity concentrations (Bq/kg)			
		^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Soil	S1	15.37	28.29	546.35	0.83
	S2	14.93	25.90	560.05	0.17
	S3	14.38	22.85	510.92	1.56
	S4	13.90	24.56	595.18	0.01
	S5	13.10	24.07	600.75	L.D.L
	S6	13.97	29.03	583.05	0.25
	Range	13.10 - 15.37	22.85 - 29.03	510.92 - 600.75	0.01 - 1.56
	Average	14. 28	25.78	566.05	0.56
	UNSCEAR 2000	30	35	400	
Granite rock samples	G1	42.25	102.36	1480.26	1.15
	G2	37.36	83.93	1031.26	0.87
	G3	53.33	109.22	1058.50	0.75
	G4	45.17	103.89	1489.20	0.61
	G5	53.67	128.75	1076.01	0.57
	G6	38.21	104.71	1272.81	0.04
	Range	37.36 - 53.67	83.93 - 128.75	1031.26 - 1489.2	0.04 - 1.15
	Average	45	106	1235	0.67
	UNSCEAR 2000	50	50	500	

higher than the world average value [8]. Higher concentration values of ^{40}K were obtained from the soil of Shabwah region, probably because the use of inorganic fertilizer in some locations and could also be attributed to the wearing away from the weathered surfaces of the potassium rich, igneous rocks which dominate a part of the geology of this region. The artificial radionuclide of ^{137}Cs concentrations in the soil samples are within the global atmospheric fallout and lower than the reported data for other countries. For granite samples, ^{226}Ra, ^{232}Th and ^{40}K average concentrations are 45, 106, and 1235 Bq/kg respectively. The average values of ^{226}Ra fall within the worldwide average values. While, ^{232}Th and ^{40}K average values are twice the worldwide average values (50, 50 and 500 Bq/kg) respectively [8]. The content of ^{40}K in granite samples is the highest in all the sampling areas. So, it is the most abundant radionuclide of the total (^{238}U + ^{232}Th + ^{40}K), it is abundant about 89% followed by ^{232}Th 7.7%. And finally ^{226}Ra is 3.3%. ^{137}Cs is detected in all granite samples under investigation. The mean concentration of ^{137}Cs is 0.67 Bq/kg. These values are not radiologically important. **Table 2** shows the comparison between the activity concentrations of soil samples with that of other countries of the World. The variations in the activity concentrations in the soil of the various locations of the world, depend upon the geological and geographical conditions of the area and the extent of fertilizer applied to the agricultural lands [8]. **Table 3**, shows that, for granite samples results obtained in the present work are consistent with previous results and all results being within the range given in the report [8]. In general, the radioactivity in granite samples varied from one country to another [8]. **Figure 2** shows a comparison between the obtained average values activity concentrations in soil and granite and the recommended values by UNSCEAR2000.

3.2. Radiological Hazard Indices in Soil and Granite Rock Samples

The computed results of the radiological hazard indices were listed in **Table 4**.

Table 2. Comparison of natural radioactivity concentrations (Bq/kg) in the present soil samples with the reported values from different countries of the world.

Country	Average activity concentration (Bq/kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Yemen	14. 28	25.78	566.05	Present study
India	45.68	17.11	1535.44	[9]
Saudi Arabia (Al-Qassim)	9.3	12.3	535	[10]
Nigeria	12.12	60.117	426.51	[11]
Malaysia	57	68	427	[12]
Egypt	16.4	7.1	102	[13]
Turkey	21.0	23.5	363.5	[14]
Jordan	57.7	18.1	138.1	[15]
World average	30	35	400	[8]

Table 3. Comparison of natural radioactivity concentration (Bq/kg) in the present granite samples with the reported values from different countries of the world.

Country	Average activity concentration (Bq/kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Yemen	45	106	1235	Present study
India	82	112	1908	[16]
Yemen	54	127	1743	[17]
Spain	84	42	1138	[18]
Saudi Arabia	75	71	987	[19]
Egypt	137	82	1082	[20]
Greek	74	85	881	[21]
Turkey	70	83	1234	[22]
Iran	74	69	1130	[23]
Italy	112	107	1063	[24]
Brazil	45	106	1320	[25]
Japan	43	72	1004	[26]
World average	50	50	500	UNSCEAR 2000 [8]

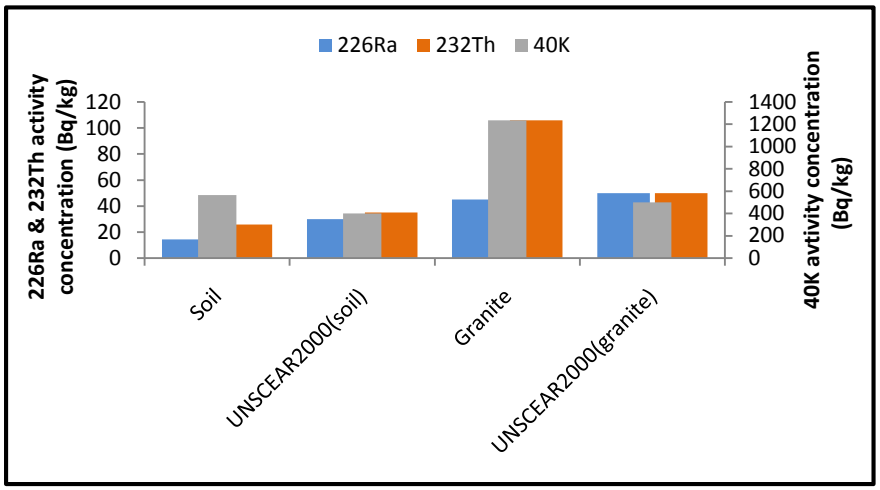

Figure 2. The activity concentrations of ^{226}Ra,^{232}Th and ^{40}K average values in soil and granite samples under investigation and UNSCEAR2000 values.

The values of Ra_{eq} Bq/kg for soil and granite rock samples are lower than the allowed value of 370 Bq/kg [8]. Representative level index (I_γ) average value is less than one, this means that the external radiation dose within the soil samples is less than the recommended dose of 1 Bq/kg [8]. The I_γ average values for granite rock is higher than 1 Bq/kg. External hazard index (Hex) for soil and granite samples are less than the limit value of unity. As can be seen in **Table 4**. The total absorbed dose rate calculated for Shabowah's soil, it less than the world average value of 57 nGy/h. The presence of ^{40}K in Shabwah's soil contributes a maximum of 52% to the total absorbed dose rate, followed by ^{232}Th of 35% and ^{226}Ra of 13%, these contributions were illustrated in **Figure 3**.

Table 4. Shows values of radium equivalent (Ra_{eq}), level index (I_γ) and external hazard (H_{ex}) for soil samples (Shabwah) and granite rock samples (Hadramout), Yemen.

Sample type	Sample code	*Radiological Hazard*				
		Ra_{eq} (Bq/kg)	Hex	I_γ (Bq/kg)	D (nGy/h)	D (eff) mSv/y
Soil	S1	97.89	0.26	0.38	47.68	0.032
	S2	95.09	0.26	0.37	46.59	0.031
	S3	86.39	0.23	0.33	42.34	0.028
	S4	94.85	0.26	0.37	46.83	0.031
	S5	93.76	0.25	0.36	46.42	0.031
	S6	100.38	0.27	0.39	49.12	0.033
	Range	86.39 - 100.38	0.23 - 0.27	0.33 - 0.39	42.34 - 49.12	0.028 - 0.033
	Average	94.73	0.26	0.36	46.50	0.031
Granite rock	G1	302.61	0.82	1.15	145.47	0.097
	G2	236.79	0.64	0.89	112.58	0.075
	G3	291.02	0.79	1.08	136.33	0.091
	G4	308.40	0.83	1.17	148.05	0.099
	G5	320.64	0.87	1.18	149.40	0.1
	G6	285.95	0.77	1.08	136.28	0.091
	Range	236.79 - 320.64	0.64 - 0.87	0.89 - 1.18	112.58 - 149.40	0.075 - 0.1
	Average	291.68	0.79	1.08	138.36	0.092

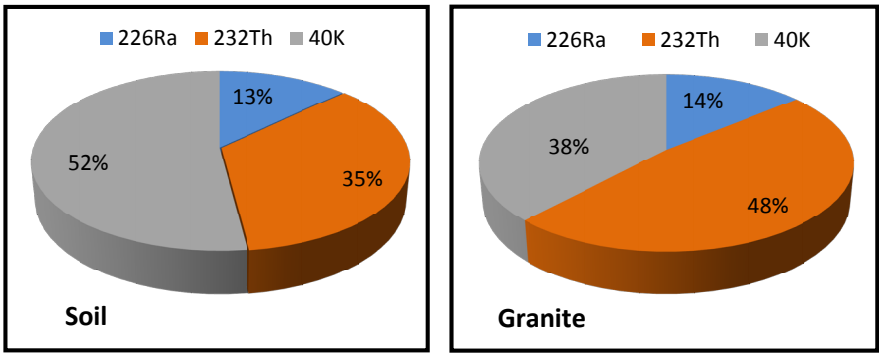

Figure 3. Comparison between percentage contributions absorbed dose of ^{226}Ra, ^{232}Th and ^{40}K to total absorbed dose of soil and granite rock samples, Yemen.

The average value of annual effective dose equivalent of the study soil less than the world average value effective dose of 0.07 mSv/y [8]. According to these results of radiogecal hazard indices, one can indicate that the soil samples are safe and can be used as a construction material without posing any significant radiological threat to the population. As shown in Table 4, the average value of the absorbed dose rate of Hadramout region's granite samples is almost twice the world average value. So, the local people must avoid using these granite

samples in the building construction, especially in the interior decorative materials of dwelling without radioactivity control. The average total effective dose rates (D_{eff}) for granite samples is far lower than the 1.0 mSv/y recommended by [8]. This value is According to these results of radiogecal hazard indices, one can indicate that the soil samples are safe and can be used as a construction material without posing any significant radiological threat to the population. As shown in Table 4, the average value of the absorbed dose rate of Hadramout region's granite samples is almost twice the world average value. So, the local people must avoid using these granite samples in the building construction, especially in the interior decorative materials of dwelling without radioactivity control. The average total effective dose rates (D_{eff}) for granite samples is far lower than the 1.0 mSv/y recommended by [8].

4. Conclusion

The natural radioactivity levels of ^{226}Ra, ^{232}Th and ^{40}K have been measured in soil and granite rock samples of two regions in Yemen using gamma ray spectroscopy. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil are 14.28, 25.78 and 566.05 Bq/kg, respectively, and for the granite rock samples the mean concentrations are 45,106 and 1235 Bq/kg, respectively. These values are compared with published values of other countries. The estimated hazard indices in soil samples are well lower than the recommended limit. Therefore, the present soil can be used as a construction or building materials without posing any radiological effect to the population. In granite rocks, the calculated dose rate was observed twice the world average value of 57 μSv/Y, which put the users of the granite rocks and people around the area on radiological hazard. This work has established background guideline on the natural radioactivity levels in the study area, which will provide a future reference for other studies.

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