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Gamma Radioactivity Levels and Their Corresponding External Exposure of Some Soil Samples from Taif Governorate, Saudi Arabia

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Abstract: Using high-resolution γ-ray spectroscopy the activity concentration of naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K were determined in soil samples from El Taif, in Saudi Arabia. The soil activity ranges from 13 ±1.2 to 33±3.4 Bq.kg^{-1} for ^{226}Ra, 11±1 to 27±4.2 Bq.kg^{-1} for ^{232}Th and 129±5.7 to 230±11 Bq.kg^{-1} for ^{40}K with mean values of 23.8±2.4, 18.6±1.7 and 162.8±7.6 Bq.kg^{-1}, respectively. The concentrations of these radionuclides are compared with the available data from other countries. The measured activity concentration of ^{226}Ra,^{232}Th ^{40}K in soil is lower than the world average. Radium equivalent activities are calculated for the analyzed samples to assess the radiation hazards arising due to the use of these soil samples in the construction of dwellings. All the soil samples have radium equivalent activities lower than the limit set in the OECD report (370 Bq.kg^{-1}). The overall mean outdoor terrestrial gamma dose rate is 28.98 nGy.h^{-1} and the corresponding outdoor annual effective dose is 0.04 mSv.y^{-1}.

Key words: Gamma ray · soil · Raeq activities · dose rate

INTRODUCTION

Knowledge of natural radionuclides concentration levels and their distribution in the environment is of great interest in several fields of science. The high geochemical mobility of radionuclides in the environment allows them to move easily and to contaminate much of the environment with which humans come in contact. Therefore it is important to know the distribution of source-rock materials containing elevated levels of radionuclides and to understand the physical and geochemical processes that concentrate the radionuclides.

The word "soil" has a variety of different meanings depending upon its relevance to the society. Farmers consider it as the part of the earth's surface containing decayed and organic material in sufficient quantity to grow plants and crops. Geologists take it as the residual (left over) material from underlying parent rock that supports root growth. To the engineer, soils include all earth materials overlying the rock crust and contain particles of minerals, gasses and liquids. According to the Soil Science Society of America (SSSA), soil is a living system that represents a finite resource vital to life on earth. It forms the thin skin of unconsolidated mineral and organic matter on the earth's surface. It develops slowly from various parent materials and is modified by time, climate, macro- and microorganisms, vegetation and topography.

Soil not only consists of organic and inorganic compounds but also radionuclides. The naturally occurring radionuclides present in soil include ^{226}Ra, ^{232}Th and ^{40}K [1]. Gamma radiation emitted from those naturally occurring radioisotopes, called terrestrial background radiation, represents the main source of irradiation of the human body and contribute to the total absorbed dose via ingestion, inhalation and external irradiation [2]. Calculations by Beck [3] suggested that 50 - 80 % of the total gamma flux at the earth's surface arises from ^{40}K, ^{238}U and ^{232}Th series in topsoil.

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the soils of each region in the world [4]. Since these radionuclides are not uniformly distributed, the knowledge of their distribution in soils play an important role in radiation protection and measurement [5]. Also, the radioactivity of soils is essential for understanding changes in the natural background [6, 7].

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The aims of this article is to identify and determine the activity level and resulting human impact due to natural occurring radionuclides, ^{226}Ra,^{232}Th and ^{40}K, in soil samples from El Taif, in Saudi Arabia. For this purpose 45 surface soil samples were collected from Taif governorate. The obtained results will serve as base line data for radioactivity level in this environment.

MATERIALS AND METHODS

In order to measure natural radioactivity in soil, Fourty five surface soil samples were collected from undisturbed sites. After removing the stones and organic materials, the samples were dried in an oven at about 105°C for 1–2 h. to remove the moisture content and then crushed to pass through a 150 mesh sieve to homogenize it. The representative powdered samples were filled in a polyethylene circular disc of 55-mm diameter and 13 mm height. Finally, every sample was stored for four weeks to reach the equilibrium state between radon and its decay products, since radium measurements are usually based on the activities of radon daughters ^{214}Bi, ^{214}Pb and then the gamma ray spectrum was accumulated for up to 900 min. The method is discuss in earlier publication, [8]. Each sample was subjected to a gamma ray spectrometer with HP Ge setup and multichannel analyzer. The applied low-level gamma-ray spectrometer consists basically of high purity germanium detector with its electronic circuits. The detector is coaxial closed end, closed facing window geometry with vertical dipstick (500-800 microns). The HPGe detector GEM is p-type with the following specifications:

Resolution (FWHM) at 122 keV, ^{57}Co is 1100 eV. And at 1.33 MeV, ^{60}Co is 2.00 k eV, Peak -to-Compton Ratio, ^{60}Co is 46, Relative efficiency at 1.33 MeV, ^{60}Co is 20%, Operation bias voltage is + 2000 V dc.

The detector is shielded in a chamber of four layers starting with Plexiglas (10 mm thick), copper (30 mm thick), lead (100 mm thick) and finally cadmium (3 mm thick). This shield serves in reducing different radiation hazards. The soft component of cosmic rays, consisting of photons and electrons, is reduced to a very low level by 100 mm of lead shielding. The x-ray (73.9 keV) emitted from lead by its interaction with external radiation is suppressed by the cupper layer [9].

The emitted x-rays from lead which contains radioactive impurities due to antimony impurities, can be absorbed by lining the inside of the shield with a graded layer of 0.05 inch cadmium and 0.25 inch prespex [9]. To minimize the effect of the scattered radiation from the shield, the detector is located in the center of the chamber. The spectra were evaluated with the computer software programme Mastro (EG& G ORTIC), or manually with the use of a spread sheet (Microsoft Excel) to calculate the natural radioactivity. ^{226}Ra activity of the samples was determined through the intensity of the 295.2 keV, 351.9keV and 609.3keV γ-lines for ^{214}Pb and ^{214}Bi respectively. ^{232}Th activity was determined through 238, 583.1 and 911.1 keV γ-lines for ^{212}Pb,^{208}Tl and ^{228}Ac respectively. ^{40}K measured directly through the gamma line emission at 1460.8 keV.

RESULTS AND DISCUSSION

The ^{226}Ra, ^{232}Th and ^{40}K activity concentrations measured in soil samples Taif governorate, Saudi Arabia are shown in Table 1. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples ranges from 13±1.2 to 33±3.4, 11±1 to 27±4.2 and 129±5.7 to 230±11 Bq.kg^{-1}, with mean values 23.8±2.4, 18.6±1.7 and 162.8±7.6, respectively. From the obtained data, it is evident that the mean value of ^{40}K in all measured samples were found to be higher when compared with ^{226}Ra and ^{232}Th. The mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in all soil samples under test are lower than the most published data. It is important to point out that these values were not the representative values for the countries mentioned but for the regions from where the samples were collected.

All the values of the activity per unit mass are in the ranges of the corresponding typical world values [4] which are 50, 50 and 500 Bq.kg^{-1} for ^{226}Ra and ^{232}Th and ^{40}K, respectively. The results of the present work indicate that the area under investigation has a normal level of natural background, so these materials do not pose a significant radiological hazard when used for construction of buildings.

Radiation hazard indices

Radium equivalent activity (Raeq): It is important to assess the gamma radiation hazards to human associated with the used sand for buildings, this is done by calculating the different radiation hazard indices. In order to compare the radiological effects from the sand samples containing Ra, Th and K. A common index called the radium equivalent (Raeq) has been introduced [10].

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_{K} \quad (1)$$

where; C_{Ra}, C_{Th} and C_{K} are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq.kg^{-1}, respectively. While defining Ra_{eq} activity according to Eq. (1), it has been assumed that

Table 1: Activity concentrations, radium equivalent (Bq.kg^{-1}) and calculated absorbed dose rate (nGy.h^{-1}), Effective dose rate (m Sv.y^{-1}) for soil samples

Sample No.	Ra- 226	Th-232	K-40	Raeq	absorbed dose rate	Effective dose rate
1	18±3.0	17±2.8	142±6.9	53.24	24.51	0.03
2	14±2.0	20±3.2	155±7.1	54.54	25.01	0.03
3	13±1.2	17±2.8	154±7.2	49.17	22.70	0.03
4	19±3.1	19±3.2	129±5.7	56.10	25.63	0.03
5	30±4.7	27±4.2	230±11.0	86.32	39.76	0.05
6	26±4.1	16±2.7	184±8.2	63.05	29.35	0.04
7	22±3.2	19±3.1	173±7.7	62.49	28.85	0.04
8	24±3.5	23±3.2	154±7.0	68.75	31.40	0.04
9	30±4.1	26±4.1	166±6.8	79.96	36.49	0.04
10	23±3.1	17±2.9	178±7.9	61.02	28.32	0.03
11	27±4.3	16±1.5	182±8.1	63.89	29.73	0.04
12	21±3.1	13±1.4	143±5.3	50.60	23.52	0.03
13	23±3.3	16±2.4	131±4.9	55.97	25.75	0.03
14	28±4.1	18±2.8	180±7.7	67.60	31.31	0.04
15	26±3.9	20±3.0	156±6.8	66.61	30.60	0.04
16	25±3.2	24±3.4	223±10.0	76.49	35.35	0.04
17	23±3.1	21±3.0	164±7.9	65.66	30.15	0.04
18	22±3.0	17±2.8	154±7.1	58.17	26.85	0.03
19	21±2.6	21±2.8	171±7.6	64.20	29.52	0.04
20	24±2.9	23±3.0	152±6.9	68.59	31.32	0.04
21	25±2.8	14±1.9	133±5.1	55.26	25.55	0.03
22	19±2.4	17±2.8	182±7.8	57.32	26.64	0.03
23	17±2.2	11±1.0	171±7.5	45.90	21.63	0.03
24	26±3.8	18±2.3	166±7.0	64.52	29.81	0.04
25	19±2.9	19±1.9	143 ±5.6	57.18	26.22	0.03
26	21±2.2	16±1.4	151±5.8	55.51	25.66	0.03
27	24±2.6	18±1.6	163±6.1	62.29	28.76	0.04
28	22±2.1	21±1.9	172±7.3	65.27	30.02	0.04
29	23±2.4	19±1.6	149±5.5	61.64	28.32	0.03
30	19±2.1	14±1.2	151±5.8	50.65	23.53	0.03
31	23±2.9	19±1.7	153±6.0	61.95	28.48	0.03
32	29±3.8	21±1.9	157±6.2	71.12	32.63	0.04
33	27±3.6	17±1.4	191±8.7	66.02	30.71	0.04
34	20±2.1	16±1.2	150±5.7	54.43	25.16	0.03
35	25±2.7	11±1.0	182±7.9	54.74	25.78	0.03
36	28±3.1	20±1.9	152±6.1	68.30	31.35	0.04
37	26±2.9	16±1.4	149±5.9	60.35	27.89	0.03
38	33±3.4	19±1.8	178±7.4	73.88	34.14	0.04
39	32±3.3	18±1.8	163±6.3	70.29	32.45	0.04
40	21±2.0	19±1.9	169±6.6	61.18	28.23	0.03
41	23±2.3	21±2.0	131±5.6	63.12	28.77	0.04
42	24±2.3	19±1.9	179±7.8	64.95	30.03	0.04
43	26±2.5	21±2.1	151±5.7	67.66	30.99	0.04
44	33±3.4	18±1.9	134±5.7	69.06	31.71	0.04
45	26±2.7	23±2.4	186±7.9	73.21	33.66	0.04
Mean	23.8±2.4	18.6±1.7	162.8±7.6	62.85	28.98	0.04

370 Bq.kg^{-1} ^{226}Ra or 259 Bq kg^{-1} ^{232}Th or 4810 Bq.kg^{-1} ^{40}K produce the same gamma dose rate.

The radium equivalent activities of samples under investigation were calculated on the basis of the above equation and are shown in Table 1. For all soil samples under investigation, the radium equivalent values are lower than the acceptable value 370 Bq.kg^{-1} ranging from 45.9 to 86.3 Bq.kg^{-1}.

The total air absorbed dose rate: The total air absorbed dose rate (nGy h^{-1}) in air 1 m above the ground due to the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}) was calculated using the formula [4, 11].

$$D\ (nGy\ h^{-1}) = 0.0417C_K + 0.462C_{Ra} + 0.604C_{Th} \quad (2)$$

To estimate the annual effective dose rate, account must be taken of (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor. Using the dose rate data obtained from the concentration values of natural radionuclides in sand, adopting the conversion factor from the absorbed dose in the air to the effective dose (0.7 Sv Gy^{-1}) and the outdoor occupancy factor (0.2) proposed by UNSCEAR [4], the annual effective dose rate was calculated from the formula [4, 12].

$$\text{Effective dose rate (m Sv y}^{-1}) = D(nGy\ h^{-1}) \times 8760\ (h\ y^{-1}) \times 0.2 \times 0.7(Sv\ Gy^{-1}) \times 10^{-6} \quad (3)$$

The gamma absorbed dose rates in *air* of soil in areas under study are comparable to the average global terrestrial radiation of 55 nGy.h^{-1}. For soil samples the values of absorbed dose rates fluctuate from 22.7 to 39.8 nGy.h^{-1}, with a mean value of 28.98 nGy.h^{-1} and the annual effective dose rates in the air varied from 0.03 to 0.05 m Sv.y^{-1}.

The average radiation hazard parameters for all samples under investigation are lower than the acceptable value and also less than most the published data. The calculations of dose rate and external hazard index indicate that there is no high exposure for either inhabitants or workers dealing with transportation of soil and there is a good safety index for all building materials.

Comparison of activity concentrations with similar studies: The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from studied area was compared with those from similar investigations in other countries and a

Table 2: Comparison of natural radioactivity levels in soil samples under investigation with those in other countries

	Activity concentration (Bq kg^{-1})			
	^{226}Ra	^{232}Th	^{40}K	References
Saudi Arabia Taif	23.8	18.6	162.8	Present work
Jordan (Amman Aqaba Highway)	22-104	21-103	138-601	Al-Jundi *et al.* [13].
Syrian	20	20	270	UNSCEAR [4].
Turkey (Istanbul)	21	37	342	Karahan and Byulken[14].
Bangladesh (Southern districts)	42	81	833	Chowdhury *et al.* [15].
Pakistan (Lahore)	25.8	49.2	561.6	Akhtar *et al.* [10].
Egypt (Farm soil)	13.7	12.3	1233	
Nile island's soil	11.9	10.5	1636	Ahmed and El-Arabi [17].
Nigeria	16.2	24.4	34.8	Arogunjo *et al.* [18].
Cyprus	7.1	5	104.6	Tzortzis *et al.* [19].
Denmark	17	19	460	UNSCEAR [4].
Spain	39	41	578	Quindòs *et al.* [20].
Canada (Saskatchewan)	19	8	480	Kiss, J. *et al.* [21].
Brazil (Rio Grande do Norte)	29.2	47.8	704	Malanca *et al.* [22].
Mexico (Zacatecas and Guandalupe)	23	19	530	Mireles *et al.* [23].
South India	35	29.8	117.5	Narayanq *et al.* [24].
Japan		54	794	Chen *et al.* [25].
Vietnam (South- east)	19.6	31	34.6	Huy and Luyen [26].

summary results were given in Table 2. It can be seen that, ^{226}Ra values matches with those of other countries. ^{232}Th values obtained from this study fall within the same side of most reported values from other countries except in the case of Egypt, Cyprus and Canada. In contrast values of ^{40}K obtained in this study fall within the lowest side of all reported values from other countries except in the cases of Vietnam.

CONCLUSIONS

This study has presented the results of measuring the activity concentrations of terrestrial gamma emitters for soil samples from Taif governorate, Saudi Arabia. The obtained results indicated that, samples from the study area have activity concentrations ranging from 13±1.2 to 33±3.4 Bq.kg^{-1} for ^{226}Ra, 11±1.0 to 27±4.2 Bq.kg^{-1} for ^{232}Th and 129±5.7 to 230±11 Bq.kg^{-1} for ^{40}K Bq.kg^{-1}. The values of absorbed dose rates in samples range from 22.7 to 39.8 nGy.h^{-1} with a mean value of 28.98 nGy.h^{-1}. The annual effective dose rates in the air varied from 0.03 to 0.05 mSv.y^{-1} with an average value of 0.04 mSv.y^{-1}. The obtained values of natural radioactivity and γ-absorbed dose rates due to the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K of soil in the air show that none of the studied samples is considered a radiological hazard and soil can be safely used in construction without posing any significant radiological threat to population.

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