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Measurement of Natural Radioactivity in Sand Samples Collected from Ad-Dahna Desert in Saudi Arabia

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ABSTRACT

Natural radioactivity is a source of continuous exposure to human beings. The natural radioactivity due to the presence of ^{226}Ra, ^{232}Th and ^{40}K in sand samples collected from *Ad-Dahna* was measured by means of HPGe. The measured activity concentrations of radionuclides were compared with the worldwide reported data. Mean measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K varied between 16.2 - 30.6, 15.8 - 36.7 and 285.3 - 533.2 Bq·kg^{-1} respectively with a mean value of 23.4 ± 4.3 Bq·kg^{-1}, 29.7 ± 5.9 Bq·kg^{-1} and 380 ± 65 Bq·kg^{-1} respectively. Mean values of radium equivalent activity, absorbed dose rate and external radiation hazard index were 106 ± 8 Bq·kg^{-1}, 51.4 nGy·h^{-1} and 0.29 respectively. The annual effective radiation dose was calculated to be 0.32 mSv·y^{-1}. The Ra_{eq} values of sand samples are lower than the limit of 370 Bq·kg^{-1}, equivalent to a gamma dose of 1.5 mSv·yr^{-1}.This study shows that the measured sand samples do not pose any significant source of radiation hazard and are safe for use in building materials.

Keywords: Natural Radioactivity; Sand; Gamma-Ray Spectrometry; Dose Rate; Ad-Dahna

1. Introduction

Naturally occurring radioactive materials (NORM) is wide spread in the earth's environment. The presence of natural radioactivity in soil and other building materials results in internal and external exposure to the occupants. NORM existing in soil could pose potential health physics risk [1]. Terrestrial radioactivity, and the associated external exposure due to the gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in the soils of each region [1,2]. The largest contribution to the radiation field is due to the cosmic rays, the natural radionuclides in soil, radioactivity of the ground and the radioactive decay products of radon in the air. Under normal conditions, artificial radioactivity emitted from the nuclear power plants, industrial plants and research facilities has smaller contribution to the overall radiation. Natural environmental radioactivity arises mainly from primordial radionuclides, such as^{226}Ra, ^{232}Th, ^{40}K and their decay products, which occur at trace levels in all ground formations [4]. Accumulation of these radionuclides in the environment raises many problems concerning safety of biotic life, food chain and ultimately humans. To address these problems, it is necessary to know the dose limits of public exposures and to measure the natural environmental radiation level for the estimation of the exposures to natural radiation sources [5]. Many studies have investigated the levels of natural background radiationby in situ measurements or by analysis of radionuclideconcentration in sand samples [6-15].

Desert is the most prominent feature of Arabian Peninsula of which Saudi Arabia is the largest country (**Figure 1**). About 35% of the land in Saudi Arabia is covered by sandy-deserts. The country has three major deserts. *Rub-al-Khali* extends over much of the southeast and beyond the southern frontier. *Rub-al-Khali* has an estimated area of about 650,000 km^2. *An-Nafud* is an upland desert of red sands, due to iron oxide coating, covering an area of 64,000 km^2. It lies at an elevation of 900 meters in the northern part of Saudi Arabia. *Ad-Dahna* is a narrow strip of sandy terrain. This reddish sandy desert is in the central Saudi Arabia, extending about 1300 km southward from the northeastern edge of *An-Nafud* to the northwestern borders of *Rub-al-Khali*. The sand available along *Ad-Dahna*is used as a construction material. Therefore, radiometric characterization provides a useful technique of acquiring better knowledge of the local environment and radiation doses to be received by the general public [16].

2. Materials and Methods

Sand samples were collected from twenty three sites of *Ad-Dahna* desert around Riyadh City. At every sampling site, samples were collected from about 30 cm deep of

Figure 1. Maps of deserts in Saudi Arabia.

four corners and the center of a square area corresponding to 1 m^2. The five samples were mixed together in situ; and this sand mixture, weighing approximately 1.25 kg, was considered representative of the sampling site [13]. They were placed in plastic bags, labeled and carried to the laboratory. They were oven dried at a temperature of 110˚C for 12 hours, and sieved through a 1 mm mesh. A 200 g of the homogenous samples were then packed in standard Marinelli beakers, weighed and carefully sealedto prevent the escape of gaseous ^{222}Rn and ^{220}Rn from the samples. They were stored for at least 4 weeks before counting to allow time for ^{238}U and ^{232}Th to reach equilibrium with their respective radionuclide daughters [17]. The measurement of activity concentrations of naturally occurring radionuclides of ^{238}U ^{226}Ra, ^{232}Th and ^{40}K in the samples were carried out using a high purity germanium (HPGe) detector coupled with a multi-channel analyzer (MCA). The measurement procedures and activity calculations performed, were as described by [14]. Similarly, the assessment of radiation hazards: the radium equivalent activity (Ra_{eq}), the absorbed gamma radiation dose rate in air (D), the annual effective dose (E), the external radiation hazard index (H_{ex}).

3. Assessment of Radiation Hazards

3.1. Radium Equivalent Activity

The radiation hazards associated with the radionuclides are estimated by calculating the radium equivalent activity (Ra_{eq}). It is a weighted sum of activities of ^{226}Ra, ^{232}Th and ^{40}K; and it is based on the assumption that 370 Bq·kg^{-1} of ^{226}Ra, 259 Bq·kg^{-1} of ^{232}Th and 4810 Bq·kg^{-1} of ^{40}K produce the same gamma radiation dose rate [18]. To avoid radiation hazards, materials whose Ra_{eq} is greater than 370 Bq·kg^{-1} should not be used. Ra_{eq} is defined by the following formula:

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

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

3.2. Air Absorbed Gamma Radiation Dose Rate

Effects of gamma radiation are normally expressed in terms of the absorbed dose rate in air, which originate from radioactive sources in the soil. The activity concentrations in soil correspond to total absorbed dose rate in air at 1 m above the ground level. The absorbed dose rate in air (D) for the population living in the studied area is calculated using the following equation [18]:

$$D = \left(F_{Ra} \cdot A_{Ra} + F_{Th} \cdot A_{Th} + F_{K} \cdot A_{K}\right) \times 10^{-6} \quad (2)$$

where D is the absorbed dose rate in air (nGy·h^{-1}) at 1 m height above the ground level. F_{Ra}, F_{Th} and F_{K} are the dose conversion factors for ^{226}Ra, ^{232}Th and ^{40}K respectively. They are taken as 4.27, 6.62 and 0.43 for ^{226}Ra, ^{232}Th and ^{40}K respectively as assessed by UNSCEAR [3].

3.3. Annual Effective Dose

The annual effective dose received by the population is calculated using the following formula:

$$E = T \cdot Q \cdot D \times 10^{-6} \quad (3)$$

where D is the absorbed dose rate in air, Q is the conversion factor of 0.7 Sv·Gy^{-1}, which converts the absorbed dose rate in air to human effective dose received, and T is the time for 1 year, *i.e.* 8760 hrs.

3.4. Internal and External Radiation Hazard Index

Radiation hazards due to natural radionuclides of ^{40}K, ^{232}Th and ^{226}Ra may be internal or external depending upon the location of a receptor indoor (inside a dwelling) or outdoor (outside a dwelling) on the ground. These hazards are defined in terms of internal or indoor and external or outdoor radiation hazard index and are denoted by H_{in} and H_{ex}, respectively. These are computed by using the following expressions:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \quad (4)$$

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \quad (5)$$

where A_K, A_{Th} and A_{Ra} are the activity concentrations of ^{40}K, ^{232}Th and ^{226}Ra respectively. The indoor hazard index is calculated to determine the radiation hazards from ^{40}K, ^{232}Th and ^{226}Ra. There are no wooden houses in Riyadh. All houses are built with soil and concrete. All floors are lined with soil beneath tiles. So, internal radia-

tion hazard index has been calculated.

4. Results and Discussion

The mean values of measured activity concentrations of selected radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in sand samples from all twenty three sites in *Ad-Dahna* are shown in **Table 1**. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are in the range from 32.55 - 16.20 Bq·kg^{-1}, 28.30 - 39.95 Bq·kg^{-1}, 333 – 533 Bq·kg^{-1},with a mean value of 23.4 ± 4.3, 29.7 ± 5.9 and 380 ± 65 Bq·kg^{-1}, respectively. The measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were compared with world-wide reported values as shown in **Table 2**. It is found that the measured activity concentrations of the three naturally occurring radionuclides in this study are lower than most of the reported values from other countries as well as the world's average values. The results shown in **Table 1** indicate that mean value of ^{226}Ra (23.4 ± 4.3 Bq·kg^{-1}) < ^{232}Th (29.7 ± 5.9 Bq·kg^{-1}) < ^{40}K (380 ± 65 Bq·kg^{-1}).

Radium equivalent activity (Ra_{eq}) owing to activity concentration of the three natural radionuclides from all sites varies from 90.5 to 119.5 Bq·kg^{-1}. The mean value of Ra_{eq} is 106 ± 8 Bq·kg^{-1}, which is much less than the threshold value of 370 Bq·kg^{-1}. The mean values of air absorbed gamma radiation dose rate (D), annual effective dose (E_{air}), and external radiation hazard index (H_{ex}) calculated in this work are shown in **Table 2**. It is shown that mean value of D, E_{air} and H_{ex} are 51.4 nGy·h^{-1}, 0.32 mSv·y^{-1} and 0.13 respectively. Mean annual effective radiation dose of 0.32 mSv·y^{-1} computed in this work is much less than the dose rate reported world-wide.

Table 1. Activity concentrations (Bq·kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in sand samples; and their corresponding radium equivalent activity (Ra_{eq}), Internal radiation hazard index (H_{in}), external radiation hazard index (H_{ex}), absorbed dose rate (D) and annual effective dose (E_{air}).

Site	Activity concentrations (Bq·kg^{-1})			Ra_{eq} (Bq·kg^{-1})	H_{in}	H_{ex}	D (nGy·h^{-1})	E_{air} (mSv·y^{-1})
	^{226}Ra	^{232}Th	^{40}K					
S 1	22.0	23.9	285	78.1	0.27	0.21	37.48	0.23
S 2	20.8	34.8	347	97.3	0.32	0.26	46.83	0.29
S 3	23.1	31.4	368	96.4	0.32	0.26	46.48	0.29
S 4	21.6	32.0	479	104.2	0.34	0.28	50.96	0.31
S 5	30.2	29.9	533	114.0	0.39	0.31	55.61	0.34
S 6	20.5	32.2	333	92.1	0.30	0.25	44.35	0.27
S 7	20.7	35.3	402	102.1	0.33	0.28	49.49	0.30
S 8	25.0	28.0	375	93.8	0.32	0.25	45.30	0.28
S 9	18.6	16.1	295	64.4	0.22	0.17	31.30	0.19
S 10	23.4	32.4	478	106.6	0.35	0.29	52.01	0.32
S 11	16.2	31.9	297	84.6	0.27	0.23	40.77	0.25
S 12	16.9	29.5	456	94.1	0.30	0.25	46.32	0.28
S 13	29.7	34.4	429	111.8	0.38	0.30	53.86	0.33
S 14	28.5	36.1	393	110.2	0.37	0.30	52.90	0.32
S 15	25.9	31.5	316	95.3	0.33	0.26	45.50	0.28
S 16	24.3	36.8	390	106.9	0.35	0.29	51.49	0.32
S 17	17.2	20.0	413	77.5	0.26	0.21	38.28	0.23
S 18	30.6	31.6	307	99.3	0.35	0.27	47.15	0.29
S 19	27.4	35.4	378	107.1	0.36	0.29	51.39	0.32
S 20	26.1	31.6	330	96.6	0.33	0.26	46.21	0.28
S 21	19.1	15.8	408	73.0	0.25	0.20	36.12	0.22
S 22	23.9	28.3	340	90.5	0.31	0.24	43.56	0.27
S 23	27.7	24.6	385	92.5	0.32	0.25	44.65	0.27
Mean	23.4	29.7	380	95	0.32	0.26	46.00	0.28
Std	4.3	5.9	65	13	0.04	0.03	6.11	0.04
UNSCEAR	35	30	400	108.7	0.39	0.29	52.01	0.32
World-wide	30 ± 14	37 ± 20	397 ± 220	113.5	0.39	0.31	54.38	0.33

Table 2. Activity concentrations (Bq·kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K measured worldwide.

Ref.	Activity concentration (Bq·kg^{-1})			Region
	^{40}K	232Th	226Ra	
[19]	398.3	-	26.3	Taiwan
[6]	425.5	33.3	70.3	Malaysia
[7]	528	27	24	Italy
[20]	200	10.6	8.1	The Netherlands
[21]	-	22.8	22.8	Mexico
[8]	842	27	24	Hong Kong
[9]	807	18	14.3	Brazil
[22]	714	26	24	Zambia
[10]	188	8	25	Jordan
[23]	188.1	14.6	25.1	Jordan
[11]	158	25	14	Bangladesh
[24]	456	64	44	India
[25]	367	17	18	Greece
[12]	618	21.4	25.3	Egypt
[26]	508.8	43.2	24.5	Pakistan
[13]	859	39	22.1	China
[27]	188	16	17	Cuba
[28]	586	31	14	Cameroon
[15]	441	26	44	Turkey

5. Conclusion

The present study has been carried out to establish a base line data regarding concentration levels of naturally occurring radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in soils and the corresponding radiation doses in Riyadh, Saudi Arabia. Measured mean activity concentrations of the three radionuclides are found less than the world's average values. Calculated values of external radiation doses are also lower than the world average of about 0.5 mSv per year. It is concluded that there is no potential radiological health risk associated with the soils of area investigated during this study. The data generated here may be useful for the introduction of radiation safety standards by the State Authorities for the protection of general population from radiation hazards owing to terrestrial sources.

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