

Original Research

Investigation of Natural Radioactivity Levels and Evaluation of Radiation Hazards in Residential-Area Soil Near a Ras Tanura Refinery, Saudi Arabia

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Abstract

One of the oldest oil refineries in the Middle East is located south of Ras Tanura in eastern Saudi Arabia, Arabian Gulf. Naturally occurring radionuclides may be associated with the extraction processes of oil and gas. Therefore, the activities concentrations of ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs in soil samples near Ras Tanura refinery were measured using the gamma ray spectrometric technique. The mean activity concentrations of the radionuclides ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs were 39.0 ± 4.8 Bq/kg, 23.2 ± 1.4 Bq/kg, 7.73 ± 1.2 Bq/kg, 278 ± 9.8 Bq/kg, and 1.42 ± 0.5 Bq/kg, respectively. Radiation hazard indices were calculated to evaluate the radiological risk for the public and environment. The results show that the mean values of radium equivalent activity (Ra_{eq}) and gamma absorbed dose rate (D) in air, annual effective dose equivalent (E), and external radiation hazard indices for analyzed samples were lower than the recommended limit by the United Nations Scientific Committee on the Effect of Atomic Radiation. This study is the first to evaluate the radiological impacts in the investigation area. Accordingly, the present study could be considered a baseline for natural radioactivity levels in soil near a refinery area in Ras Tanura.

Keywords: soil, radiological hazards, natural radioactivity, Ras Tanura Refinery, Saudi Arabia

Introduction

The naturally occurring radionuclides present in soil, rocks, and water are not uniformly distributed all over the world, and depend primarily on geological and geographical conditions. Terrestrial gamma rays derive

essentially from ^{40}K and the radio nuclides belong to ^{238}U and ^{232}Th series that are present in the earth's crust. Apart from these natural sources, modern scientific and technological activities also contribute to radiation levels in the environment [1-2]. ^{137}Cs is regarded as the most important constituent of the worldwide radioactive fallout. In the case of an accidental release of fission products from a nuclear power plant, cesium isotopes are especially significant due to their volatility and large inventory that builds up in the reactor over time.

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Therefore, measuring ^{137}Cs levels in soil is also necessary in the environment as such data would serve as baseline data. Its presence in soil would be an indicator that the area in question might have received some fallout radioactivity in the past [3].

Radioactive materials that occur naturally (NORM) and expose people to radiation occurring widely. NORM is an acronym for naturally occurring radioactive material, which includes long-lived radioactive elements (e.g., uranium, thorium, and potassium) found in the environment [4]. NORM wastes concentrate and accumulate in tubing and surface equipment in the form of scale and sludge [5]. In the exploration and extraction processes of oil and gas, the natural radionuclides ^{238}U , ^{235}U , and ^{232}Th , as well as the radium-radionuclides ^{223}Ra , ^{224}Ra , ^{226}Ra and ^{228}Ra , and ^{210}Pb , etc., are brought to slurry surfaces and may contain levels of radioactivity above the surface background [4, 6]. Several studies have been conducted on the concentrations of naturally radionuclides in the environment in different regions throughout the world [7-13].

Radionuclides present in the environment may enter the human body through air, food, and water, thereby adversely affecting human health at higher radiation dose levels. Humans and other living organisms are continuously exposed to ionizing radiation from natural and anthropogenic sources that are present everywhere in the environment [8, 14-17].

The levels of background radiation vary significantly from area to area, and hence radiation doses received by the general public [18]. In Saudi Arabia there is a lack of scientific information concerning naturally occurring radioactive material wastes in the environment around the refinery area and petroleum industries. Therefore, knowledge about the distribution pattern of both anthropogenic and natural radionuclides plays an important role in minimizing the expected health risks to the general public. The present work deals with the measurement of specific activities of ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs , calculation of the radium equivalent activity, external and internal hazard indices, absorbed dose, and annual effective dose equivalent for Ras Tanura soil.

Materials and Methods

Study Area

The city of Ras Tanura is located on the Arabian Gulf in Eastern Province of Saudi Arabia and its geographical coordinates are $26^{\circ}38'38''\text{N}$ and $50^{\circ}9'33''\text{E}$. Seawater surrounds the city on three sides. The tide rise ranges from 1.5 to 2 m during the year. Its area is about 290 km² and a population is 74,000 inhabitants. Wind is strong and blowing dust during the year – especially in summer. Ras Tanura is one of the most important cities in Saudi Arabia because of the presence of one of the largest and oldest oil refineries in the Middle East, which began operating in 1945. Also, the study area contains a

gas plant and two ports for shipping oil. West and south of the city, the coast is mainly composed of sand, mud, sediment, and sludge, while the east coast is composed of sand and marine sediments. In general, the soil in Ras Tanura is sandy and composed of calcareous soil that varies in depth, thickness, and composition. A number of spring waters are located to the west.

Sampling and Sample Preparation for Gamma Spectroscopy

Thirty four soil samples were collected from different locations in Ras Tanura city nearby oil refinery and around residential area (Table 1, Fig. 1). All samples were bulked as a single sample and dried in an oven at 70°C for 24 hours. After drying the samples and removing stones, leaves and foreign particles, soil samples were crushed and prepared for radiation counting by sieving through 0.2 mm mesh. Each sample was packed into 62.172 cm³ standard size can and tightly sealed and stored for one month to acquire secular equilibrium between ^{226}Ra and its progenies. Reference material was packed into the same standard size beaker for efficiency calibration [19].

Experimental Setup

A hyper-pure germanium detector (HPGe), coaxial type, p-type with relative efficiency of 20% was used. The resolution (FWHM) at 122 keV, ^{57}Co is 0.934 keV, and at 1332 keV, ^{60}Co is 1.79 keV. The detector is shielded with a low-level background lead shield. The HPGe was calibrated for efficiency using the reference material RGU-1 from IAEA. The certified activity of uranium is 400 ppm, which is equivalent to 4,960 Bq/kg. The energy transitions of the ^{226}Ra daughters (^{214}Pb and ^{214}Bi) were used to develop the efficiency calibration curve [19-20]. A 4th-degree polynomial fitting was performed to reach the best R^2 value (= 0.983).

Gamma-Spectrometric Analysis

The gamma transmissions used for activity calculations are ^{214}Pb with energies 295.2 keV and 351.93 keV, and ^{214}Bi with energies 609.31 keV, 1120.29 keV, and 1764.49 keV for ^{226}Ra (^{238}U) series. For ^{232}Th , the specific activity concentration was determined using the gamma lines 338.40 keV and 911.07 keV for ^{228}Ac and 583.14 keV for ^{208}Tl . The average values were calculated. In the case of ^{40}K and ^{137}Cs , the specific activity concentrations were estimated directly by their gamma lines of 1460.75 keV and 661.7 keV, respectively [19]. The software used for analysis and reducing the gamma-ray spectra was Quantum Gold version 4.04.00. The minimum detectable activity (MDA) for each isotope (^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs) in the background was calculated separately based on the

Table 1. Activities concentrations of ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs (Bq/kg) in soil samples collected from different sites in Ras Tanura.

Sample ID	Latitude	Longitude	^{238}U	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
S1	26°42'29.1"N	50°5'46.7"E	40.6±9	8.68±0.6	3.21±0.6	108±5.4	<MDA*
S2	26°42'45.9"N	50°5'20.1"E	40.2±11	9.49±0.4	2.76±0.2	116±4.6	<MDA
S3	46°42'59.1"N	50°4'57.8"E	55.3±7.7	9.46±0.5	3.59±0.6	129±6.4	<MDA
S4	26°43'15.4"N	50°4'35.2"E	41.4±7.9	13.1±0.7	3.03±0.4	132±7.5	<MDA
S5	26°42'44.3"N	50°4'51.7"E	31.1±8.4	9.93±0.9	2.84±0.4	115±6.4	<MDA
S6	26°43'15.7"N	50°4'18.0"E	24.2±7.2	69.3±3.3	9.78±1.1	389±13	0.50±0.1
S7	26°43'26.4"N	50°3'57.1"E	25.2±7.6	20.9±1.9	6.34±1.3	311±9.9	<MDA
S8	26°44'25.1"N	50°3'45.2"E	39.3±9.9	10.6±0.5	4.93±0.6	195±8.9	1.71±0.3
S9	26°45'35.5"N	50°2'15.6"E	51.5±9.9	12.5±0.9	4.80±0.9	147±7.5	1.30±0.3
S10	26°45'58.6"N	50°1'59.3"E	45.4±13	14.2±1.5	4.69±1.0	205±9.9	1.48±0.3
S11	26°42'18.7"N	50°4'39.5"E	42.5±7.4	19.5±2.0	8.76±1.2	294±12	0.20±0.04
S12	26°42'15.8"N	50°4'35.7"E	29.6±8.8	19.9±1.6	9.05±0.4	344±9.9	0.18±0.04
S13	26°42'5.20"N	50°4'20.6"E	26.8±6.4	22.7±1.8	8.96±0.5	357±9.6	1.23±0.3
S14	26°41'52.2"N	50°4'9.30"E	39.7±8.8	31.1±1.5	10.08±1.7	362±11	<MDA
S15	26°41'48.4"N	50°3'53.7"E	62.8±7.7	67.8±3.8	12.8±1.8	311±17	<MDA
S16	26°41'44.2"N	50°3'27.8"E	45.1±8.7	30.4±2.8	8.90±0.8	446±12	1.3±0.3
S17	26°41'44.6"N	50°3'8.50"E	58.5±9.8	37.5±2.9	12.1±1.3	453±13	<MDA
S18	26°41'42.1"N	50°2'21.8"E	41.5±6.0	156±3.9	11.9±1.7	407±13	3.83±0.6
S19	26°41'50.1"N	50°2'21.8"E	45.0±7.2	16.3±1.1	9.58±0.6	344±12	1.73±0.3
S20	26°41'49.7"N	50°1'58.7"E	46.2±6.6	17.5±1.3	8.67±1.3	406±11	<MDA
S21	26°42'14.6"N	50°1'51.1"E	27.2±5.7	17.6±2.3	12.2±0.6	346±10	1.61±0.3
S22	26°42'37.3"N	50°1'38.9"E	29.9±6.4	16.2±1.2	8.89±1.5	335±14	<MDA
S23	26°43'4.70"N	50°1'27.1"E	37.4±7.0	19.3±1.7	11.0±1.8	400±11	<MDA
S24	26°43'32.9"N	50°1'9.70"E	51.5±7.4	17.3±1.4	9.44±1.6	249±10	1.36±0.3
S25	26°43'41.7"N	50°1'22.4"E	19.0±4.4	21.5±1.4	11.0±1.6	425±13	<MDA
S26	26°45'7.70"N	50°1'58.6"E	25.1±5.1	9.96±0.8	5.85±1.0	172±6.4	0.24±0.05
S27	26°45'31.3"N	50°1'28.9"E	51.9±10	16.5±1.1	5.81±0.6	229±7.4	0.79±0.2
S28	26°43'57.6"N	50°3'16.4"E	43.8±8.6	14.7±0.8	8.40±1.2	213±8.1	1.85±0.4
S29	26°43'34.4"N	50°3'11.7"E	45.3±7.6	20.5±1.1	9.24±1.2	257±10	2.50±0.5
S30	26°43'22.1"N	50°2'52.8"E	46.7±7.1	14.7±0.7	9.04±0.9	340±9.8	3.55±0.5
S31	26°43'4.90"N	50°3'0.40"E	39.6±5.8	23.5±1.5	9.70±0.7	301±10	<MDA
S32	26°43'13.3"N	50°3'23.0"E	24.1±4.8	20.8±1.4	10.1±1.4	385±10	<MDA
S33	26°43'4.00"N	50°3'28.2"E	25.4±5.0	14.1±0.9	11.8±0.7	431±11	0.94±0.1
S34	26°42'52.2"N	50°3'6.60"E	32.3±6.4	20.7±1.0	10.8±1.2	345±9.4	<MDA

*MDA is the minimum detectable activity.

sample's weight (90 gm) using the detection limit according to the formula [21]:

$$\text{MDA (Bq)} = (2.7 + 4.65 (\text{BG})^{1/2}) / (\epsilon I_{\gamma} t) \quad (1)$$

...where BG is the background count below the peak of interest, ϵ is absolute efficiency, I_{γ} is gamma line intensity, and t is the counting time in seconds. The MDAs for ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs were 0.18, 0.11, 0.94, and 0.003 Bq, respectively.

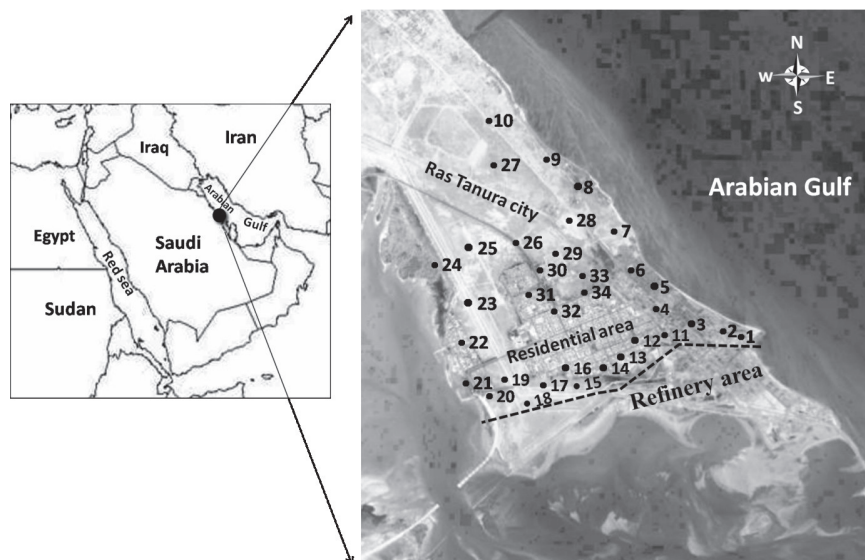


Fig. 1. Location map of soil samples, Ras Tanura, Arabian Gulf, Saudi Arabia.

Results and Discussion

Activity Concentrations

The activity concentrations of naturally occurring radionuclides (^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs) were determined in soil samples from Ras Tanura city, Saudi Arabia. The statistics of the activity concentrations expressed in Bq/kg are presented in Tables 1 and 2. The activity concentrations of ^{238}U ranged from 19.0 ± 4.4 to 62.8 ± 7.7 Bq/kg, with a mean value of 39.0 ± 4.8 Bq/kg. The activity concentrations of ^{226}Ra ranged from 8.68 ± 0.6 to 156 ± 3.6 Bq/kg, with a mean value of 23.2 ± 1.4 Bq/kg. The highest activity concentration of Radium was found to be 156 ± 3.6 Bq/kg for soil sample S18, which was higher than the allowed limit of 30 Bq/kg [22]. The site of this sample is located in an area composed of sandy soil, marine sediments, and mud. The high value of radium in sample 18 may be attributed to the near of the sample collection site from the sludge area, where the NORM waste is concentrated and accumulates in the environment in the form of sludge and scale. Sludge area may contain a level of radioactivity above the surface background, where radium is the most important naturally occurring radionuclide content in sludge [23-24].

The activity concentrations of ^{232}Th ranged from 2.76 ± 0.2 to 12.8 ± 1.8 Bq/kg with a mean value of 7.73 Bq/kg. The concentrations of ^{40}K and ^{137}Cs ranged from 108 ± 5.4 to 446 ± 12 Bq/kg and from below the MDA to 3.83 ± 0.6 Bq/kg, respectively. The obtained results show that the mean values of ^{40}K concentrations in soil samples were lower than the range of the world average 370 Bq/kg [22]. The activity level of ^{137}Cs was found to be lower than the minimum detection limit in 44% of soil samples. The variations in activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in soil samples are based on the nature of its geological formations in the study area. Otherwise, naturally occurring radioactive materials encountered in oil and gas exploration, development, and production operations originate in subsurface formations that may contain radioactive materials such as uranium, thorium, and their daughter products [25]. This can be brought to the surface and contribute in the surface background. In addition, some weather phenomena such as rainfall and direction of wind may contribute to the distribution of radionuclides in the study area during the year.

The low values of the standard deviations obtained for the three radionuclides show the relative uniformity in the distribution of the radionuclides within the study

Table 2. Descriptive statistical parameters of ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs (Bq/kg) in soil samples collected from different sites in Ras Tanura.

Radionuclides	^{238}U	^{226}Ra	^{232}Th	^{40}K	^{137}Cs
Min.	19.0 ± 4.4	8.68 ± 0.6	2.76 ± 0.2	108 ± 5.4	< MDA
Max.	62.8 ± 7.7	156 ± 3.9	12.8 ± 1.8	446 ± 12	3.83 ± 0.6
Mean	39.0 ± 4.8	23.2 ± 1.4	7.73 ± 1.2	278 ± 9.8	1.42 ± 0.5
Std. Deviation	10.99	26.92	3.02	108	--
Std. Error	1.89	4.62	0.52	18.44	--

area. The distribution also reflects uniformity in the geology of the study area. The relative contribution to dose due to ^{40}K was 80%, and ^{238}U was 11%, followed by the contribution due to ^{226}Ra and ^{232}Th as 7% and 2%, respectively, while ^{137}Cs do not contribute to the dose rate (Fig. 2). In order to test the correlations between ^{238}U versus ^{226}Ra and ^{232}Th and ^{238}U versus ^{137}Cs , the correlations between uranium and these radionuclides were plotted as shown in Figs 3-4. The results show weak relationships between ^{238}U versus ^{226}Ra and ^{232}Th with correlation coefficient values (R) of 0.008 and 0.008, respectively. Similarly, the relationship between ^{238}U and ^{137}Cs was poor correlation with correlation coefficient value (R) of 0.034. The poor correlation between uranium and other radionuclides may be due to the possible input of radium, thorium, and cesium in soil as a result of oil exploration activities. According to the recommended reference level of 30, 35, and 400 Bq/kg for ^{226}Ra , ^{232}Th , and ^{40}K , respectively, for the world average concentrations published by the United Nations Scientific Committee on the Effects of Atomic Radiation [22], it is noted that the obtained results in most samples are lower than the recommended reference levels.

The activity concentration measured in this study was compared with those from local and other countries (Table 3) [7, 26, 30-45]. The values of ^{226}Ra activity concentration in our study are lower than the values in similar studies in Yemen, Hungary, Yunnan, China, Turkey, Thailand, Algeria, Egypt, Pakistan, Iraq, and Jordan, while it is little higher than that of Sudan, Nigeria, and Malaysia, and within the range of India. The mean value of ^{232}Th activity concentration in the study area was less than those of all compared countries. Similarly, the mean value of ^{40}K activity concentration in the study area was less than the values of all countries except Nigeria, Jordan, Sudan, and Malaysia. However, the mean values of ^{226}Ra , ^{232}Th , and ^{40}K in the present study are within the range of the local studies from Qassim (north), Albaha (south), and Riyadh (middle). Variations of radioactivity levels in soil locally

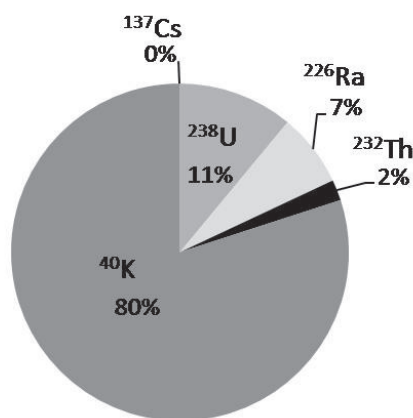


Fig. 2. Percentage contribution of ^{238}U , ^{226}Ra , ^{232}Th , and ^{40}K in activity concentration for Ras Tanura soil.

and in other countries worldwide may depend upon geological and geographical conditions of the area and the presence of NORM, or the applications of phosphate fertilizers in agricultural soil [19, 26]. Some of these countries have a geological structure that differs from the geology of Ras Tanura. Soils from Sudan, Yemen, and Nigeria contain volcanic sediments, while soils from Jordan and Egypt are composed mainly of coarse sand and sandy loam mixed with limestone, marble, and gravel. Similarly, the geology of the study area in Hungary and Yunnan is sandstone, clay rocks, and a few tens of kilometers are granitic stock, while the geological nature of Iraq is similar to Ras Tanura geology along the Arabian Gulf.

Radiological Parameters

Radium Equivalent Activities (Ra_{eq})

The Gamma- ray radiation hazards in soil due to the specified radionuclides ^{226}Ra , ^{232}Th , and ^{40}K can be assessed using different indices. Radium equivalent activity, Ra_{eq} , is the most widely used as a radiation

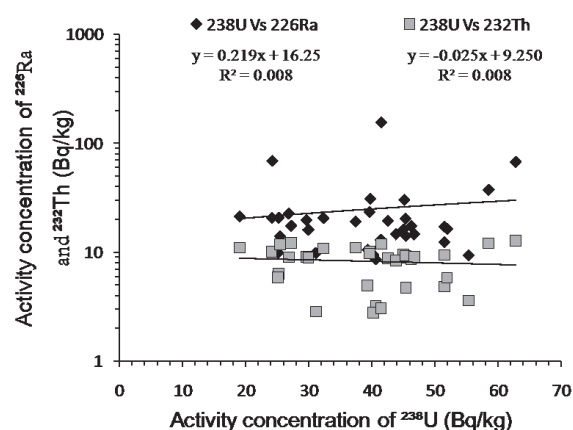


Fig. 3. Correlations between ^{238}U with ^{226}Ra and ^{232}Th for Ras Tanura soil.

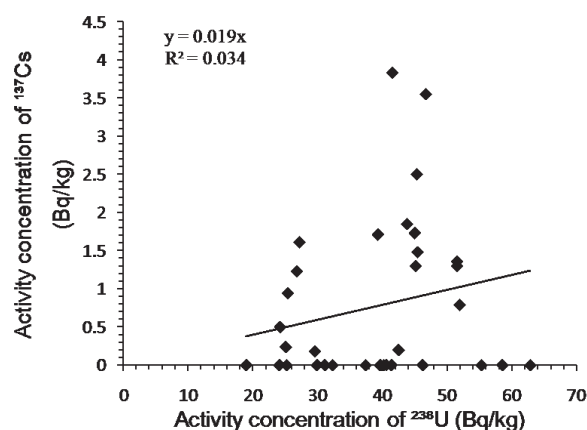


Fig. 4. Correlation between ^{238}U with ^{137}Cs for Ras Tanura soil.

Table 3. Comparison of radioactivity levels in local and global soil samples.

Country	²²⁶ Ra (Bq/kg)	²³² Th (Bq/kg)	⁴⁰ K (Bq/kg)	Reference
China	134	187	680	[21]
Sudan	7.54	20.74	111.87	[22]
Jordan	57.7	18.1	138.1	[23]
Hungary	29.7	32.1	418	[24]
Egypt	46.15	30.57	553.14	[25]
Yunnan	53.4	120.9	632.2	[26]
Pakistan	45	59	648	[27]
Thailand	54.5- 65.4	60.7- 69.1	393-478	[28]
Nigeria	18	22	210	[29]
Yemen	44.4	58.2	822.7	[30]
Algeria	53.2	50.0	311.4	[31]
Turkey	48.4	20.5	744.8	[32]
Malaysia	6.56	10.62	41.02	[33]
India	18-46	53-92	248-756	[34]
Iraq	58.44	19.38	321.76	[35]
Qassim, Saudi Arabia (North)	14.1	15.5	143.1	[17]
Albaha, Saudi Arabia (South)	37	23	343	[36]
Riyadh, Saudi Arabia (Middle)	14.5	11.2	225	[37]
Ras Tanura, Saudi Arabia (East)	23.19	7.73	278	Present work

hazard index associated with the three radionuclides of ²²⁶Ra, ²³²Th, and ⁴⁰K. Ra_{eq} is a weighted sum of activities of these radionuclides based on the estimation that 370 Bq/kg of ²²⁶Ra, 259 Bq/kg of ²³²Th, and 4810 Bq/kg of ⁴⁰K produce the same γ -ray dose rates. Ra_{eq} is given by the following equation [19, 22]:

$$Ra_{eq} \text{ (Bq/kg)} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

...where A_{Ra} , A_{Th} , and A_K are the activity concentrations (Bq/kg) of ²²⁶Ra, ²³²Th, and ⁴⁰K, respectively. When the value of Ra_{eq} is 370 Bq/kg, this corresponds to 1 mSv/y. The radium equivalent concept allows a single index or number, which is a widely used hazard index to describe the gamma output from different mixtures of radium, thorium, and potassium in the soil samples from different locations. The calculated values vary from 21.6 (sample No. 1) to 204 (sample No. 18) Bq/kg with an average of 62.1 Bq/kg (Table 4). These values are lower than the permissible maximum value of 370 Bq/kg [22].

Absorbed Dose Rate (D)

The absorbed gamma dose rate D (nGy/h) in air at 1 m above the ground surface for the uniform distribution

of radionuclides were calculated based on guidelines provided by [22]:

$$D \text{ (nGy/h)} = 0.462 A_{Ra} + 0.604A_{Th} + 0.0417 A_K \quad (3)$$

...where A_{Ra} , A_{Th} , and A_K are the activity concentrations (Bq/kg) of ²²⁶Ra, ²³²Th, and ⁴⁰K, respectively, in the samples. The absorbed dose rate expresses the received dose in the open air from the radiation emitted from radionuclide concentrations in environmental materials. Also, it is the first major step for evaluating health risk and is expressed in Gray (Gy). The calculated total absorbed dose rates of samples are tabulated in Table 3. It is observed that the total absorbed dose rate resulting from ²²⁶Ra, ²³²Th, and ⁴⁰K ranges between 10.5 (sample 1) to 96.4 (sample 18), and the average value was 29.3, which was lower than the limits as recommended by the International Commission on Radiological Protection, 55 nGy/h [27]. The highest value in site No. 18 is slightly higher than the world average. This value is due to the significant amount of radium, which reflects the highest value of absorbed gamma dose rate in soil sample 18. The location of this soil sample was observed close to the sludge area, and consists of sand mixed with a large amount of suspended materials which are thought to be re-sedimented.

Table 4. Radium equivalent activity (Ra_{eq}), air absorbed gamma radiation dose rate (D), annual effective dose equivalent outdoor (E_{out}), annual effective dose equivalent indoor (E_{in}), internal radiation hazard index (H_{in}), external radiation hazard index (H_{ex}), and representative level index (I_{yr}) for soil samples.

Sample ID	Ra_{eq} (Bq/kg)	D (nGy/h)	E_{out} (mSv/y)	E_{in} (mSv/y)	H_{ex}	H_{in}	I_{yr}
S1	21.6	10.5	0.013	0.052	0.058	0.082	0.162
S2	22.4	10.9	0.013	0.053	0.060	0.086	0.168
S3	24.5	12.0	0.015	0.059	0.066	0.092	0.185
S4	27.6	13.4	0.016	0.066	0.075	0.110	0.206
S5	22.8	11.1	0.014	0.054	0.062	0.089	0.171
S6	113	54.3	0.067	0.266	0.306	0.493	0.819
S7	53.9	26.6	0.033	0.130	0.146	0.202	0.410
S8	32.7	16.1	0.020	0.079	0.088	0.117	0.250
S9	30.7	14.9	0.018	0.073	0.083	0.117	0.229
S10	36.7	18.0	0.022	0.088	0.099	0.137	0.278
S11	54.7	26.7	0.033	0.131	0.148	0.200	0.414
S12	59.3	29.2	0.036	0.143	0.160	0.214	0.453
S13	63.0	30.9	0.038	0.152	0.170	0.232	0.479
S14	73.4	35.7	0.044	0.175	0.198	0.282	0.549
S15	110	52.2	0.064	0.256	0.297	0.481	0.787
S16	77.5	38.2	0.047	0.187	0.209	0.291	0.589
S17	89.7	43.7	0.054	0.214	0.242	0.344	0.673
S18	204	96.4	0.118	0.473	0.552	0.974	1.43
S19	56.5	27.8	0.034	0.136	0.153	0.197	0.434
S20	61.2	30.4	0.037	0.149	0.165	0.212	0.474
S21	61.7	30.1	0.037	0.148	0.167	0.214	0.470
S22	54.7	27.0	0.033	0.132	0.148	0.192	0.420
S23	65.8	32.4	0.040	0.159	0.178	0.230	0.505
S24	50.0	24.2	0.030	0.119	0.135	0.182	0.376
S25	70.0	34.5	0.042	0.169	0.189	0.247	0.537
S26	31.6	15.4	0.019	0.076	0.085	0.112	0.240
S27	42.4	20.8	0.025	0.102	0.115	0.159	0.321
S28	43.1	20.9	0.026	0.103	0.116	0.156	0.324
S29	53.5	25.9	0.032	0.127	0.145	0.200	0.400
S30	53.8	26.6	0.033	0.130	0.145	0.185	0.415
S31	60.5	29.4	0.036	0.144	0.164	0.227	0.454
S32	64.9	31.9	0.039	0.156	0.175	0.231	0.496
S33	64.2	31.8	0.039	0.156	0.173	0.211	0.499
S34	62.7	30.7	0.038	0.151	0.169	0.225	0.476
Min	21.6	10.5	0.013	0.052	0.058	0.082	0.162
Max	204	96.4	0.118	0.473	0.552	0.974	1.43
Average	62.1	29.3	0.038	0.148	0.156	0.235	0.453

Annual Effective dose Equivalent (E)

The annual effective dose equivalent (E) was calculated from the absorbed dose by applying the dose conversion factor of 0.7 Sv/Gy with an occupancy factor of 0.2 for outdoor and occupancy factor of 0.8 for indoor [22]:

$$E_{\text{out}} = D \text{ (nGy/h)} \times 8760 \text{ (h/y)} \times 0.7 \text{ (Sv/Gy)} \times 10^{-6} \times 0.2 \quad (4)$$

Equation (4) simplifies into $E_{\text{out}} = D \times 1.226 \times 10^{-3}$ (mSv/y)

$$E_{\text{in}} = D \text{ (nGy/h)} \times 8760 \text{ (h/y)} \times 0.7 \text{ (Sv/Gy)} \times 10^{-6} \times 0.8 \quad (5)$$

Equation (5) simplifies into $E_{\text{in}} = D \times 4.905 \times 10^{-3}$ (mSv/y)

To estimate annual effective doses, account must be taken of (a) the conversion coefficient from absorbed dose in air to effective dose and (b) the indoor occupancy factor. The average numerical values of those parameters vary with the age of the population and the climate at the location considered. In the UNSCEAR report, the committee used 0.7 Sv/Gy for the conversion coefficient from absorbed doses in the air to the effective dose received by adults and 0.8 for the indoor occupancy factor, i.e., the fraction of time spent indoors and outdoors is 0.8 and 0.2, respectively [28]. The resulting worldwide average of the annual effective dose is 0.48 mSv, with the results for individual countries being generally within the range of 0.3-0.6 mSv. For children and infants, the values are about 10% and 30% higher in direct proportion to an increase in the value of the conversion coefficient from absorbed doses in air to effective doses [22].

As shown in Table 4, the annual effective dose rate for the outdoors ranged between 0.013-0.118 mSv/y with a mean value of 0.038 mSv/y, while the annual effective dose rate for indoors ranged between 0.052-0.743 mSv/y with a mean value of 0.148 mSv/y. The corresponding world average value is 0.48 mSv/y, of which 0.07 mSv/y is from outdoor and 0.41 mSv/y from indoor exposure [22]. Therefore, the study area is still in the zones of normal radiation levels, which can be considered as less of a threat to the environment as well as human health. The variations of the average values of radium equivalent (Ra_{eq}), absorbed dose rate (D), annual effective dose for outdoor E_{out} , and annual effective dose for indoor E_{in} in the different locations are due to the distributions of radionuclides in soil samples.

External and Internal Hazard Indices (H)

The external exposure to gamma rays in the study area is called external hazard index, or H_{ex} . This index is given by the following equation [20]:

$$H_{\text{ex}} = A_{\text{Ra}}/370 + A_{\text{Th}}/259 + A_{\text{K}}/4810 \leq 1 \quad (6)$$

In addition to H_{ex} , internal exposure to radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by the internal hazard index (H_{in}), which is given by the following equation [22]:

$$H_{\text{in}} = A_{\text{Ra}}/185 + A_{\text{Th}}/259 + A_{\text{K}}/4810 \leq 1 \quad (7)$$

...where A_{K} , A_{Ra} , and A_{Th} are the activity concentrations ((Bq/kg) of the specific radiation) of ^{226}Ra , ^{232}Th , and ^{40}K , respectively. The maximum value of H_{ex} was found to be less than unity corresponds to the upper limit of Ra_{eq} (370 Bq/kg). If the maximum concentration of radium is half that of the normal acceptable limit then H_{in} will be less than 1. The prime objective of this index is to limit the radiation dose to dose equivalent limit of 1 mSv/y [27]. Gamma Index deals with the assessment of excess gamma radiation originating from the present soil. The calculated values of H_{in} are ranged from 0.082 to 0.974 with an average of 0.235, which is lower than the recommended limit. H_{ex} values vary from 0.058 to 0.552 with a mean value of 0.156, and all values are less than the critical value of unity. As shown in Table 4, the internal hazard index is greater than the external hazard index at all sampling sites.

Representative Level Index (I_{yr})

The level of gamma radiation hazard due to the specified radionuclides of ^{226}Ra , ^{232}Th , and ^{40}K were assessed by another index called representative level index, or I_{yr} . The representative level index, I_{yr} , must be less than unity to keep the radiation hazard insignificant for the public. The following equation was applied to calculate I_{yr} for soil samples under investigation [29]:

$$I_{\text{yr}} = A_{\text{Ra}}/150 + A_{\text{Th}}/100 + A_{\text{K}}/1500 \leq 1 \quad (8)$$

...where A_{Ra} , A_{Th} , and A_{K} are the specific activities of ^{226}Ra , ^{232}Th , and ^{40}K in Bq/kg, respectively. I_{yr} varies from 0.162 to 1.43, with a mean value of 0.453 as shown in Table 3. The values of representative level index for all soil samples were lower than unity, with the exception of the sample from site No. 18. However, the average value of representative level index (I_{yr}) is less than unity.

Conclusions

In the present study, the activity concentrations for ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs were measured in 34 soil samples collected from Ras Tanura city, Saudi Arabia, near an oil refinery and around a residential area using gamma-ray spectrometry. The measurements of all samples under investigation showed that the mean values of radioactivity levels were lower than the world average for ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K and ^{137}Cs . The maximum value of ^{226}Ra in soil was 156 ± 3.6 Bq/kg,

which is higher than the recommended value. However, the mean values of radium equivalent activity (Ra_{eq}), total absorbed dose rate in air 1 m above the ground (D), annual effective dose for outdoor E_{out} , annual effective dose for indoor E_{in} , internal hazard index (H_{in}), and external hazard index H_{ex} were found to be lower than the allowed limits recommended by the international agencies (UNSCEAR and ICRP). Based on these results of radium equivalent activity and radiation hazard indices, one can conclude that there is no radiological health hazard from the soil of Ras Tanura to the people living near a refinery area as far as gamma radioactivity is concerned.

A comparison of the results of the analyzed soil samples with those from other studies shows that the activity concentrations of ^{238}U , ^{226}Ra , ^{232}Th , ^{40}K , and ^{137}Cs were within the range in the literature.

This study is the first conducted on Ras Tanura soil. Therefore, the information gathered from this study will help get the information regarding the background radiation levels in the studied area and, very importantly, figure out the baseline data of the radioactivity levels in the Arabian Gulf region.

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Conflict of Interest

The authors declare no conflict of interest.

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