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Distribution of Natural Radionuclides in the Surface Soil in Some Areas of Agriculture and Grazing Located in West of Riyadh, Saudi Arabia

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Authors' contributions

This work was carried out in collaboration between both authors. Author MAAS managed the instrumentation system, reviewed the measurements and the final manuscript. Author AMA conducted field experiments, made data analysis, managed the literature review, and wrote the first draft of the manuscript. Both authors read and approved the final manuscript

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ABSTRACT

The distribution of ^{238}U (Uranium-238), ^{232}Th (Thorium-232), ^{40}K (Potassium-40) and ^{137}Cs (Caesium-137) in surface soil at various sites of agriculture and grazing located in west of Riyadh, Saudi Arabia was investigated under natural field conditions. These sites were located at cities of Huraimla, Thadeq and Sajir, Saudi Arabia. The latitude of these sites was in the range of 25.08 °N to 25.30 °N, the longitude was in the range of 44.4 3 °E to 46.17 °E and the altitude was in the range of 721 m to 803 m. Data were collected by scanning the surface soil by the help of the Mole (proximal sensor for gamma radiation, the soil company, the Netherlands). The Mole was mounted on fabricated iron carriage. Four surfaces soil in each location were scanned. From the data analysis, average activity concentration was determined for ^{40}K (range from 96.81 to 337.91 Bq/kg), ^{137}Cs (range from 8.04 to 17.13 Bq/ kg), ^{238}U (range from 13.02 to 38.70 Bq/kg) and ^{232}Th (range from 10.47 to 33.73 Bq/ kg). The best-fitting relationship between the concentrations of ^{232}Th and ^{40}K versus ^{238}U and also of ^{40}K versus ^{232}Th was found to be linear type with reasonable coefficients of determination (R^2). However, R^2 of 0.799 for ^{232}Th vs. ^{238}U, 0.6366 for ^{40}K vs. ^{238}U and 0.4295 for

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^{40}K vs. ^{232}Th. The ^{232}Th /^{238}U, ^{40}K /^{238}U and ^{40}K /^{232}Th ratios (slopes) extracted were equal to 0.9124, 8.5351 and 6.6979, respectively. The total annual effective dose for the studied locations was in the range of 0.02 to 0.06 mSv/year. The calculated external hazard index value for the soil samples studied was ranged between 0.10 and 0.30 with an average value of 0.20. The results showed a reasonably low radiation outdoor absorb dose (less than unity), which is a good indication for the farmers for agricultural activities and for animal pasture.

Keywords: Uranium; thorium; caesium; potassium; soil.

1. INTRODUCTION

In the environment, the sources of radiation and radioactivity are natural and man-made. Only natural radionuclides with half-lives comparable with the age of the earth or their corresponding decay products existing in terrestrial material such as ^{232}Th (Thorium-232**)**, ^{238}U (Uranium-238), ^{235}U (Uranium-235), and ^{40}K (Potassium-40) are of great interest [1]. On the other hand, man-made radionuclides are produced from nuclear industrial activities, nuclear power plant accidents, or military uses. However, the ^{137}Cs (Caesium-137) is a man-made radionuclide released from nuclear fission and activation processes, the latitude and rate of precipitation are the main factors affecting its distribution on the earth's surface [2].

Natural radionuclides in a soil generate a significant component of the background radiation exposure to the population [3] and their levels are relatively distributed in a soil based on the nature of its geological formations [4-5]. In addition, the concentration of natural radionuclides in a soil depends upon the rock formation and chemical properties within the earth [6]. Besides, these radionuclides could pose health problems to the populations of a given location especially when the concentrations of the natural radionuclides are high. Thus, it is important to explore the amount of concentration of natural and man-made radionuclides in a soil to evaluate whether it is harmful or otherwise [7].

A great awareness of safe crop production is needed by selecting the suitable production items like uncontaminated soil [8]. Thus knowledge of natural radionuclides concentration level and their distribution in a soil is important for the efficient management of agricultural and grazing activities while at the same time protecting the environment. Additionally, the interaction of natural radionuclide with soil has been recognized as one of the most important processes determining the migration of natural radionuclide in the groundwater [9]. Furthermore, a proper assessment of soil properties is essential for achieving a sustainable agricultural production [10].

A determination of the concentration and the distribution of soil radioactivity are essential in establishing reference data, allowing the observation of possible future changes due to future radiological contamination [11]. Thus, there have been many studies concerning naturally occurring radioactive materials in soil media which provide information on the nature and levels of background radiation and to observe the change in radioactivity levels in a particular area [12]. Measurements of naturally-occurring and some man-made radionuclides in Saudi Arabia have been carried out since 1982 till now [13-33] but more research on exploring natural radionuclides in Saudi environment is required. Conducting such a research is indispensible due to the fact that human beings are constantly exposed to soil radioactivity [34] and that radionuclides keep moving in the soil and consequently have a free access to groundwater and plantation [35].

The mean activity concentration levels arising from radionuclides ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs in surface soils in some regions of Saudi Arabia (Hail, Al-Kharj, Al-Qassim, Wadi Aldawaser, Aljouf, Tabuk and Riyadh) were carried out by [36] with the values of 266.86, 33.18, 33.67 and 10.10 Bq/kg, respectively. Measuring the natural radioactivity in soil levels of Um Hablayn north Jeddah of Saudi Arabia by [32] was carried out and the average concentrations of activity of ^{238}U, ^{232}Th and ^{40}K in agricultural soil samples in the area surveyed were found to be of being 74.95, 54.59 and 2652.30 Bq/kg, respectively and the high concentrations of such elements were due to extensively phosphate fertilizers applied in this area. Activity concentrations (^{232}Th, ^{226}Ra (Radium-226), ^{40}K and ^{137}Cs) were measured through soil samples collected from Najran region, Saudi Arabia by [37]. However, the ^{232}Th activity ranged from 1.08 Bq/kg to 7.76 Bq/kg, ^{226}Ra activity ranged from 8.56 Bq/kg to 49.09 Bq/kg, ^{40}K activity ranged from 8.67 Bq/kg to 41.54 Bq/kg, ^{137}Cs activity ranged from 202.85 Bq/kg to 993.07 Bq/kg and 0.08 Bq/kg to 7.65 Bq/kg. The average whole region was found to be less than the international level for soil in the United States, China and Japan. Moreover, the average annual effective dose for Najran region was evaluated to be 0.33 mSv/year, which was comparatively less than the annual average dose worldwide from all natural sources of exposure (2.40 mSv/year).

The natural background radiation of the study area has not been carried out before and has not been reported in literatures. Therefore, the main objective of the present study was to study the distribution level of radioactive element viz. Thorium (^{232}Th), Uranium (^{238}U), potassium (^{40}K) and Caesium (^{137}Cs) in the surface soils at various locations in west of Riyadh, Saudi Arabia under natural field conditions for health risk assessment. These locations were at cities of Huraimla, Thadeq and Sajir, Saudi Arabia. In these locations activities of agricultural production and grazing of cattle and camels were dominance. This study is important to provide a baseline data for natural radioactivity in soils of the study area in the future and the data obtained are essential for management of soil at these locations.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out during period from 1 to 30 May 2014 in agricultural production and grazing areas that were surrounded the communities of cities of Huraimla, Thadeq and Sajir in Saudi Arabia. These cities were located in the west of Riyadh capital. The position and elevation of the selected sites were determined using a global positioning system (GPS). Table 1 illustrates the latitude, longitude and altitude of the selected sites. In these sites activities of agricultural production and grazing of cattle and camels were dominance. These activities depend on groundwater as the main source of water supply through wells. In the grazing areas, the vegetation was wild plants (Fig. 1) and the vegetation types of other sits were agricultural land and garlic plant was removed, landscape and agricultural land planted with Rhodes grass.

For the purposes of determining soil moisture content, soil bulk density and soil texture, five soil samples were collected randomly within the scanned area using hand-operated auger (20 cm long and 7.5 cm diameter) from each site. All these samples were weighed in the field and packed in plastic bags for laboratory analysis. At the laboratory, each of the soil samples was put in an electric oven at a temperature of 105℃ for 72 h. The physical properties were determined according to standard methods. Particle size distribution was analysed by sieving with different meshes. Table 2 shows the characteristics of the soil from the selected sites. The soils of the studied fields looked very similar in terms of texture. The gravel content was variable. The 12 soil samples showed the sand content was dominance (Table 2).

Fig. 1. The vegetation type was wild plants in the grazing areas

2.2 Measurement of Natural Radioactivity

The natural radioactivity survey was performed by "The Mole" sensor, made by the Soil Company and the University of Groningen, The Netherlands [38-39]. The Mole was a gamma-ray spectrometer with a CsI (Caesium Iodide) scintillator crystal of 70 × 150 mm, coupled to a photomultiplier unit and a multichannel analyzer system with 512 energy bands between 0.4 and 2.85 MeV [40].The sensor was carried within the fields on a fabricated iron carriage (Fig. 2) pushed by the hand. The Mole sensor was at 1 m above the soil surface. The length of the scanned areas was about 100 m and the width was about 1 m. The Mole sensor was hitched to a laptop. The laptop had data logger software, coupled with GPS and used to store the survey data. The GPS recorded coordinates and the sensor recorded Gamma -ray spectra (about one spectra/second). The survey was conducted during two consecutive days for each site. There was no rain and dust storms were found during surveying days. The gamma-ray spectra were analysed by a Full Spectrum Analysis [41], using "The Gamman" software (Medusa Systems, The Netherlands). This software allowed to identify and delete data outliers and to process gamma-ray spectrum for calculation of individual nuclide concentrations (^{40}K, ^{238}U, ^{232}Th, ^{137}Cs) in Bq/kg.

Table 1. Latitude, longitude, altitude and vegetation type of the study sites

City	Site	Vegetation type	Latitude (ºN)	Longitude (ºE)	Altitude (m)
Sajir	1	Wild plants	25.12	45.05	779.21
	2	Wild plants	25.10	44.68	737.03
	3	Agricultural land and garlic plant was removed	25.21	44.59	722.09
	4	Agricultural land planted with Rhodes grass	25.27	44.43	754.81
Huraimla	1	Wild plants	25.13	46.11	774.40
	2	Wild plants	25.08	46.06	803.05
	3	Wild plants	25.10	46.14	769.19
	4	Wild plants	25.16	46.17	744.48
Thadeq	1	Wild plants	25.16	45.95	803.48
	2	Landscape	25.26	45.87	731.74
	3	Wild plants	25.30	45.88	721.53
	4	Wild plants	25.28	45.94	720.53

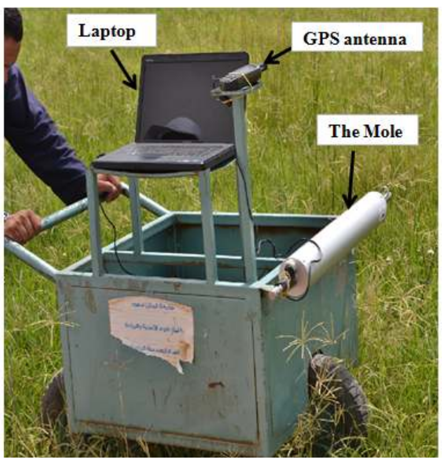

Fig. 2. Operation of the Mole Gamma-ray spectrometer in the field

In other studies, the Mole sensor has been utilized for scanning soil surface to explore nuclide concentrations for almost 10 years [42]. The Mole sensor was also used to determine soil properties [43-51]. Gamma-ray spectra was analysed by a Full Spectrum Analysis, using Gamman software. This method fitted the measured spectra with the spectrum of ^{40}K, ^{137}Cs, ^{238}U, ^{232}Th with an activity of 1 Bq/kg (Becquerel per kilogram), using a chi-square algorithm [39- 41].

2.3 The Dose Rates from Uranium, Thorium, Potassium and Cesium

The absorbed dose rate (D, nGy/ h) in air at 1 m above the ground surface due to the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs (Bq/kg) can be calculated by the following formula [52-54] using Eq. (1):

$$D = AE_i \times CF \quad (1)$$

Where AE_i is the activity concentration measured in Bq/kg and *CF* is the dose rate conversion factor (nGy/h per Bq/kg). In the present study, the considered dose rate conversion factors for the ^{232}Th was 0.604 and for ^{238}U was 0.462 and for ^{40}K was 0.0417 nGy/h per Bq/kg [55] and for ^{137}Cs it was 0.1125 nGy/h per Bq/kg [1]. Using these dose rate conversion factors, the total absorbed dose rate (D_t, nGy/ h) in air due to Uranium, Thorium, Potassium was calculated as given in the Eq.(2) [55,56]:

$$D_t = 0.604 \times C_{Th} + 0.462 \times C_U + 0.0417 \times C_K \quad (2)$$

Where C_U, C_{Th} and C_K are the activity concentrations (Bq/kg) of uranium, thorium and potassium, respectively in the samples.

To estimate the annual effective doses, one has to take into account the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. In the recent [56] reports, a value of 0.7 Sv/Gy was used for the conversion coefficient from absorbed dose in air to effective dose received by adults, and 0.8 for the indoor occupancy factor, implying that 20 % of time is spent outdoors, on average, around the world. The annual effective dose rate (E_a, mSv/year) was estimated using the formula (Eq. 3) [56]:

$$E_a = \left(D_t(\text{nGy/ h}) \times 24\text{h/day} \times 365.25\ \text{day/year} \times 0.2 \times 0.7\text{Sv/Gy}\right) \times 10^{-6} \quad (3)$$

Table 2. The characteristics of the soil from the selected sites

City	Site	Gravel	Sand	Silt	Clay	Soil texture	Soil moisture content	Soil bulk density
		(%)	(%)	(%)	(%)	(-----)	(% db)	(g/cm^3)
Sajir	1	0.5	82.7	10.0	6.8	Sandy loam	2.79	1.82
	2	0.0	96.2	3.8	0.0	Sand	2.51	1.91
	3	2.3	83.1	10.6	4.0	Loamy sand	2.39	1.93
	4	5.2	70.0	13.0	11.8	Loamy sand	13.14	1.81
Huraimla	1	1.2	85.0	8.8	5.0	Loamy sand	2.63	1.89
	2	0.3	42.5	44.2	13.0	Loam	2.42	1.78
	3	0.0	68.8	24.2	7.0	Sandy loam	3.31	1.87
	4	0.0	62.8	31.2	6.0	Sandy loam	3.48	1.85
Thadeq	1	0.2	58.8	34.7	6.3	Sandy loam	3.18	1.86
	2	2.0	85.5	8.2	4.3	Loamy sand	5.48	1.74
	3	1.4	91.3	7.3	0.0	Sand	1.59	1.84
	4	1.1	87.1	7.8	4.0	Sand	1.45	1.91

2.4 Estimation of External Hazard Index

The decay of naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) in a soil produces a radiation field that also crosses the soil–air interface to produce significant human exposure [55]. The external hazard index, H_{ex}, was calculated and examined using the formula (Eq. 4) [57]:

$$H_{ex} = \frac{C_U}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{4}$$

The H_{ex} value must be less than 1 to keep the radiation hazard insignificant to the people.

3. RESULTS AND DISCUSSION

3.1 Statistical Description of Radio-activity Concentration Levels

Statistical description of the activities of three natural radionuclides (^{238}U, ^{232}Th, ^{40}K) and the artificial one ^{137}Cs is shown in Tables 3-5 for Sajir, Huraimla and Thadeq cities, respectively. As could be observed in Table (3) for sites at Sajir region, the concentration of ^{40}K varies from 278.59 Bq/kg to 337.91 Bq/kg with an average of 307.94 Bq/kg. Similarly, the concentration of ^{238}U varies from 23.38 Bq/kg to 38.70 Bq/kg with an average of 28.30 Bq/kg while the concentration of ^{232}Th varies from 14.36 Bq/kg to 33.73 Bq/kg with an average of 26.09 Bq/kg. Besides the concentration of ^{137}Cs varies from 12.22 Bq/kg to 17.13 Bq/ kg with an average of 14.74 Bq/kg. The difference in the radionuclide concentration in the sites may be related to the soil texture and vegetation type of the study site. The highest standard deviation was for ^{40}K measurements as illustrated in Table 3.

From Table (4), for sites at Huraimla city, the concentration of ^{40}K varies from 218.37 Bq/kg to 269.87 Bq/kg with an average of 252.53 Bq/kg. Similarly, the concentration of ^{238}U varies from 22.90 Bq/kg to 25.88 Bq/kg with an average of 23.73 Bq/kg while the concentration of ^{232}Th varies from 20.30 Bq/kg to 22.85 Bq/kg with an average of 21.76 Bq/kg. Besides the concentration of ^{137}Cs varies from 10.57 Bq/kg to 16.11 Bq/ kg with an average of 13.28 Bq/kg.

From Table (5), for sites at Thadeq city, the concentration of ^{40}K varies from 96.81 Bq/kg to 244.35 Bq/kg with an average of 174.44 Bq/kg. Meanwhile, the concentration of ^{238}U varies from 13.02 Bq/kg to 20.82 Bq/kg with an average of 16.89 Bq/kg. Also, the concentration of ^{232}Th varies from 10.47 Bq/kg to 20.63 Bq/kg with an average of 15.88 Bq/kg. In addition the concentration of ^{137}Cs varies from 8.04 Bq/kg to 12.00 Bq/ kg with an average of 10.10 Bq/kg.

^{137}Cs was detected in all studied sites in Sajir, Huraimla and Thadeq cities with significant variations. Its levels ranged from 10.10 Bq/kg to 14.74 Bq/kg with overall average of 12.71 Bq/kg. However, the variability in ^{137}Cs levels is frequently associated with the soil texture and vegetation type [1]. The high level (17.13 Bq/kg) was observed in agricultural land and garlic plant surfaces in site 3 at Sajir city. This may be attributed to the soil texture and agricultural activities.

From the analysis in this study, sites at Thadeq city (Table 5) appears to have the lowest concentrations for all the elements investigated, reaching levels of 174.44,16.89,15.88 and 10.10 Bq/kg for ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs, respectively. Meanwhile, sites in Sajir city exhibit the highest concentration of ^{40}K, ^{238}U, ^{232}Th and ^{137}Cs. This may be due to vegetation type. The global average of ^{238}U, ^{232}Th and ^{40}K in soil is 35, 45, and 420 Bq/kg, respectively [56]. In the present study, these values for ^{238}U, ^{232}Th and ^{40}K were 22.98, 21.24, and 244.97 Bq/ kg, respectively and they were lower than the world averages. The results obtained from the present study were compared to average values from different locations in Saudi Arabia as shown in Table (6).

Table 3. Statistical summary for activities (in Bq/kg) in soil surfaces measured by the Mole for Sajir City

Site	Statistical criteria	^{40}K	^{238}U	^{232}Th	^{137}Cs
1	Average	278.59	24.35	25.57	14.15
	Standard deviation	115.47	12.92	10.05	9.52
	No. of observations	169.00	169.00	169.00	169.00
	Average	337.91	23.38	14.36	12.22
2	Standard deviation	123.20	12.50	9.03	9.47
	No. of observations	132.00	132.00	132.00	132.00
	Average	318.12	38.70	33.73	**17.13**
3	Standard deviation	137.15	18.16	14.61	10.74
	No. of observations	172.00	172.00	172.00	172.00
	Average	297.13	26.76	30.71	15.46
4	Standard deviation	118.84	13.85	12.66	9.39
	No. of observations	134.00	134.00	134.00	134.00
Overall average		307.94	28.30	26.09	14.74

Table 4. Statistical summary for activities (in Bq/kg) in soil surfaces measured by the Mole for Huraimla City

Site	Statistical criteria	^{40}K	^{238}U	^{232}Th	^{137}Cs
1	Average	254.03	22.92	20.30	10.90
	Standard deviation	107.04	12.25	9.23	7.82
	No. of observations	266.00	266.00	266.00	266.00
2	Average	218.37	22.90	21.15	10.57
	Standard deviation	95.12	13.16	9.81	8.02
	No. of observations	132.00	132.00	132.00	132.00
3	Average	267.87	25.88	22.76	16.11
	Standard deviation	113.22	14.75	11.27	11.20
	No. of observations	179.00	179.00	179.00	179.00
4	Average	269.87	23.23	22.85	15.52
	Standard deviation	103.27	12.01	9.32	10.71
	No. of observations	164.00	164.00	164.00	164.00
Overall average		252.53	23.73	21.76	13.28

Table 5. Statistical summary for activities (in Bq/kg) in soil surfaces measured by the Mole for Thadeq City

Site	Statistical criteria	^{40}K	^{238}U	^{232}Th	^{137}Cs
1	Average	96.81	13.02	10.47	8.04
	Standard deviation	64.80	7.19	5.78	5.58
	No. of observations	50.00	50.00	50.00	50.00
2	Average	207.21	18.65	20.63	12.00
	Standard deviation	78.80	10.34	8.73	9.11
	No. of observations	113.00	113.00	113.00	113.00
3	Average	149.41	15.09	13.39	8.56
	Standard deviation	71.76	8.32	7.36	6.45
	No. of observations	100.00	100.00	100.00	100.00
4	Average	244.35	20.82	19.02	11.80
	Standard deviation	96.10	11.96	8.56	7.89
	No. of observations	127.00	127.00	127.00	127.00
Overall average		174.44	16.89	15.88	10.10

Table 6. Average of specific activity concentrations in the soil of other previous works in some regions of Saudi Arabia as compared the present study

Regions	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{137}Cs (Bq/kg)	Reference
Central province	200.9	12.9	17.79	4.76	[58]
Saudi coastline of the Gulf of Aqaba	649.6	17	22.5	Not available	[23]
El Taif	162.8	NA	18.6	Not available	[35]
Jeddah	369	9.3	7.4	0.3	[59]
Al-Kharj city	211.33 to 378.97	2.87 to 18.83	5.32 to 16.40	0 to 3.19	[5]
Al-Qassim	210.44	25.29	26.69	4.46	
Tabuk	324.72	58.05	71.73	18.48	
Al-Kharj	153.40	18.38	15.31	4.05	
Wadi Aldawaser	195.54	22.59	24.31	5.26	[36]
Aljouf	279.79	35.32	32.36	10.88	
Hail	533.21	54.07	49.09	19.03	
Riyadh	170.92	18.54	16.19	8.57	
Present study	244.97	22.98	21.24	12.71	

3.2 Relationship among Radioactivity Concentration Levels

A detailed analysis of the results indicates that there was a moderate positive correlation between the activity concentrations of ^{238}U and ^{40}K for the studied soil surfaces samples (coefficient of determination, R^2=0.6366) as illustrated in Fig. 3. Additionally, there was a moderate positive correlation between the activity concentrations of ^{238}U and ^{232}Th for the studied soil surfaces samples (coefficient of determination, R^2=0.7599) as illustrated in Fig. 3. Meanwhile, there was low positive correlation between the activity concentrations of ^{232}Th and ^{40}K for the studied soil surfaces samples (coefficient of determination, R^2=0.4295) as illustrated in Fig. 3. The ^{232}Th/^{238}U, ^{40}K /^{238}U and ^{40}K/^{232}Th ratios (slopes) extracted were equal to 0.9124, 8.5351 and 6.6979, respectively as shown in Fig. 3.

3.3 The Dose Rates Due to the Activity Concentrations and External Hazard Index

The absorbed dose rate (D, nGy/ h) in air at 1 m above the ground surface due to the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs (Bq/kg) was estimated using Eq. (1) for all the sampling locations and presented in Table 7. The total absorbed dose rate (D_t, nGy/h), a relevant quantity when considering radiation risk to humans, at a height of 1 m above the ground surface due to the concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil was estimated using Eq. (2) for all the sampling locations and presented in Table 7. The annual effective dose rate (E_a, mSv/year) due to the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs (Bq/kg) was estimated using Eq. (3) for all the sampling locations and presented in Table 7. External hazard index due to the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs (Bq/kg) was estimated using Eq. (4) for all the sampling locations and presented in Table 7.

In the present study, the average outdoor gamma dose rate (D_t, nGy/h) estimated from all surfaces soils at the studied sites ranged from 16.38 nGy/h to 50.52 nGy/h with a mean value of 33.58 nGy/h which agrees well with the global average values (51 nGy/h) as reported by [56]. The annual effective dose in the environment to the population was estimated and in the present study, the annual effective dose rate ranged between 0.02 mSv/year and 0.06 mSv/year with a mean value of 0.04 mSv year, which was lower compared to 0.07 mSv/year given in [56] as the worldwide representative value.

The calculated external hazard index value for the soil samples studied ranged between 0.10 and 0.30 with an average value of 0.20 (Table 7). These values were far below the criterion limit [60]. The surfaces soils at the studied sites have no high exposure for either inhabitants and soil can be used for grazing and agricultural activities.

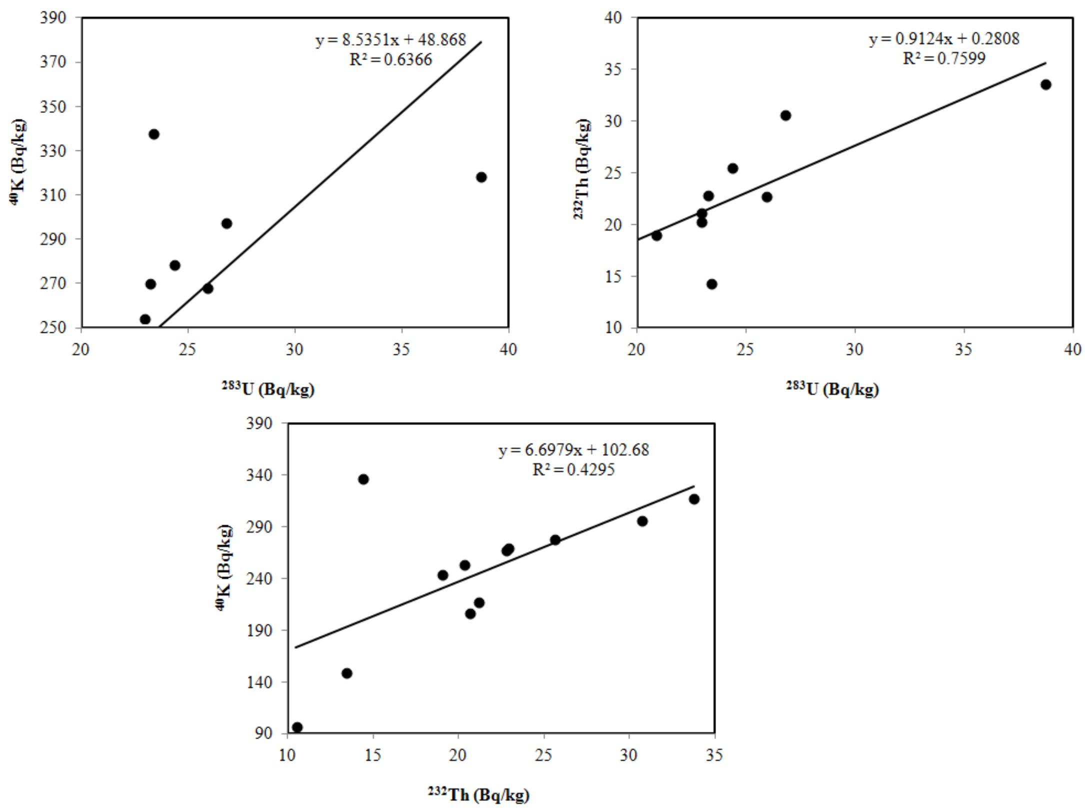

Fig. 3. Relationship among radioactivity concentration levels

Table 7. Air-absorbed dose rate, annual effective dose and external hazard indices at the studied sites

City	Site	D (nGy/ h)				D_t	E_a	External
		^{40}K	^{238}U	^{232}Th	^{137}Cs	(nGy/h)	(mSv/year)	hazard index
Thadeq	1	4.04±2.70	6.02±3.32	6.32±3.49	0.90±0.63	16 .38±4.26	0.02±0.01	0.10±0.02
	2	8.64±3.29	8.62±4.78	12.46±5.27	1.35±1.02	29.72±3.93	0.04±0.01	0.17±0.02
	3	6.23±2.99	6.97±3.85	8.09±4.44	0.96±0.72	21.29±3.1 1	0.03±0.01	0.12±0.02
	4	10.19±4.01	9.62±5.52	11.49±5.17	1.33±0.89	31.29±3.93	0.04±0.01	0.18±0.02
Sajir	1	11.62±4.82	11.25±5.97	15.45±6.07	1.59±1.07	38.31±4.19	0.05±0.01	0.22±0.03
	2	14.09±5.13	10.80±5.78	8.67±5.46	1.38±1.07	33.56±5.46	0.04±0.01	0.19±0.03
	3	13.27±5.72	17.88±8.39	20.37±8.82	1.93±1.21	50.52±6.03	0.06±0.01	0.30±0.04
	4	12.39±4.96	12.36±6.40	18.55±7.64	1.74±1.06	43.30±4.97	0.05±0.01	0.25±0.03
Huraimla	1	10.59±4.46	10.59±5.66	12.26±5.57	1.23±0.88	33.44±3.77	0.04±0.01	0.19±0.02
	2	9.11±3.97	10.58±6.08	12.77±5.93	1.19±0.90	32.46±4.18	0.04±0.01	0.19±0.03
	3	11.17±4.72	11.96±6.81	13.75±6.80	1.81±1.26	36.87±5.37	0.05±0.01	0.21±0.03
	4	11.25±4.31	10.73±5.55	13.80±5.63	1.75±1.21	35.79±4.14	0.04±0.01	0.21±0.02
Overall average		10.22	10.62	12.83	1.43	33.58	0.04	0.20

4. CONCLUSION

The data obtained in the present work cover a wide area in the west of Riyadh, Saudi Arabia which can be considered as the base-line of the region. The lowest concentration of ^{238}U (13.02 Bq/kg) was observed in Thadeq soils and the highest (38.70 Bq/kg) was observed in Sajir soils. Similarly, the lowest (10.47 Bq/kg) and highest (33.73 Bq/kg) levels of ^{232}Th were found in Thadeq soils and in Sajir soils, respectively. The lowest (96.81 Bq/kg) and highest (337.91 Bq/kg) levels of ^{40}K were found in Thadeq soils and in Sajir soils, respectively. Similarly, the lowest (8.04 Bq/kg) and highest (17.13 Bq/kg) levels of ^{137}Cs were found in Thadeq soils and in Sajir soils, respectively. The total absorbed radionuclides from ambient air ranges from 16.38 nGy/h to 50.52 nGy/h with an average of 33.58 nGy/h. The highest dose rates were found in Sajir soils, which were lower than the international recommended limit. The total annual effective dose for the studied locations was in the range of 0.02 mSv/year to 0.06 mSv/year. The calculated external hazard index value for the investigated soil samples was ranged between 0.10 and 0.30 with an average value of 0.20. The surfaces soils at the studied sites have no high exposure for either inhabitants and soil can be used for grazing and agricultural activities.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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