Evaluation of Natural Radionuclides, Cesium-137 and Radiological Hazard Indices of Agricultural Soils in Saudi Arabia

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ABSTRACT

The radioactivity concentrations of ^{40}K, ^{238}U, ^{232}Th, and ^{137}Cs in agricultural surface soils located in the Al-Kharj, Al-Qassim, Wadi Al-Dawaser, Hail, Al-Jouf, Tabuk, and Riyadh regions of Saudi Arabia were measured using a gamma ray sensor (The Mole). The means of ^{40}K, ^{238}U, ^{232}Th, and ^{137}Cs in the soils were 290.12, 33.48, 37.94, and 10.70Bq/kg, respectively. The adsorbed and annual effective dose rates due to ^{238}U, ^{232}Th, and ^{40}K were 15.47–139.57 nGy/h and 0.019–0.171 mSv/year, respectively, while those due to ^{137}Cs were 0.34–0.285 nGy/h and 0004–0.003 mSv/year, respectively. The radium equivalent activity was 33.7–314.57 Bq/kg. The external hazard index was 0.23–1.75 and the internal hazard index was 0.27–1.95. Based on the measured activity and hazard indices, it was concluded that the some surface soils investigated at the selected sites did not pose any significant radiological risk to the population or environment. The results from this study can therefore be used as a reference for background radiation levels in Saudi Arabia.

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INTRODUCTION

Uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K) compose gamma radiation that is emitted from naturally occurring radioactive materials, providing terrestrial background radiation that is the main external source of irradiation to the human body (**UNSCEAR, 2000**). These radionuclides are distributed in the soil, with concentrations depending on the geological formations of a given area (**Al-Jundia *et al.*, 2003; Orabi *et al.*, 2006**). In addition to naturally occurring radioactivity, anthropogenic radionuclides are also important sources of radiation exposure for humans (**International Commission on Radiological Protection, 1990**). Artificial radioisotopes, such as cesium-137 (^{137}Cs), may be released into the environment during nuclear weapons testing, nuclear explosions, and effluent discharges from nuclear facilities (**Ramasamy *et al.*, 2009**). Artificial radioisotopes released from these sources are retained by environmental materials, including soil (**Shenber, 2001**). Thus, measurement of the artificial and natural radionuclides in soil samples provides a better understanding of the causes for fluctuations in the dose rates of environmental radiation at a given location (**Alaamer, 2012**).

Natural radionuclides in soil generate a significant component of the background radiation exposure to the population (**Murty and Karunakara, 2008**). These radionuclides could pose health problems to the population of a given location, especially at high concentrations. Naturally occurring and anthropogenic radionuclide concentrations are important for assessing radiation risks to the population (**Alias *et al.*, 2008**). Measurements of naturally occurring and anthropogenic radionuclides have been completed periodically for Saudi Arabia since 1982, with field research efforts carried out by **Al-Kusayer and Al-Haj (1987), Al-Zahrani (2004), Alaamer (2008),**

Al-Saif (2009), Al-Othmany (2012), and **Ibrahim *et al.* (2014).** Measurement of the natural radioactivity in the agricultural soils of Um Hablayn north Jeddah of Saudi Arabia was carried out by **Hamidalddin (2014),** and the mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K measured in the surveyed area were 74.95, 54.59, and 2,652.30 Bq/kg, respectively. These high concentrations of radio nuclides were due to extensive application of phosphate fertilizers in the surveyed area. In the Najran region of Saudi Arabia, activity concentrations of ^{232}Th, ^{226}Ra, ^{40}K, and ^{137}Cs were measured by **Al-Zahrany and Al-Mogabes (2014),** at 1.08–7.76 Bq/kg, 8.56–49.09 Bq/kg, 8.67–41.54 Bq/kg, 202.85–993.07 Bq/kg, and 0.08–7.65 Bq/kg, respectively.

In general, natural radioactivity is found uniformly through the soil depth, with concentration depending mainly on geological and geographical circumstances (**UNSCEAR, 2000**). Assessment of radionuclides in the soils of many parts of the world has been increasing because of the hazard radionuclides pose to the health of the human population (**Gbadebo, 2011**). Therefore, the main objectives of the present study was to measure natural radioactivity and cesium-137 using The Mole in situ, and to evaluate the radiological hazards from agricultural surface soils in Saudi Arabia under natural field conditions. This study is important for providing baseline data of natural radioactivity and cesium-137 in soils of the investigated areas.

MATERIALS AND METHODS

The investigated areas

The study was carried out in the Riyadh, Al-Kharj, Al-Qassim, Wadi Al-Dawaser, Hail, Tabuk, and Al-Jouf regions of Saudi Arabia. For each location, different agricultural sites were selected. The latitudes, longitudes, and altitudes of the selected sites were measured using a Garmin GPS 60, which is a satellite-based positioning and navigation system that provides position with an accuracy of less than

15 meters. Surface soil samples (to 20 cm depth) were collected using an auger. Physical characteristics of the soil samples were determined according to the method described by **Black *et al.* (1965)**, and are given in Table 1. The selected areas were relatively flat and open, and the soil was undisturbed.

Table (1) *Some physical characteristics of the tested soils.*

Region	Sand (%)	Silt (%)	Clay (%)	Soil texture
Al-Kharj	79.8	12.8	7.4	Loamy sand
Al-Qassim	83.8	10.2	6.0	Loamy sand
Wadi Al-Dawaser	79.8	15.5	4.7	Loamy sand
Hail	72.3	16.2	11.5	Sandy loam
Al-Jouf	84.6	9.4	6.0	Loamy sand
Tabuk	70.4	14.2	15.4	Sandy loam
Riyadh	82.5	11.0	6.5	Loamy sand

Radioactivity measurements

Radionuclide concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were measured in situ using a gamma ray spectrometer (The Mole), which was made by the Soil Company and Groningen University, Netherlands (**Van Egmond *et al.*, 2010; Van Der Klooster *et al.*, 2011**). The Mole is a gamma ray spectrometer with a CsI (cesium 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 (**Priori *et al.*, 2014**). The sensor was carried on a fabricated iron carriage (Fig. 1) that could be pushed by hand or vehicle, as shown in Fig. 2. The Mole has been used for radioactivity measurements for the last 10 years (**Loonstra, 2011**). It has also been used to determine soil properties (**Loonstra and van Egmond, 2009; Mahmood *et al.*, 2011; Loonstra, 2012; Mahmood *et al.*, 2013; Priori *et al.*, 2013; Coulouma *et al.*, 2013; Piikki *et al.*, 2013a; Piikki *et al.*, 2013b**).

The Mole sensor was lifted about 1 m from the soil surface on a fabricated carriage. Each scanned area was about 100 m long by 1 m wide. The Mole was attached to a laptop with data logger software to
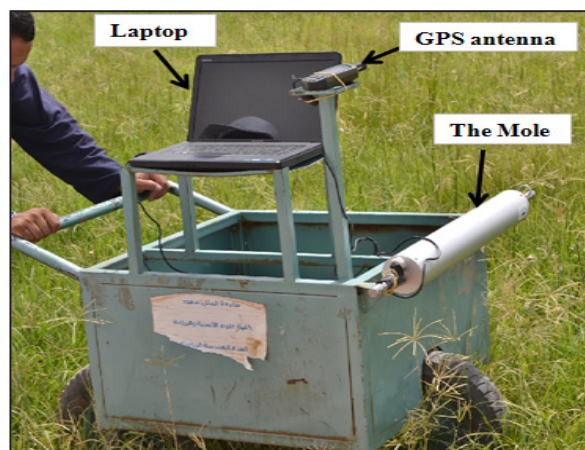

Fig. (1): Operation of the Mole gamma ray spectrometer in the field.

Fig. (2): A vehicle pulls the fabricated Mole carriage over the field.

store the survey data, while a linked GPS recorded coordinates. The Mole sensor recorded gamma ray spectra (about one spectra/second). The surface soils were scanned on different days from October 2011 to May 2012. The gamma ray spectra were analyzed using the GAMMAN software (Medusa Systems, Netherlands) to perform full spectrum analysis (**Hendriks *et al.*, 2001**) (Figs. 3 and 4). The GAMMAN software allows identification and deletion of data outliers and processing of gamma ray spectra for the calculation of individual nuclide concentrations (^{40}K, ^{238}U, ^{232}Th, and ^{137}Cs) in Bq/kg.
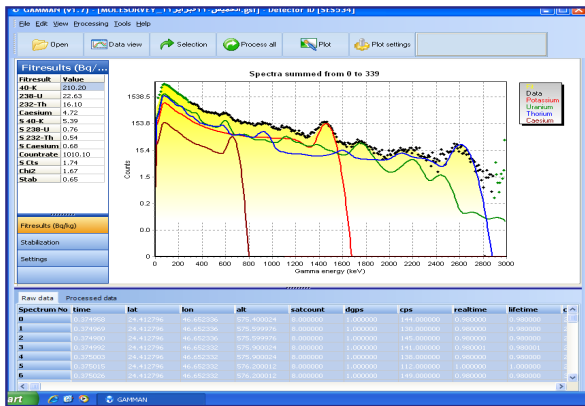

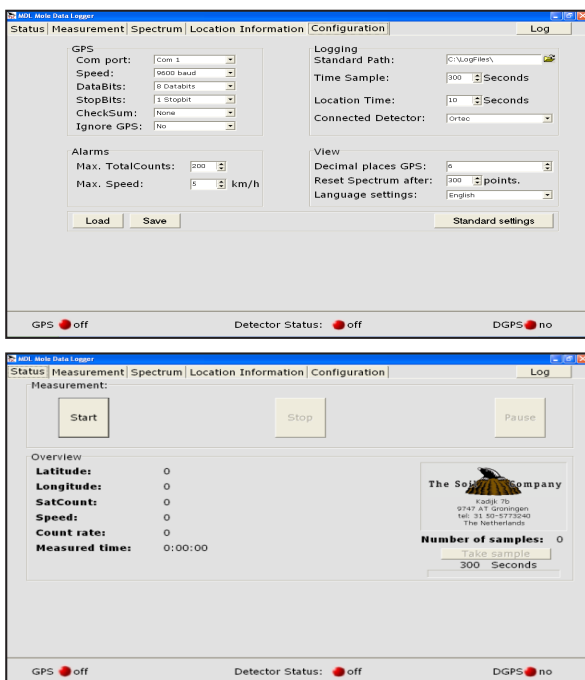Fig. (3): Gamma spectrum of a surface soil sample.

Fig. (4): Screen shots from the GAMMAN software used to process the data.

RADIATION HAZARD INDICES

The absorbed dose rate from natural radionuclides

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, and ^{40}K Bq/kg can be calculated by the following formula (**Kohshi *et al.*, 2001; Abbady *et al.*, 2005**):

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

where AE_i is the activity concentration measured in Bq/kg and CF is the absorbed dose rate conversion factor (nGy/h per Bq/kg). The conversion factors for the gamma absorbed dose rates at 1 m above the soil surface for ^{238}U, ^{232}Th, and ^{40}K are 0.462, 0.604, and 0.042, respectively (**Chandrasekaran *et al.*, 2015**). Therefore, the absorbed dose rate (nGy/h) can be calculated from the following formula:

$$D_t = 0.604 \times C_{Th} + 0.462 \times C_U + 0.042 \times C_K \qquad (2)$$

where C_U, C_{Th}, and C_K are the respective activity concentrations (Bq/kg) of ^{238}U, ^{232}Th, and ^{40}K in the soil samples.

The annual effective dose rate from natural radionuclides

To estimate the annual effective dose rates, the conversion coefficient to calculate the effective dose from the absorbed dose rate in air and the indoor occupancy factor are needed. In the **UNSCEAR (2000)** reports, a value of 0.7 Sv/Gy was used for the conversion coefficient and 0.8 was used for the indoor occupancy factor, implying that 20% of human time is spent outdoors, on mean, around the world. Thus the annual effective dose rate (E_a, mSv/year) was estimated using the following formula (**UNSCEAR, 2000**):

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

The absorbed dose rate from ^{137}Cs

The absorbed dose rate in air at 1 m from the ground surface due to ^{137}Cs levels in the soil was calculated using the following formula (**Salah, 2012**):

$$D_{Cs} = 0.1125 \times Cs \qquad (4)$$

The annual effective dose rate from ^{137}Cs

The annual effective dose rate (E_{Cs}, mSv/year) was estimated using the following formula (**Salah, 2012**):

$$E_{Cs} = \left(D_{Cs}(\text{nGy/h}) \times 24\text{h/day} \times 365.25\,\text{day} \right.$$
$$\left. /\text{year} \times 0.2 \times 0.7\text{Sv/Gy}\right) \times 10^{-6} \qquad (5)$$

External hazard index

The external hazard index, H_{ex} was calculated using the following formula (**Yu et al., 1992**):

$$H_{ex} = \frac{C_U}{370(Bq/kg)} + \frac{C_{Th}}{259(Bq/kg)} + \frac{C_K}{4810(Bq/kg)} \qquad (6)$$

where C_U, C_{Th}, and C_K are the respective concentrations of ^{238}U (Bq/kg), ^{232}Th (Bq/kg) and ^{40}K (Bq/kg) in the soil sample.

Internal hazard index

The internal hazard index, H_{in} was calculated using the following formula (**Farai and Vincent, 2006**):

$$H_{in} = \frac{C_U}{185(Bq/kg)} + \frac{C_{Th}}{259(Bq/kg)} + \frac{C_K}{4810(Bq/kg)} \qquad (7)$$

The values of the external and internal indices must be less than unity for the radiation hazard to be negligible (**Diab et al., 2008**).

Radium equivalent activity

The radium equivalent activity (Ra$_{eq}$, Bq/kg) is defined as an estimation of radiation that produces the same gamma ray dose rate as radium, and has values of 370 for ^{238}U, 259 for ^{232}Th, and 4810 for ^{40}K. It is computed to assess the gamma radiation risk to humans (**Nwaka et al., 2014**). Radium equivalent activity is convenient for comparing the specific activities of ^{238}U, ^{232}Th, and ^{40}K in the surface soils, since the activities are not uniform. The permissible limit of Ra$_{eq}$ is 370 Bq/kg in a soil that contains ^{238}U, ^{232}Th, and ^{40}K (**UNSCEAR, 2000**). This index is determined using the following formula (**Beretka and Mathew, 1985; Hayambu et al., 1995; Rahman et al., 2009; Kavitha et al., 2016**):

$$Ra_{eq} = C_U + 1.43 \times C_{Th} + 0.077 \times C_K \qquad (8)$$

RESULTS AND DISCUSSION

Activity concentrations by region

The activity concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs, as well as the ground position coordinates (longitude and latitude) and altitudes, at the studied sites located in the Tabuk, Al-Jouf, Al-Qassim, Hail, Al-Kharj, Riyadh, and Wadi Al-Dawaser regions are presented in Table 2. Selected sites were at 20.44–29.96°N latitude and 36.76–47.30°E longitude, with altitudes of 438.40–862.06 m. The means over all regions for the activity concentrations of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were 290.12, 33.48, 37.94, and 10.70 Bq/kg, respectively. Table 3 shows means of the specific activity concentrations of ^{40}K, ^{238}U, ^{232}Th, and ^{137}Cs as found from previous research in various regions of Saudi Arabia. The obtained activity concentrations of ^{40}K, ^{238}U, ^{232}Th, and ^{137}Cs concentrations in the investigated regions in the present study were similar to the previously measured activity concentrations.

Tabuk region

The measured activity concentration of ^{238}U was 42.20–77.84 Bq/kg, with an overall mean of 59.81 Bq/kg (Table 2). The noticeable difference in the activity concentration of ^{238}U is attributable to the differences in sand, silt, and clay contents in the soils, as reported in **Abu Samreh et al. (2014)**. The measured activity concentrations of ^{232}Th were 45.28–145.00 Bq/kg, with an overall mean of 81.97

Bq/kg. However, the activity concentrations of ^{40}K were 310.45–381.67 Bq/kg, with an overall mean of 332.68 Bq/kg. These differences were attributable to differences in the soil type. The mean activity concentration of ^{232}Th was higher than that of ^{238}U, at about 1.37 times higher in the Tabuk region.

All mean concentrations of ^{238}U and ^{232}Th in the Tabuk region were higher than the global background. The activity concentration of ^{40}K was within the reported range for the global background **(UNSCEAR, 2000).** The high concentrations may be due to agricultural activities in the region, since phosphate fertilizers contain elevated levels of ^{238}U, ^{232}Th, and ^{40}K **(Saleh, 2012)**. The activity concentration of ^{137}Cs was 16.09–25.30 Bq/kg, with an overall mean of 19.41 Bq/kg. The reported differences in ^{137}Cs may be due to differences in latitude, which is the one of factors affecting the global distribution of ^{137}Cs **(Ritchie and Henry, 1990)**.

Table (2) *Activity concentrations of radionuclides in the surface soil samples collected from different regions in Saudi Arabia.*

Statistic	Latitude °N	Longitude °E	Altitude (m)	Activity concentration (Bq/kg) ^{40}K	^{238}U	^{232}Th	^{137}Cs	No. of samples	Region
Minimum	28.40	36.62	770.92	310.45	42.20	45.28	16.09		
Maximum	28.43	36.87	802.67	381.67	77.84	145.00	25.30	7	Tabuk
Overall mean	28.41	36.76	793.21	332.68	59.81	81.97	19.41		
Minimum	29.89	38.57	607.94	154.44	29.63	22.60	5.61		
Maximum	30.00	40.12	614.94	565.57	41.78	57.93	19.62	6	Al-Jouf
Overall mean	29.96	39.61	610.47	371.00	35.61	40.89	13.79		
Minimum	26.21	43.69	642.36	153.98	19.27	19.47	4.09		
Maximum	26.45	43.89	699.53	283.11	28.04	33.65	6.27	10	Al-Qassim
Overall mean	26.39	43.76	672.07	225.39	24.74	25.78	4.83		
Minimum	24.18	47.13	395.25	76.87	12.88	10.42	3.03		
Maximum	24.33	47.57	465.06	245.27	19.45	25.03	6.31	13	Al-Kharj
Overall mean	24.24	47.30	438.40	153.83	17.49	14.72	4.38		
Minimum	20.42	44.71	697.28	169.92	18.15	17.03	4.06		
Maximum	20.45	44.77	710.37	303.98	29.67	32.18	6.56	8	Wadi Al-Dawaser
Overall mean	20.44	44.74	701.45	211.89	22.70	24.06	5.25		
Minimum	27.79	41.69	848.28	435.53	43.73	36.18	13.96		
Maximum	27.85	41.75	871.74	644.54	71.95	56.76	23.63	6	Hail
Overall mean	27.82	41.73	862.06	520.13	54.75	46.86	19.20		
Minimum	24.23	45.89	396.36	114.65	12.88	10.42	4.81		
Maximum	24.41	47.65	694.45	221.63	21.28	19.21	10.45	4	Riyadh
Overall mean	24.35	46.83	532.58	170.92	18.54	16.19	8.57		
Mean for all regions				290.12	33.48	37.94	10.70		
Global range (UNSCEAR, 2000)				400	35	30			

Table (3) *Mean specific activity concentrations previously measured for soils in various regions of Saudi Arabia.*

Regions	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{137}Cs (Bq/kg)	References
Central province	200.9	12.9	17.79	4.76	Al-Kheliewi and Al-Mogabes (2001)
Saudi coastline of the Gulf of Aqaba	649.6	17	22.5	NA	Al-Trabulsy *et al.* (2013)
El Taif	162.8	NA	18.6	NA	El-Aydarous (2007)
Jeddah	369	9.3	7.4	0.3	Abdul-Majid and Abulfaraj (1992)
Al-Qassim	363	13.6	NA	NA	El-Taher and Al-Turki (2014)
Al-Qassim	212 to 915	NA	2.5 to 39	NA	El-Taher and Al-Zahrani (2014)
Wadi Al-Numan area	378.2 to 592.6	9.2 to 18.1	9.5 to 22.6	NA	Al-Garni (2008)
Al-Madinah Al-Monawarah	64 to 754.2	7.01 to 15.55	5.23 to 21.8	NA	Fakeha *et al.* (2012)
Wadi Al Numan area	378.2 to 557.8	NA	9.5 to 15.2	NA	Hamidalddin *et al.* (2012)
Al-Kharj city	211.33 to 378.97	2.87 to 18.83	5.32 to 16.40	0 to 3.19	Orabi *et al.* (2006)
Cities of Huraimla, Thadeq, and Sajir	244.97	22.98	21.24	12.71	Al-Sulaiman and Aboukarima (2016)

NA = not available

Al-Jouf region

The ^{238}U activity in the surface soils was 29.63-41.78 Bq/kg, with an overall mean of 35.61 Bq/kg (Table 2). The ^{232}Th activity was 22.60-57.93 Bq/kg, with an overall mean of 40.89 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th in all studied sites of the Al-Jouf region, at 154.44-565.57 Bq/kg with an overall mean of 371.00 Bq/kg. The wide variation in activity concentrations for the detected radionuclides in the Al-Jouf region could be attributed to the diversity of formations and textures of the soil at the studied sites (**Saleh, 2012**). The soils contain a large proportion of sand (84.6%, Table 1). Agriculture is also practiced near the sampling sites. The mean concentrations of ^{238}U and ^{232}Th were higher than the global background, while the activity concentration of ^{40}K was within the reported international radioactivity levels (**UNSCEAR 2000**). The activity concentration of ^{137}Cs was 5.61–19.62 Bq/kg, with an overall mean of 13.79 Bq/kg (Table 2).

Al-Qassim region

The ^{238}U activity in the surface soils was 19.27–28.04 Bq/kg, with an overall mean of 24.74 Bq/kg (Table 2). The ^{232}Th activity was 19.47–33.65 Bq/kg, with an overall mean of 25.78 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th in the Al-Qassim region at all sites, at 153.98–283.11 Bq/kg with an overall mean of 225.39 Bq/kg. The activity concentration of ^{137}Cs was 4.09–6.27 Bq/kg, with an overall mean of 4.83 Bq/kg.

Hail region

The ^{238}U activity in the surface soils was 43.73-71.95 Bq/kg, with an overall mean of 54.75 Bq/kg (Table 2). The ^{232}Th activity was 36.18-56.76 Bq/kg, with an overall mean of 46.86 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th for all sites in the Hail region, at 435.53-644.54 Bq/kg

with an overall mean of 520.13 Bq/kg. The activity concentration of ^{137}Cs was 13.96-23.63 Bq/kg, with an overall mean of 19.2 Bq/kg.

Al-Kharj region

The ^{238}U activity in the surface soils was 12.88–19.45 Bq/kg, with an overall mean of 17.49 Bq/kg

Table (4) *Adsorbed and annual effective dose rates for natural radionuclides and ^{137}Cs in the investigated soils.*

Region	Statistic	Adsorbed dose rate from ^{238}U, ^{232}Th, and ^{40}K nGy/ h	Annual effective dose rate from ^{238}U, ^{232}Th, and ^{40}K mSv/year	Adsorbed dose rate from ^{137}Cs nGy/ h	Annual effective dose rate from ^{137}Cs mSv/year
Tabuk	Minimum	59.88	0.073	1.81	0.0022
	Maximum	139.57	0.171	2.85	0.0035
	Overall mean	91.12	0.112	2.18	0.0027
Al-Jouf	Minimum	33.83	0.042	0.63	0.0008
	Maximum	78.05	0.096	2.21	0.0027
	Overall mean	56.73	0.070	1.55	0.0019
Al-Qassim	Minimum	27.13	0.033	0.46	0.0006
	Maximum	45.17	0.055	0.70	0.0009
	Overall mean	36.47	0.045	0.54	0.0007
Al-Kharj	Minimum	15.47	0.019	0.34	0.0004
	Maximum	34.40	0.042	0.71	0.0009
	Overall mean	23.43	0.029	0.49	0.0006
Wadi Al-Dawaser	Minimum	25.81	0.032	0.46	0.0006
	Maximum	45.91	0.056	0.74	0.0009
	Overall mean	33.92	0.042	0.59	0.0007
Hail	Minimum	60.35	0.074	1.57	0.0019
	Maximum	94.60	0.116	2.66	0.0033
	Overall mean	75.44	0.093	2.16	0.0027
Riyadh	Minimum	17.06	0.021	0.54	0.0007
	Maximum	30.67	0.038	1.18	0.0014
	Overall mean	25.47	0.031	0.96	0.0012
Range for all regions		15.47-139.57	0.019-0.171	0.34-0.285	0.0004-0.003
Mean for all regions		50.03	0.061	1.21	0.0015

(Table 2). The ^{232}Th activity was 10.42–25.03 Bq/kg, with an overall mean of 14.72 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th for all sites in the Al-Kharj region, at 76.87–245.27 Bq/kg with an overall mean of 153.83 Bq/kg. The activity concentration of ^{137}Cs was 3.03–6.31 Bq/kg, with an overall mean of 4.38 Bq/kg.

Riyadh region

The ^{238}U activity in the surface soils was 12.88–21.28 Bq/kg, with an overall mean of 18.54 Bq/kg (Table 2). The ^{232}Th activity was 10.42–19.21 Bq/kg, with an overall mean of 16.19 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th for all sites in the Riyadh region, at 114.65–221.63 Bq/kg

Table (5) *External and internal hazard indices, as well as radium equivalent activities, in the investigated soils.*

Region	Statistic	External hazard index	Internal hazard index	Radium equivalent activity
		(---)	(---)	Bq/kg
Tabuk	Minimum	0.93	1.05	130.86
	Maximum	1.56	1.77	314.57
	Overall mean	1.17	1.33	202.65
Al-Jouf	Minimum	0.49	0.57	73.84
	Maximum	1.51	1.63	168.18
	Overall mean	1.03	1.12	122.64
Al-Qassim	Minimum	0.45	0.50	58.97
	Maximum	0.79	0.87	97.95
	Overall mean	0.63	0.70	78.96
Al-Kharj	Minimum	0.23	0.27	33.70
	Maximum	0.66	0.71	74.12
	Overall mean	0.42	0.47	50.38
Wadi Al-Dawaser	Minimum	0.47	0.52	55.59
	Maximum	0.84	0.92	99.09
	Overall mean	0.59	0.66	73.42
Hail	Minimum	1.16	1.28	129.01
	Maximum	1.75	1.95	202.75
	Overall mean	1.41	1.56	161.81
Riyadh	Minimum	0.31	0.35	36.61
	Maximum	0.59	0.65	65.81
	Overall mean	0.47	0.52	54.85
Range for all regions		0.23-1.75	0.27-1.95	33.7-314.57
Mean for all regions		0.83	0.92	108.85

with an overall mean of 170.92 Bq/kg. The activity concentration of ^{137}Cs was 4.81–10.45 Bq/kg, with an overall mean of 8.57 Bq/kg.

Wadi Al-Dawaser region

The ^{238}U activity in the surface soils was 18.15–29.67 Bq/kg, with an overall mean of 22.7 Bq/kg (Table 2). The ^{232}Th activity was 17.03–32.18 Bq/kg, with an overall mean of 24.06 Bq/kg. The activity of ^{40}K was higher than that of both ^{238}U and ^{232}Th for all sites in the Wadi Al-Dawaser region, at 169.92–303.98 Bq/kg with an overall mean of 211.89 Bq/kg. The activity concentration of ^{137}Cs was 4.06–6.56 Bq/kg, with an overall mean of 5.25 Bq/kg.

Radiation hazards indices

The activity concentrations were used to evaluate the radiological hazards associated with the surface soils of the studied regions. Since more than one radionuclide contributes to the gamma dosage (i.e., ^{238}U, ^{232}Th, and ^{40}K), the radiological hazards are presented in terms of a single quantity called the hazard index. The calculated adsorbed and annual effective dose rates from ^{238}U, ^{232}Th, and ^{40}K, and from ^{137}Cs in the investigated soils are given in Table 4. The external and internal hazard indices of the soils, as well as the radium equivalent activities, are given in Table 5.

Absorbed and annual effective dose rates from natural radionuclides

In the present study, the adsorbed dose rate (D$_t$, nGy/h) estimated from all the investigated surface soils due to ^{238}U, ^{232}Th, and ^{40}K were 15.47–139.57 nGy/h, with a mean of 50.03 nGy/h (Table 4), which agrees well with the global mean (51 nGy/h) as reported by **UNSCEAR (2000)**. Meanwhile, the annual effective dose rates due to ^{238}U, ^{232}Th, and ^{40}K were 0.019–0.171 mSv/year with a mean of 0.061 mSv/year (Table 4), which is lower than the global background value of 0.07 mSv/year given in **UNSCEAR (2000)**. Obviously, radiation backgrounds at some of the inspected sites were slightly higher

than the international recommended maximum of 51 nGy/h. However, for the Al-Qassim region of Saudi Arabia, in another study conducted by **El-Taher and Al-Zahrani (2014)**, the mean annual effective and adsorbed dose rates from ^{238}U, ^{232}Th, and ^{40}K were 0.37 mSv/year and 35.2 nGy/h, respectively. **Fakeha et al. (2012)** reported that the adsorbed dose rates for some soils in Al-Madinah Al-Monawarah, Saudi Arabia were 10.05–52.17 nGy/h.

Absorbed and annual effective dose rates from ^{137}Cs

The mean estimated external gamma ray dose rate from ^{137}Cs for all of the investigated surface soils was computed at 0.34-0.285 nGy/h, as shown in Table 4. The estimated annual effective dose rates from ^{137}Cs were 0.0004–0.003 mSv/year, with a mean of 0.0015 mSv/year (Table 4), which is well below the dose rate limit of 1.0 mSv/year for members of the general public recommended by the **International Commission on Radiological Protection (1990)** as well as the external gamma radiation dose of 0.48 mSv/year received per head from the natural sources of radiation assessed by **UNSCEAR (2000)**. Thus, ^{137}Cs contamination in the surface soils did not pose a radiation hazard to the populations of the investigated regions. However, in a previous study conducted by **Alaamer (2012)** on 25 locations within Riyadh Province, the ^{137}Cs activity concentrations and adsorbed dose rates were 0.8–3.1 Bq/kg and 0.05–0.8 nSv/h, respectively, with means of 1.70 ± 0.7 Bq/kg and 0.11 ± 0.05 nSv/h, respectively. **Fakeha et al. (2012)** reported that the only hazard was from ^{137}Cs fallout, especially in the eastern parts of the studied area (Al-Madinah Al-Monawarah, Saudi Arabia), since the activity concentrations of ^{137}Cs were 0.94–3.6 Bq/kg.

External and internal hazard indices

In order to assess the radiological hazards, external and internal hazard indices were calculated (Table 5). The external hazard index was 0.23–1.75,

with a mean of 0.83, and was significant in some regions as it exceeded unity. These are similar to results in Tumkur, Karnataka, India, where the external hazard index was 0.21–1.58 with a mean of 0.75 (**Jayasheelan et al., 2013**). In some of the investigated regions, the external hazard index was less than unity and therefore these surface soils are safe for human activities. The mean external hazard index was 2.03 in the Eastern Desert of Egypt (**Arafa, 2004**), 0.99 in the Southeast part of Eskisehir of Turkey (**Orgun et al., 2005**), and 0.84 in the Xiazhuang Granite area of China (**Yang et al., 2005**). Meanwhile, in another study, the mean external hazard index was 0.18 in the Al-Qassim region of Saudi Arabia (**El-Taher and Al-Zahrani, 2014**). The internal radiation hazards due to the inhalation of radon and its short-lived products were evaluated using the internal hazard index, which was 0.27–1.95 with a mean of 0.92, as shown in Table 5, and was significant in some regions as it exceeded unity. The current mean external and internal hazard indices were 40% and 46% more than the global mean (0.5), respectively. In another study on the Al-Qassim region of Saudi Arabia, the mean internal hazard index was 0.21 (**El-Taher and Al-Zahrani, 2014**).

Radium equivalent activity

The radium equivalent activity for the investigated surface soils was 33.7–314.57 Bq/kg, with a mean of 108.85 Bq/kg, as shown in Table 5. The radium equivalent activities for the investigated surface soils were all less than 370 Bq/kg. The values measured in this work were lower than those measured previously in other countries, e.g., 493.8 Bq/kg in the Eastern desert of Egypt (**Arafa, 2004**), 366.9 Bq/kg in the southern part of Eskisehir of Turkey (**Orgun et al., 2005**), and 266 Bq/kg in the Xiazhuang Granite area of China (**Yang et al., 2005**). However, in the Al-Qassim region of Saudi Arabia, the mean radium equivalent activity was 68.1 Bq/kg (**El-Taher and Al-Zahrani, 2014**). **Fakeha et al. (2012)** reported that the radium equivalent activities for the inves-

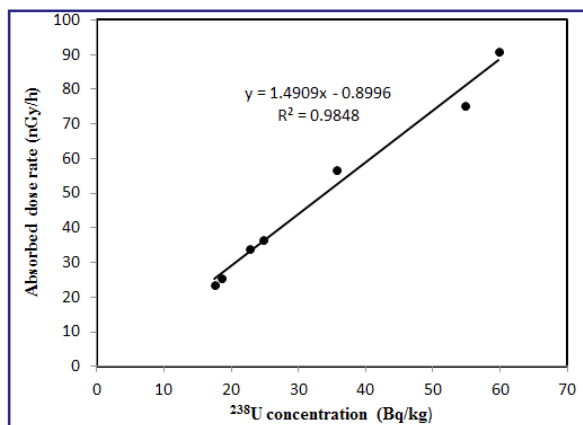tigated soils in Al-Madinah Al-Monawarah, Saudi Arabia, were 21.93–104.86 Bq/kg.

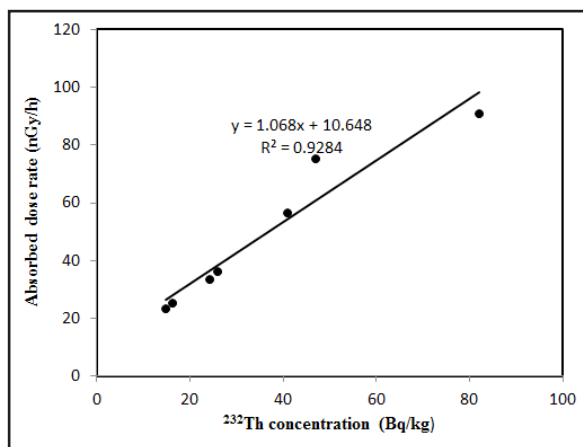Fig. (5): Variation in the absorbed dose rate versus ^{238}U concentration.

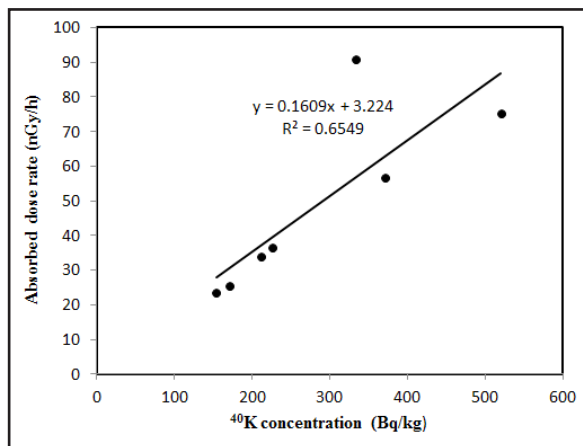Fig. (6): Variation in the absorbed dose rate versus ^{232}Th concentration.

Fig. (7): Variation in the absorbed dose rate versus ^{40}K concentration.

Correlation analysis

Correlation analysis was carried out for the absorbed dose rate versus ^{40}K, ^{232}Th, and ^{238}U concentrations. From this correlation analysis, the contribution of individual radionuclide ratios to the absorbed dose rate were identified (**Kavitha *et al.*, 2016**). High correlations were found for the absorbed dose rate (D_t) versus ^{238}U and ^{232}Th, with coefficients of determination (R^2) equal to 0.9848 and 0.9284, respectively (Figs. 5 and 6). These findings are in agreement with those obtained by **Kavitha *et al.* (2016),** who reported good correlations for the absorbed dose rate versus ^{238}U and ^{232}Th. There was only a moderate correlation for the absorbed dose rates (D_t) versus ^{40}K, with the coefficient of determination (R^2) equal to 0.6549, as shown in Fig. 7.

CONCLUSION

The concentration of ^{40}K was 76.87–644.54 Bq/kg, with a mean of 290.12 Bq/kg. The concentration of ^{238}U was 12.88–77.84 Bq/kg, with a mean of 33.48 Bq/kg. The concentration of ^{232}Th was 10.42–145 Bq/kg, with a mean of 37.94 Bq/kg. The concentration of ^{137}Cs was 3.03–25.3 Bq/kg, with a mean of 10.70 Bq/kg. The results indicate that the adsorbed dose rate due to ^{238}U, ^{232}Th, and ^{40}K was 15.47–139.57 nGy/h, with a mean of 50.03 nGy/h. The annual effective dose rate was 0.019–0.171 mSv/year, with a mean of 0.061 mSv/year. The estimated external gamma ray dose rate from ^{137}Cs was 0.34-0.285 nGy/h. The estimated annual effective dose rate of ^{137}Cs was 0.0004-0.003 mSv/year, with a mean of 0.0015 mSv/year. The radium equivalent activity was 33.7–314.57 Bq/kg, with a mean of 108.85 Bq/kg. The external hazard index was 0.23–1.75, with a mean of 0.83. The internal radiation hazard was 0.27–1.95, with a mean of 0.92.

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تقييم النويدات المشعة الطبيعية، السيزيوم 137 ومؤشرات المخاطر الإشعاعية في بعض الترب الزراعية بالمملكة العربية السعودية

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قيست تركيزات النويدات المشعة الطبيعية مثل البوتاسيوم K^{40} واليورانيوم ^{238}U والثوريوم ^{232}Th والمواد المشعة المصنعة مثل السيزيوم ^{137}Cs في أسطح بعض الأراضي الزراعية التي تقع في مناطق الخرج، القصيم، وادي الدواسر، حائل، الجوف، وتبوك والرياض، المملكة العربية السعودية باستخدام جهاز استشعار أشعة جاما The Mole. وكان المتوسط الكلي لتركيزات المواد المشعة الطبيعية للمناطق المدروسة هي ٢٩٠٫١٢، ٣٣٫٤٨، ٣٧٫٩٤ و ١٠٫٧٠ بكريل/كجم للبوتاسيوم K^{40} واليورانيوم ^{238}U والثوريوم ^{232}Th و السيزيوم ^{137}Cs على الترتيب. ومن هذه القياسات تم تقييم المخاطر الإشعاعية في هذه المناطق من خلال حساب بعض الدلائل مثل مؤشر المخاطر الداخلي والخارجي، ومعدل الجرعة الممتصة والجرعة الفعالة السنوية ومؤشر الراديوم المعادل. حيث بينت النتائج أن معدل الجرعة الممتصة تراوح بين ١٥٫٧٤ و ١٣٩٫٥٧ نانوجراي/ساعة بمتوسط قدره 50.03 نانوجراي/ساعة، والجرعة الفعالة السنوية تراوحت بين ٠٫٠١٩ و ٠٫١٧١ مللي سيفرت/عام بقيمة متوسطة قدرها ٠٫٠٦ مللي سيفرت/عام نتيجة البوتاسيوم K^{40} واليورانيوم ^{238}U والثوريوم ^{232}Th. بينما تراوح معدل الجرعة الممتصة بين ٠٫٣٤ و٠٫٢٨٥ نانوجراي/ساعة ، والجرعة الفعالة السنوية تراوحت بين ٠٫٠٠٠٤ و ٠٫٠٠٣ مللي سيفرت/عام نتيجة السيزيوم ^{137}Cs . بينما مدى مؤشر الخطر الخارجي تراوح بين ٠٫٢٣ إلى ١٫٧٥ مع قيمة متوسطة قدرها ٠٫٨٣ ومؤشر الخطر الداخلي تراوح بين ٠٫٢٧ إلى ١٫٩٥ مع قيمة متوسطة قدرها ٠٫٩٢ . أما قيمة الراديوم المعادل تراوحت بين ٣٣٫٧٠ بكريل/كجم إلى ٣١٤٫٥٧ بكريل/كجم بمتوسط قدره ١٠٨٫٨٥ بكريل/كجم. وعلى أساس تركيز النشاط الآشعاعي والقيم المحسوبة لمؤشرات المخاطر، خلص إلى أن بعض أسطح التربة المدروسة في هذه المناطق تشكل خطر إشعاعي للسكان، حيث وجدت إشعاعات طبيعية في أسطح التربة لبعض المواقع المدروسة أعلى من المعدلات العالمية الموصى بها دوليًا.

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