Radiation Protection Dosimetry (2008), Vol. 131, No. 2, pp. 265–271
Advance Access publication 24 May 2008
doi:10.1093/rpd/ncn161

TECHNICAL NOTE

RADIOACTIVITY CONCENTRATION IN SOIL SAMPLES IN THE SOUTHERN PART OF THE WEST BANK, PALESTINE

K. M. Dabayneh*, L. A. Mashal and F. I. Hasan
Faculty of Science and Technology, Hebron University, PO Box 40, Hebron, Palestine

Received December 11 2007, revised April 8 2008, accepted April 17 2008

The activity concentrations of naturally occurring radioactive materials such as ^{238}U, ^{232}Th and ^{40}K were measured for 38 soil samples collected from diverse zones in the southern area of West Bank, Palestine using gamma-ray spectroscopy. The measured activities of ^{238}U, ^{232}Th and ^{40}K were found to range from 32.9 to 104.7, 14.5 to 76.6 and 297 to 962 Bq kg^{-1} with averages value of 68.7, 48.0 and 630 Bq kg^{-1}, respectively. The obtained values of activity concentrations are higher than the world average of 35, 30 and 500 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively. The measured ^{137}Cs activity concentration was found to range from 1.8 to 36.1 Bq kg^{-1} with an average value of 8.5 Bq kg^{-1}. The detected activities were attributed to the fallout of ^{137}Cs, which is the only man-made radionuclide. The calculated average of the total gamma-radiation dose rate of natural radionuclides, ^{137}Cs and cosmic radiation is 121.4 nGy h^{-1}. The radium equivalent activity (R_{aeq}), dose rate (D_r), external hazard index (H_{ex}) and radioactivity level index (I_γ) in all samples are presented. Some values were found to be in the range of worldwide values, whereas others were above the worldwide values.

INTRODUCTION

Mankind is continuously exposed to background ionizing radiation from cosmic and terrestrial sources. The magnitude of the background radiation depends with altitude and geology.

The naturally occurring radionuclides present in soil include ^{226}Ra, ^{232}Th and ^{40}K. Knowledge of the distribution of these radionuclides in soil and rock is of great importance for radiation protection and measurements. It was found that exposure to some radiation resulting from certain nuclides such as ^{40}K is fairly constant and uniform for all individuals everywhere; other exposures vary widely depending on location; for instance, cosmic rays are more intense at higher altitudes. Besides, concentrations of ^{238}U and ^{232}Th in soils have higher values in localised areas[1,2].

Soils and rocks contribute to environmental radioactivity in two ways. First, external dose is received by direct exposure to gamma radiation (whole body dose) and in some cases by beta radiation (skin dose). Secondly, internal dose is received by inhalation of the radioactive daughters of radon (a noble gas), which is released from soil. Radon gas contributes more than half of the background radiation in regions having very high natural radionuclide concentrations, such as of uranium and thorium[3].

A previous study reported high natural alpha particle radioactivity in the soil in some parts of Hebron district[4]. A more recent study of activity concentrations of natural occurring radionuclides in soil samples collected from several areas in Hebron district was performed by Dabayneh[5].

The purpose of the present study is to measure activity concentrations and to estimate the radiological effects and gamma-ray absorbed dose of naturally occurring, radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K in soil samples collected from several areas located in the Southern part of the West Bank, Palestine, using gamma-ray spectrometry.

MATERIALS AND METHODS

A total of 38 surface soil samples were collected from five sites of the southern part of West Bank, Palestine, using a template 25 cm by 25 cm in area and 5 cm in depth[6]. The sites are: Beit Umar (10 samples), Halhul (7 samples), Al-Fawar (5 samples), Yatta (8 samples) and Al-Dahria (8 samples) (Figure 1). In Figure 1a, the location of the study area within the West Bank is displayed, and Figure 1b exhibits the sample collection locations of the Hebron district. The samples were dried, sieved, packed in 1 l Marenilli beaker and sealed for 4 weeks to reach secular equilibrium between ^{226}Ra (daughter of ^{238}U) and ^{232}Th with their daughter nuclei[7].

After the isolation period, soil samples were analysed using a gamma-spectroscopy system consisting of an HPGe detector with 15% relative efficiency, 1.85 keV (FWHM) gamma-energy resolution at 1332.5 keV of ^{60}Co and MCA with 8000 channel. In order to reduce the gamma-ray background, a cylindrical lead shield with a fixed bottom and movable cover must be used to

*Corresponding author: drkaleelt@yahoo.com

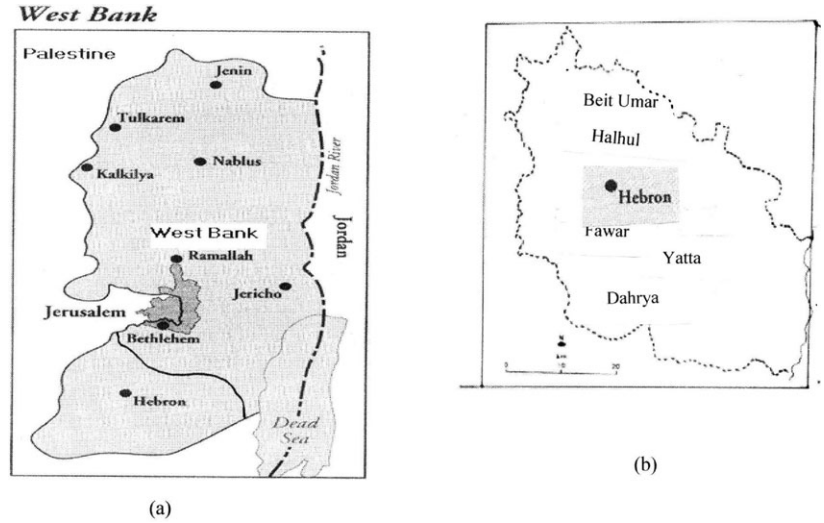

Figure 1. (a) West Bank geographical map of the studied region (Reference: www.fmep.org/maps/map)[21] and (b) map showing the region of collected samples.

shield the detector. The lead shield contained three inner concentric shells of lead, cadmium and copper[8].

The calibration of the spectrometer was carried out using standard sources: ^{139}Ce (166 keV), ^{203}Hg (279 keV), ^{113}Sn (392 keV), ^{85}Sr (514 keV), ^{137}Cs (662 keV), ^{88}Y (898 and 1836 keV) and ^{60}Co (1173 and 1332 keV) in the energy range (166–1850) keV. The calibration efficiency curve beyond 1850 keV was constructed using different energy peaks of ^{226}R in order to cover the range from 60 up to 2500 keV[9]. The standard source packed in the Marenilli beaker had the same geometry as that used for measured samples. An empty bottle with the same geometry was used for subtracting the background. The measuring time of both activity and background measurements ranged between 4.0×10^4 and 7.0×10^4 s. The background spectra were used to correct the net gamma-rays peak areas. Absolute efficiency calibration curves were calculated to study isotopes by using the last standard sources and chemically pure KCl dissolved in distilled water at different concentrations[10].

The activity of ^{238}U was determined using the gamma-lines 186.2 keV of ^{226}Ra; 295.1 and 351.9 keV of ^{214}Bi and 609.3, 1120.3 and 1764.8 keV of ^{212}Bi. The activity of ^{232}Th was determined using the gamma-lines 238.6 keV of ^{212}Pb, 583 keV of ^{208}Tl and 338.6 keV, 911.1 and 968.9 keV of ^{228}Ac. The ^{40}K and ^{137}Cs activities were measured from their own gamma-ray energies 1461.8 and 661.6 keV, respectively[11,12].

THEORETICAL BACKGROUND

The activity concentrations

The activity concentration in the environmental samples was obtained using the following standard equation[13]:

$$C(\text{Bq kg}^{-1}) = \frac{\text{Ca}}{I \times \varepsilon_{\text{ff}} \times M} \tag{1}$$

where C is the activity concentration measured in Becquerel per kilogram, Ca the net gamma-counting rate (counts per second for each peak) and $\text{Ca} = \text{Ca}_{\text{sample}} - \text{Ca}_{\text{background}}$; I the intensity of the gamma-line in a radionuclide; ε_{ff} the measured efficiency for each gamma-line observed for the same number of channels either for the sample or for the background, B.G., and M the mass of the sample measured in kilograms.

The concentration unit, m, in part per million (ppm) of U, Th and K percentages in the samples was calculated from the measured activity values using the empirical equation[13]:

$$m\,(\text{ppm}) = \left[\left(\frac{C\,M_{\text{w}}}{N_{AV} \ln 2}\right) t_{\frac{1}{2}}\right] \times 10^6 \tag{2}$$

Here C is measured in Becquerel per kilogram of the radionuclides, M_{w} the molecular weight (g/mol), N_{AV} the Avogadro's number and $t_{\frac{1}{2}}$ the half-life in seconds.

Calculation of radiological effects

In order to assess the health effects from the radioactivity of the earth's surface materials containing ^{238}U, ^{232}Th and ^{40}K, the activity of these nuclides is converted into a single quantity termed the radium equivalent (R_{aeq}). The radium equivalent activity is a weighted sum of activities of ^{226}Ra (daughter of ^{238}U), ^{232}Th and ^{40}K based on the assumption that 10 Bq kg^{-1} of ^{226}Ra, 7 Bq kg^{-1} of ^{232}Th and 130 Bq kg^{-1} of ^{40}K produce the same gamma-ray dose rates. It is calculated by using the following relation[14]:

$$R_{aeq} = C_{Ra} + (C_{Th} \times 1.43) + (C_K \times 0.077) \quad (3)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Becquerel per kilogram. The total air absorbed dose rate Dr (nGy h^{-1}) due to the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was calculated using the formula[14]:

$$\mathrm{Dr(nGy\ h^{-1})} = 0.427C_{Ra} + 0.662C_{Th} + 0.043C_K \quad (4)$$

It is worth mentioning that equation (4) is derived to calculate the absorbed dose rates in air for a height of 1 m above the ground surface.

The annual effective dose equivalent (AEDE) to a member of the population can be calculated using the conversion coefficient from absorbed dose in air to effective dose (0.7 Sv Gy^{-1}), the indoor to outdoor ratio (1.4), the outdoor occupancy factor being 0.2 and the indoor occupancy factor being 0.8. Therefore, the annual effective doses outdoors and indoors equivalent are calculated by using the relations[11,15,16]:

$$D_{outdoor}(\mathrm{mSv\ y^{-1}}) = [D_r(\mathrm{mGy\ h^{-1}}) \times 24\ \mathrm{h} \times 365.25\ \mathrm{d} \times 0.2 \times 0.7\ \mathrm{Sv\ Gy^{-1}}] \times 10^{-6} \quad (5)$$

and

$$D_{indoor}(\mathrm{mSv\ y^{-1}}) = [\mathrm{Dr(mGy\ h^{-1})} \times 24\ \mathrm{h} \times 365.25\ \mathrm{d} \times 1.4 \times 0.8 \times 0.7\ \mathrm{Sv\ Gy^{-1}}] \times 10^{-6} \quad (6)$$

The external hazard index H_{ex}, the emitted gamma-rays of the soil samples, is calculated and examined according to the following criterion[17]:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \quad (7)$$

The value of H_{ex} must be lower than unity in order to keep the radiation hazard insignificant.

The radioactivity level index, I_γ, can be used to estimate the gamma-radiation hazard levels typically those associated with the natural radionuclides. The representative level of radiation hazard index can be estimated according to the following equation[8]:

$$I_\gamma = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \leq 1 \quad (8)$$

The total gamma-radiation dose rate is modified to include the contributions from natural radionuclides, ^{137}Cs and cosmic radiation according to the following equation[14]:

$$D_\gamma(\mathrm{nGy\ h^{-1}}) = 0.427C_{Ra} + 0.662C_{Th} + 0.043C_K + 0.03C_{Cs} + 34 \quad (9)$$

where C_{Cs} is the activity concentration of ^{137}Cs radionuclide. The number 34 is a factor included to ensure that the effects of cosmic rays are implemented.

RESULTS AND DISCUSSION

The activity concentrations

The activity concentrations for ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in Becquerel per kilogram for the five sites are presented in Tables 1 and 2. As it can be seen from the tables, the activity concentrations of ^{238}U ranged from 32.9 to 104.7 Bq kg^{-1} with an average value of 68.7 Bq kg^{-1}. The ^{232}Th activity concentrations varied from 14.5 to 76.6 Bq kg^{-1} with an average value of 48.0 Bq kg^{-1}, and that of ^{40}K varies from 297 to 962 Bq kg^{-1} with an average value of 630 Bq kg^{-1}. Finally, the ^{137}Cs activity concentrations varied from 1.8 to 36.1 Bq kg^{-1} with an average value of 8.5 Bq kg^{-1}.

The observed results show that the average activity concentrations for ^{238}U, ^{232}Th and ^{40}K for each of the five investigated sites are higher than the reported international radioactivity levels of ^{238}U, ^{232}Th and ^{40}K in UNSCEAR (2000), which are 35, 30 and 400 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K, respectively[15]. The recorded high values of the radionuclides in the soil samples may be due to the presence of radioactive-rich granite, phosphate, sandstone and quartzite.

The radionuclide ^{137}Cs was detected in all of the locations, which is likely due to fallout of previous worldwide nuclear explosion and reactor accidents.

The radiological effects

The radium equivalent activity of all soil samples ranges are as follows: from 82.3 Bq kg^{-1} in Beit Umar area to 278.6 Bq kg^{-1} in Halhul district (Table 3) with an average value of 185.8 Bq kg^{-1}.

Table 1. The activity concentrations of radionuclides in soil samples collected from the southern areas of West Bank, Palestine.

Zone	Sample code	No. of samples	^{238}U		^{232}Th		^{40}K	
			Bq kg^{-1}	ppm	Bq kg^{-1}	ppm	Bq kg^{-1}	ppm
Beit Umar	B_1	2	38.7	3.2	14.5	3.6	297	9.7
	B_2	2	72.5	5.9	47.7	11.8	650	21.3
	B_3	2	71.2	5.8	40.2	9.9	601	19.7
	B_4	2	98.0	8.0	66.7	16.5	850	27.9
	B_5	2	74.2	6.1	42.6	10.5	737	24.2
	Average		70.9	5.8	42.3	10.4	627	20.6
Halhul	H_1	2	51.2	4.2	37.5	9.3	587	19.2
	H_2	2	81.2	6.6	59.7	14.7	613	20.1
	H_3	1	104.7	8.5	76.6	18.9	836	27.4
	H_4	1	64.8	5.3	31.9	7.9	565	18.5
	H_5	1	78.2	6.4	57.7	14.2	962	31.5
	Average		76.0	6.2	52.7	13.0	713	23.4
Al-Fawar	F_1	1	68.8	5.6	43.9	10.8	527	17.3
	F_2	2	75.0	6.1	50.8	12.5	681	22.3
	F_3	1	73.3	6.0	45.7	11.3	631	20.7
	F_4	1	72.7	6.0	48.5	12.0	645	21.1
	Average		72.5	5.9	47.2	11.7	621	20.4
Yatta	Y_1	2	72.4	5.9	53.4	13.2	609	20.0
	Y_2	2	64.0	5.3	41.8	10.3	521	17.1
	Y_3	2	56.5	4.6	49.0	12.1	540	17.7
	Y_4	2	68.4	5.6	52.7	13.0	628	20.6
	Average		65.3	5.3	49.2	12.1	575	18.9
Al-Dahria	D_1	2	60.6	4.9	55.8	13.8	647	21.2
	D_2	2	74.7	6.1	61.6	15.2	700	23.0
	D_3	2	50.7	4.1	50.8	12.5	673	22.1
	D_4	1	32.9	2.7	22.3	5.5	304	10.0
	D_5	1	74.3	6.0	52.8	13.0	683	22.4
	Average		58.6	4.8	48.7	12.0	601	19.7
Total average			68.7	5.6	48.0	11.9	630	20.7

This value is much less than the safe limit (370 Bq kg^{-1}) recommended by the Organization for Economic Cooperation and Development[18]. Accordingly, any radium equivalent activity concentration that exceeds 370 Bq kg^{-1} may pose radiation hazards.

The determined absorbed dose rates in air at 1 m above the ground surface as a result of gamma radiation of the detected natural radionuclides in soil samples for various sites are listed in Table 3. The results show that the dose rate varies from 38.9 to 131.4 nGy h^{-1} with an overall average value of 88.2 nGy h^{-1}. The obtained values of dose rates are higher than the world average value of 55 nGy h^{-1}[16].

The calculated values of H_{ex} for the soil samples investigated in this study range from 0.22 to 0.75 with an overall average value of 0.50 (Table 3). These values are far below the criterion limit and much less than unity ($H_{ex} < 1$).

The level index I_γ is determined to estimate the gamma-radiation hazard associated with the natural radionuclide in the soil samples. The calculated values for most samples were higher than the international values ($I_\gamma > 1$).

The results of total gamma-radiation dose rates of natural radionuclides, ^{137}Cs and cosmic radiation are presented in Table 2. As can be seen from the table, the results of total gamma-radiation dose rates range from 69.6 to 165.5 nGy h^{-1} with an overall average value of 121.4 nGy h^{-1}.

The results of outdoor, indoor and average effective dose for Southern West Bank are 0.11, 0.61 and 0.72 mSv y^{-1}, respectively (Table 4). It can be seen that the above-mentioned values are higher than the corresponding worldwide values of 0.07, 0.41 and 0.48 mSv y^{-1}, respectively[15].

For the sake of comparison, the levels of the natural radionuclides in the soil samples of various other countries are exhibited in Table 5. As can be seen, the corresponding activity concentration levels of ^{238}U, ^{232}Th and ^{40}K radioisotopes and the absorbed dose rates obtained from this

Table 2. Activity concentrations and total dose rate of natural radionuclides, ^{137}Cs and cosmic radiation in soil samples collected from five districts of southern west bank, Palestine.

Zone	No. of samples	Concentration (Bq kg^{-1})		D_γ (nGy h^{-1})	
		Range	Average	Range	Average
Beit Umar	10	2.8–14.9	7.5	69.6–162.3	119.5
Halhul	7	5.4–13.2	8.8	101.3–165.5	127.9
Al-Fawar	5	2.5–9.2	5.5	115.2–129.0	123.1
Yatta	8	1.8–36.1	13.8	94.1–132.2	117.6
Al-Dahria	8	3.3–11.3	7.0	76–140	119.0
Total	38	Min. value	1.8	Min. value	69.6
		Max. value	36.1	Max. value	165.5
		Average value	8.5	Average value	121.4

Table 3. The radium equivalent, dose rate, external hazard index and radioactivity level index of the soil samples of the southern districts of west bank, Palestine.

Zone	Location	No. of samples	R_{aeq} (Bq kg^{-1})	Dr (nGy h^{-1})	H_{ex}	I_γ
Beit Umar	B_1	2	82.3	38.9	0.22	0.60
	B_2	2	190.8	90.5	0.52	1.39
	B_3	2	175.0	82.9	0.47	1.28
	B_4	2	258.8	122.6	0.70	1.89
	B_5	2	191.9	91.6	0.52	1.41
	Average		179.8	85.3	0.49	1.31
Halhul	H_1	2	150.0	71.9	0.41	1.11
	H_2	2	213.8	100.6	0.58	1.55
	H_3	1	278.6	131.4	0.75	2.02
	H_4	1	153.9	73.1	0.42	1.03
	H_5	1	234.7	112.9	0.63	1.74
	Average		206.2	98.0	0.56	1.49
Al-Fawar	F_1	1	172.2	81.1	0.47	1.25
	F_2	2	200.1	94.9	0.54	1.64
	F_3	1	187.2	88.7	0.51	1.37
	F_4	1	191.7	90.9	0.52	1.40
	Average		187.8	88.4	0.51	1.42
Yatta	Y_1	2	195.7	92.5	0.53	1.42
	Y_2	2	163.9	77.4	0.44	1.19
	Y_3	2	168.2	79.8	0.45	1.23
	Y_4	2	192.1	91.1	0.52	1.40
	Average		180	85.2	0.49	1.31
Al-Dahria	D_1	2	190.2	90.6	0.51	1.39
	D_2	2	216.7	102.8	0.59	1.58
	D_3	2	175.2	84.2	0.47	1.29
	D_4	1	88.2	41.9	0.24	0.64
	D_5	1	202.4	96.0	0.55	1.48
	Average		174.5	83.1	0.47	1.28
Total average			185.8	88.2	0.50	1.36

study fall within the highest range of most reported values from other worldwide and neighbouring areas such as Cyprus, Greece and Spain. In other words, the South of West Bank may be considered as one of the regions of the world that has relatively high concentration levels of natural radioactivity.

Table 6 shows the ^{137}Cs activity concentration ranges reported from some of the other countries in the world[19,20]. Shown in this table, the measured values of ^{137}Cs activity concentration in the present work are compared with these values. Obviously, the measured ^{137}Cs activity concentration range is higher than in many countries.

Table 4. The annual effective doses outdoors and indoors equivalent and the total annual effective dose for the soil samples of southern districts of West Bank, Palestine.

Zone	$D_{outdoor}$ (mSv y^{-1})		D_{indoor} (mSv y^{-1})		Total AEDE (mSv y^{-1})
	Range	Average	Range	Average	
Beit Umar	0.05–0.15	0.11	0.27–0.84	0.59	0.70
Halhul	0.09–0.16	0.12	0.49–0.90	0.67	0.79
Al-Fawar	0.10–0.12	0.11	0.56–0.65	0.61	0.73
Yatta	0.09–0.11	0.10	0.53–0.64	0.59	0.69
Al-Dahria	0.05–0.13	0.10	0.29–0.71	0.57	0.67
Total average		0.11		0.61	0.72

Table 5. Comparison of natural radioactivity levels in soil and air absorbed dose at different locations of southern of West Bank area, Palestine, with those in other countries as given in UNSCEAR report[15].

Country	Activity concentration (Bq kg^{-1})						Absorbed dose rate (nGy h^{-1})	
	^{238}U		^{232}Th		^{40}K			
	Range	mean	Range	Mean	Range	Mean	Range	Mean
Jordan	—	56	—	29	—	501	—	—
Turkey	—	21	—	37	—	342	—	—
Italy	57–71	—	73–87	—	580–760	—	—	—
Egypt	5–64	17	2–96	18	29–650	320	20–133	32
USA	8–160	40	4–130	35	100–700	370	14–118	47
Japan	6–98	33	2–88	28	15–990	310	21–77	53
Cyprus	0–120	17	—	—	0–670	140	9–52	18
Malaysia	38–94	67	63–110	82	170–430	310	55–130	92
China	2–440	32	1–360	41	9–1800	440	2–340	62
India	7–81	29	14–160	64	38–760	400	20–110	56
Iran	8–55	28	5–42	22	250–980	640	36–130	71
Denmark	9–29	17	8–30	19	240–610	460	35–70	52
Poland	5–120	26	4–77	21	110–970	410	18–97	45
Greece	1–240	25	1–190	21	12–1570	360	30.109	56
Germany	5–200	—	7–134	—	40–1340	—	4–350	50
Romania	8–60	32	11–75	38	250–1100	490	21–122	59
Spain	6–250	32	2–210	33	25–1650	470	40–120	76
Present study	33–105	69	15–77	48	297–962	630	39–123	88
Worldwide average	—	35	—	30	—	400	—	55

CONCLUSIONS

It is clear from the analysis of gamma-ray spectroscopic data in the present study that the levels of natural radioactivity of soil samples collected from the southern part of the West Bank, Palestine, are higher than the international recommended limit. The average radioactivity of ^{238}U, ^{232}Th and ^{40}K is 68.7, 48.0 and 630 Bq kg^{-1}, respectively, which lead to individual (indoor–outdoor weighted) absorbed dose rate of 88.2 nGy h^{-1}, which exceeds the world average value of 55 nGy h^{-1}[16]. Therefore, the average annual effective dose outdoors, indoors and in total in the region are estimated to be 0.11, 0.61 and 0.72 mSv y^{-1}, respectively. It can be seen that the total annual effective dose is greater than the international value (0.48 mSv y^{-1}).

From the activities of ^{238}U, ^{232}Th and ^{40}K, the radium equivalent activity, the external hazard index and the radioactivity level index of soil samples can be calculated. The mean values of the radium equivalent and external hazard index determined in the soil of the study area are lower than the corresponding permissible limits (370 Bq kg^{-1} and 1).

Table 6. Range of activity concentration of ^{137}Cs in soil samples reported from some of the other locations in the world[19,20].

Country	Activity concentration range (Bq kg^{-1})
Cairo (Egypt)	1.6–19.1
Algeria	15–35
Sudan	0–18.5
Libya	0.9–1.7
Riyadh (Saudi Arabia)	0–2.0
Bay of Cadiz (Spain)	0.5–5
Kocaelibasin (Turkey)	2–25
Savart (Bangladesh)	2–3
Taiwan	1.5–27
Punjab (Pakistan)	1.1–5.3
Hiyroshima (Japan)	0.16–10.6
Hebron (South West Bank)	1.8–36.1

Generally speaking, the radioactivity level index is >1 for most samples.

The activity concentration of ^{137}Cs in soil samples is found to be ranged from 1.8 to 36.1 Bq kg^{-1} for all investigated zones.

The measurements taken in this study represent a baseline database of activity levels that can serve as a reference point for future studies to indicate impacts from future events.

ACKNOWLEDGEMENTS

This study was partially supported by the deanship of academic research, Hebron University, Hebron, Palestine.

REFERENCES

1. Asha, R. and Surinder, S. *Natural Radioactivity Levels in Soil Samples from Some Areas of Himachal Pradesh, India using γ-Ray Spectrometry.* Atmos. Environ. **39**, 6306–6314 (2005).
2. Khan, K., Khan, H. M., Tufail, M. and Ahmed, N. *Radiometric analysis of Hazara phosphate rock and fertilizers.* J. Environ. Radioact. **38**, 77–83 (1998).
3. El-Arabi, A. *^{226}Ra, ^{232}Th, and ^{40}k concentrations in igneous rocks from eastern desert, Egypt and its radiological implications.* Radiat. Meas. **42**, 94–100 (2007).
4. Hasan, F. *The natural alpha particle radioactivity in soil in Hebron District.* Hebron University Research J. **1**(1), 11–21 (1999).
5. Dabayneh, K., Soroor, A. and Abdel Haleem, S. *Environmental nuclear studies of natural and man-made radioactivity at Hebron region in Palestine.* J. of Al-Quds Open University, **12**(1), 23–42 (2008).
6. Wafaa, F., El-Tahawy, M., El-Mongy, S. and Sayed, S. *A comprehensive radiological investigation for the industrial Helwan city environment.* Seventh conference of nuclear science, Cairo-Egypt (2000).
7. Tzortzis, M., Svoukis, E. and Tsertos, H. *A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in Cyprus.* Radiat. Prot. Dosim., **109**(3), 217–224 (2004).
8. Sroor, A., Afifi, S., Abdel-Haleem, A., Salman, A. and Abdel-Sammad, M. *Environmental pollutant isotope measurements and natural radioactivity assessment for North Tushki area, South Western desert, Egypt.* Appl. Radiat. Isot., **7**, 1–10 (2002).
9. Helmer, R. *Efficiency calibration of Ge detector for 30-2800 keV gamma ray.* Nucl. Instrum. Methods, **199**, 521 (1982).
10. Sesana, L., Fumagalli, M., Carnevale, M. and Facchini, U. *Natural radionuclides in the rocks of the Valle del Cervo Pluton in Piedmont*. Radiat. Prot. Dosim., **118**(3), 337–344 (2006).
11. Huy, N. and Luyen, T. *Study of external exposure doses from terrestrial radioactivity in Southern Vietnam.* Radiat. Prot. Dosim., **118** (3), 331–336 (2005).
12. Environmental Measurements Laboratory [EML], Procedures Manual, 27th edition, US Department of Energy, 1 (1990).
13. Abbady Adel, G., El-Arabi, A. and Abbady, A. *Heat production rate from radioactive elements in igneous and metamorphic rocks in eastern desert, Egypt*. Arab J. Nucl. Sci. Appl., **38** (2), 287–294 (2005).
14. El-Shershaby, A., El-Bahi, S., Walley El-Dine, N. and Dabayneh, K. *Assessment of natural and man-made radioactivity levels of the plant leaves samples as bio-indicators of pollution in Hebron district-Palestine.* Arab J. Nucl. Sci. Appl., **39**(2), 232–242 (2006).
15. United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and effects of ionizing radiation*. Report to the General Assembly, Vol. 1, Annex B, (New York: UNSCEAR) (2000).
16. Chowhury, M., Kamal, M., Alam, M., Saleha, Y. and Mostafa, M. *Distribution of naturally occurring radionuclides in soils of the southern districts of Bangladesh.* Radiat. Prot. Dosim., **118**(1) 126–130 (2005).
17. Beretka, J. and Mathew, P. *Natural radioactivity in Australian building materials, industrial waste and by-products.* Health Phys., **48**, 87–95 (1985).
18. Nuclear Energy Agency. *Exposure to radiation from natural radioactivity in building materials.* Report by NEA Group of Experts (OECD: Paris, France) (1979).
19. Tahir, S., Jamil, K., Zaidi, J., Arif, M. and Nasir, A. *Activity concentration of ^{137}Cs in soil samples from Punjab province (Pakistan) and Estimation of gamma-ray dose rate for external exposure.* Radiat. Prot. Dosim., **118**(3), 345–351 (2006).
20. Shizuma, K., Iwatani, K., Hasai, H., Hoshi, M., Oka, T. and Okano, M. *^{37}Cs concentration in soil samples from an early survey of Hiroshima atomic bomb and cumulative dose estimation from the fallout*. Health Phys. Soc., **71**(3), 340–346 (1996).
21. www.fmep.org/maps/map.