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Determination of Alpha Particles Concentration in Some Soil Samples and the Extent of Their Impact on Health

(Penentuan Kepekatan Partikel Alfa dalam Beberapa Sampel Tanah dan Kesannya Terhadap Kesihatan)

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ABSTRACT

The radon concentration, the exhalation rates and the radiation exposure from samples of soil collected from different sites at Hebron province in Palestine were measured using the sealed-can technique based on the CR-39 detectors. The total average values of radon concentrations for 0, 20, 40 and 60 cm depths were 294, 357, 433 and 512 Bqm^{-3}, respectively. As expected, our data showed an increase of radon concentration levels with depth. The average values of surface exhalation rates, the effective dose equivalent (E_p), the annual effective dose (H_E), the dissolved in soft tissues ($D_{soft, tissue}$) and the dose rate due to alpha-radiation in lung (D_{lung}) were calculated. The values were found to be within the safe limits as recommended by ICRP and WHO. The results showed that these areas are safe from the health hazard site of view as far as the radon is concerned.

Keywords: Alpha particles; exhalation rates; Palestine; radon

ABSTRAK

Kepekatan radon, kadar penghembusan dan pendedahan radiasi daripada sampel tanah yang diambil dari tapak yang berbeza di wilayah Hebron di Palestin telah diukur menggunakan teknik takungan adang dengan pengesan CR-39. Jumlah nilai purata kepekatan radon bagi kedalaman 0, 20, 40 dan 60 cm masing-masing adalah 294, 357, 433 dan 512 Bqm^{-3}. Seperti yang dijangka, data kami menunjukkan tahap kepekatan radon meningkat mengikut kedalaman. Nilai purata kadar hembusan nafas permukaan, dos efektif setara (E_p), dos efektif tahunan (H_E), pelarutan dalam tisu lembut ($D_{lembut, tisu}$) dan kadar dos yang disebabkan oleh radiasi-alfa dalam paru-paru ($D_{paru-paru}$) telah dikira. Nilai didapati dalam had selamat seperti yang disyorkan oleh ICRP dan WHO. Hasil kajian menunjukkan bahawa kawasan ini selamat daripada bahaya kesihatan oleh radiasi radon.

Kata kunci: Kadar penghembusan; Palestin; radon; zarah alfa

INTRODUCTION

Radioactivity in the environment is the biggest concern for human beings. According to UNSCEAR (1988), about 82% of the radiation dose received by mankind are due to natural radiation sources and the remaining is due to artificial radiation. It is well known that natural radioactivity is present in rocks, soils, sediments, water, oceans that make up our planet and in our building materials. The human population is exposed to a natural background radiation level that is contributed by three components viz., cosmic rays, terrestrial radioactivity and internal radioactivity (Anil et al. 2014; Vimal et al. 2014).

Radon is produced continuously from the decay of naturally occurring radionuclide such as ^{238}U and ^{232}Th. The isotope ^{222}Rn, produced from the decay of ^{238}U, is the main source (approximately 55%) of the internal radiation exposure to human life (ICRP 1993). Radon comes from the natural decay of uranium that is found in nearly all soils. It appears mainly by diffusion processes from the point of origin following α- decay of ^{226}Ra in underground soil and rocks. It typically moves up through the ground to the air above and into homes through cracks and other holes in the foundation.

So radon and its daughter products from soil gas are the major sources of radiation exposure and recognized as one of the health hazards for mankind (Vikas et al. 2014). The radon inhalation is the main cause of lung cancer for individuals who are smoking and is the most important cause of lung cancer after smoking (WHO 2014). The presence of radon is expected everywhere, but it is found in high concentration in soil and rocks enriched in radium and uranium elements. Most of these soils and rocks are compacted and processed to produce building materials that are used for workplaces and houses in which we work and live. If radon emanated from these materials exceeds the action level of 200 Bqm^{-3}, then remedial action should be taken to reduce health hazards due to exposure to indoor radon (Nisar et al. 2014).

Due to potentially serious public health implications of exposure to high levels of radon, the measurement of radon concentration and radon exhalation rates of some soil samples of Hebron district has been carried out using canister technique. Solid state nuclear track detectors (CR-39) were used in radon detection and α- particle spectroscopy to measure the natural alpha radioactivity in human and animal tissues (Almayahi et al. 2014).

Materials and Methods

The radon and its daughters were detected by a passive technique of solid state nuclear track detectors using the 'sealed can technique' (Najam et al. 2013; Ridha et al. 2014). A total of 108 soil samples were collected from different sites in the Hebron province in Palestine (Figure 1). The samples were collected from the surface layer and at depths 20, 40 and 60 cm, respectively. These samples were milled and sieved through a 200 mesh (75 μm), (30 gm) of each sample which was placed inside a plastic cylindrical container facing a CR-39 track detector into a diffusion chamber Figure 2.

The container was then sealed for 2 months; during that time, α particles emitted by radon and their daughters bombarded the CR-39 track detectors. After the irradiation, the detectors were developed in NaOH solution 6.25N at70°C for 4 h; after chemical etching, α particle track densities were determined by an optical microscope 160×.

Radon Concentrations and Exhalation Rates

The density of the tracks (ϱ) in the samples was calculated according to the following relation (Amalds et al. 1989):

$$\rho = \frac{T_N}{A}, \tag{1}$$

where T_N is the average number of total tracks; and A is area of field view.

The Radon gas concentration in the soil samples was obtained by the comparison between track densities registered on the detectors of the sample and that of the standard soil sample which is shown in Figure 3, using the relation (Durrani & Bull 1987; Ridha et al. 2014):

$$C_X = \frac{\rho_X C_S}{\rho_S}, \tag{2}$$

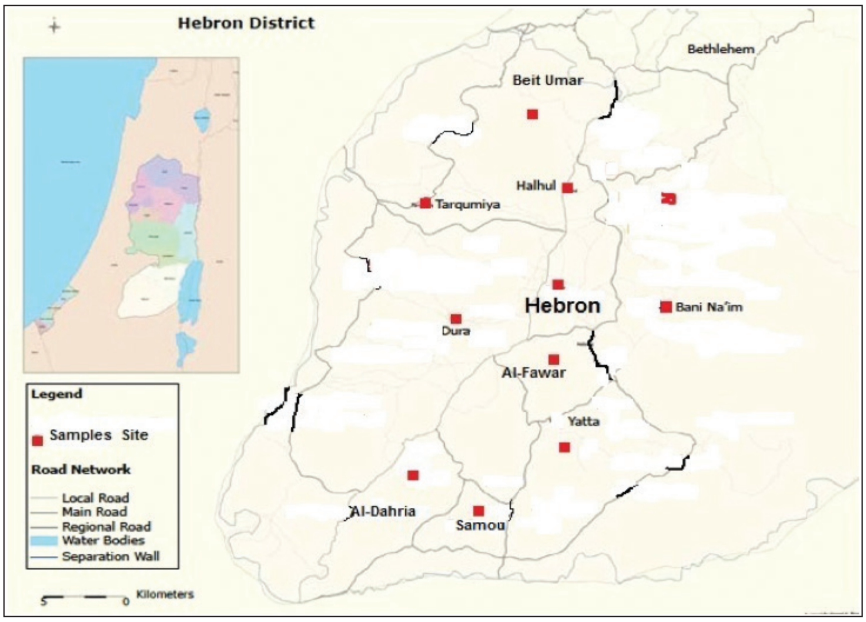

FIGURE 1. The map showing the study area

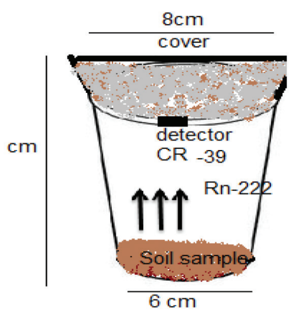

FIGURE 2. A schematic diagram of the sealed-cup technique in soil sample

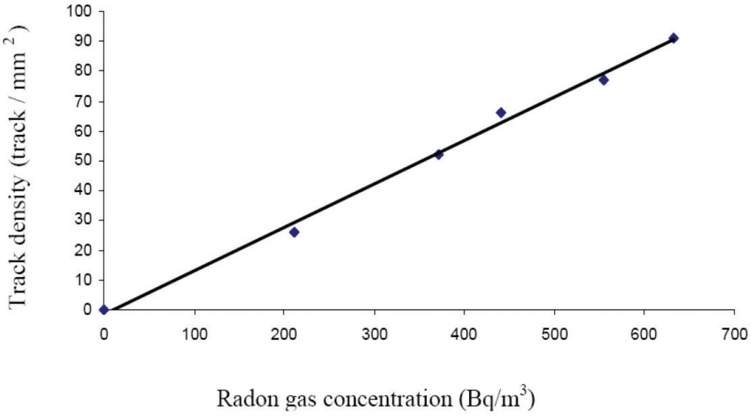

FIGURE 3. Relation of Radon gas concentration and track density in soil standard samples

where C_x is the alpha particles concentration in the unknown sample; C_s is the alpha particles concentration in the standard sample; ρ_x is the track density of the unknown sample (track/mm^2) and ρ_s is the track density of the standard sample (track/mm^2).

The radon exhalations study is important for understanding the relative contribution of the material to the total radon concentration found in cracks and dwellings. Exhalation rates in terms of area and mass were calculated from (3) and (4) which were earlier used by various researchers (Sonkawade et al. 2008; Zubair et al. 2012).

Area exhalation rate

$$E_A = \frac{CV\lambda}{A\left[T+\lambda^{-1}\left(e^{-\lambda T}-1\right)\right]}\left(Bqm^{-2}h^{-1}\right). \quad (3)$$

Mass exhalation rate,

$$E_M = \frac{CV\lambda}{M\left[T+\lambda^{-1}\left(e^{-\lambda T}-1\right)\right]}\left(Bqkg^{-1}h^{-1}\right), \quad (4)$$

where, C is radon exposure (Bqm^{-3}h); V is the effective volume of Can (m^3); A is surface area of the sample in m^2; T is time of exposure (h); M is mass (kg) of the sample in Can; and λ is the decay constant for radon (h^{-1}).

THE RADIATION EXPOSURE

The annual exposure to potential alpha energy E_p (effective dose equivalent) is then related to the average radon concentration C_{Rn} by the following expression (Mahur et al. 2009):

$$E_P = \frac{8760 \times n \times F \times C_{Rn}}{170 \times 3700}\left(WLM \cdot y^{-1}\right), \quad (5)$$

where C_{Rn} is in Bqm^{-3}; n is the fraction of time spent indoors; 8760 is the number of h per year; and 170, the number of h per working month and breathing in air in which radon concentration of 3700 Bqm^{-3}. The values of $n = 0.8$ and $F = 0.42$ as suggested by UNSCEAR (UNSCEAR 2002), were used to calculate E_p. The effective dose received by the area under investigation of human lungs has been calculated by using a conversion factor of 6.3 mSv (WLM)$^{-1}$ given by ICRP (1987).

The annual effective dose (H_E) was calculated (Alsaedi 2014; UNSCEAR 2002):

$$H_E\,(MSvy^{-1}) = C_{Rn} \times F \times T \times D, \quad (6)$$

where C_{Rn} is the radon concentration in Bqm^{-3}; F is the ^{222}Rn indoor equilibrium factor (0.4); T is time (8760 hyr^{-1}); and D is dose conversion factor (9×10^{-6} mSvyr^{-1} (Bqm^{-3})$^{-1}$).

Because of their different physical properties, radon gas and radon decay products were considered separately. Inhaled radon is constantly present in the air volume of the lungs at the concentration in air ($C_{Rn,\,air}$) and is partly dissolved in soft tissues. Taking the soluble factor for the soft tissues to be 0.4 and assuming that the short-lived decay products decay in the same tissue as radon gas, the following relationship for soft tissues other than the lungs was derived (Alsaedi 2014; ICRP 1993, 1981):

$$D_{Soft\ ttissuis}\,(nGyhr^{-1}) = 0.005C_{Rn,surface}(Bqm^{-3}). \quad (7)$$

In the case of the lungs, in addition to the dissolved radon, the radon content of air in the lungs must be taken into account. Assuming the air volume in the lungs to be 3.2×10^{-3} m^3 for the 'Reference Man' and assuming further that the short-lived decay products will stay in the lungs, the dose rate due to alpha-radiation was determined as ICRP (1993) and Alharbi and Abbady (2013):

$$D_{lung}(nGyhr^{-1}) = 0.04C_{Rn,surface}(Bqm^{-1}). \quad (8)$$

RESULTS AND DISCUSSION

RADON CONCENTRATIONS

Soil is the basic ingredient used in agricultural purposes and also for housing construction in Palestine. Thus, it is quite important to find the radon activity concentration to have an estimation of radiation risk to the habitants. The values of radon activity in soil samples at the selected sites in the area under investigation at the depths of 0, 20, 40 and 60 cm are presented in Table 1. The average radon concentration in soil samples for 0, 20, 40 and 60 cm depths ranged from 253-345, 291-452, 363-532 and 422-633 Bqm^{-3}, respectively. The total average values of radon concentrations for 0, 20, 40 and 60 cm depths are 294, 357, 433 and 512 Bqm^{-3}, respectively.

Looking for the whole data in the Table 1, one can see that in the majority of locations, there is linearity between the average radon concentrations and the depth for the same sample point as shown in Figure 4. The results suggested that the maximum average radon concentrations are observed at 60 cm depths and minimum at 0 cm surfaces. This may be due to the increase in moisture content with depth of the soil and may be due to the presence of uranium prospect beneath the soil (Garg et al. 2014). The possible difference in compaction of the soil (difference in soil profile) could also explain the more rapid increase in the soil gas concentration at different sites. This would mean that less radon would diffuse to the surface as more and more radon is potentially trapped in the interstitial pore space in the soil. Another reason that might influence the difference in the radon concentrations at the four depths in the soil is the air pressure at the surface.

TABLE 1. Radon concentration in soil samples at specified depths collected from area under investigation

Zone	Sample code	C_{Rn} (Bqm^{-3})			
		0 cm	20 cm	40 cm	60 cm
Hebron City	HcS1	288	344	522	615
	HcS2	375	477	628	716
	HcS3	344	390	446	567
	Average	336	404	532	633
Dura	DuS1	414	578	677	866
	DuS2	323	424	398	470
	DuS3	297	355	447	416
	Average	345	452	507	584
Al-Fawar	FaS1	270	330	377	419
	FaS2	310	376	399	456
	FaS3	300	352	414	517
	Average	293	353	397	464
Yatta	YaS1	300	344	398	489
	YaS2	295	343	402	476
	YaS3	230	265	288	301
	Average	275	317	363	422
Samou	SaS1	223	287	344	432
	SaS2	357	421	532	616
	SaS3	244	294	377	413
	Average	275	334	418	487
Al-Dahria	DaS1	245	288	355	432
	DaS2	305	412	523	643
	DaS3	209	244	298	326
	Average	253	314	392	467
Tarqumia	TaS1	255	301	376	431
	TaS2	321	389	477	612
	TaS3	300	378	488	466
	Average	292	356	447	503
Beit Umar	BuS1	160	144	212	287
	BuS2	310	376	455	522
	BuS3	295	354	427	566
	Average	255	291	364	458
Halhul	HaS1	210	266	312	387
	HaS2	331	398	473	578
	HaS3	425	512	655	802
	Average	322	392	480	589
Total Average		294	357	433	512

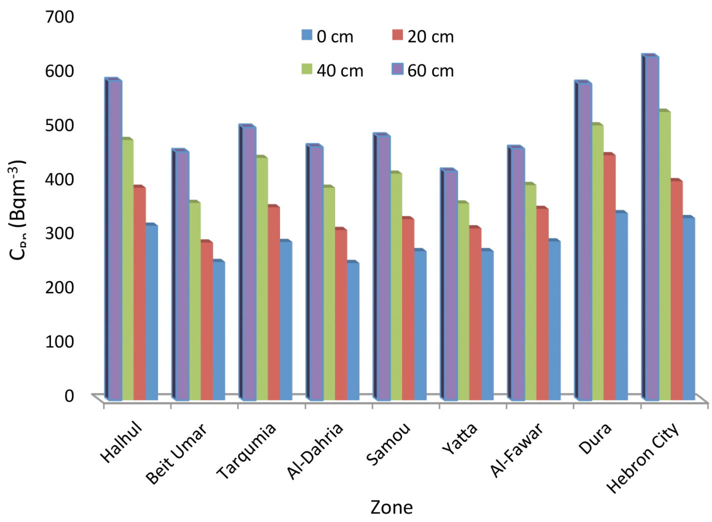

FIGURE 4. Variation of radon concentration with depth of the soil in different sites of Hebron province- Palestine

Radon release from soils is complex and its release is affected by moisture content, permeability, porosity and temperature (Douglas 1990). Each site may have distinct characteristic soil properties and must be evaluated accordingly.

The obtained values in this study are within that the worldwide average value of outdoor radon activity recommended by UNSCEAR (2000). Your risk of lung cancer increases substantially with exposure to higher radon levels. The lung cancer risk rises 16% per 100 Bqm^{-3} (2.7 pCiL^{-1}) increase in radon exposure. At surface soil samples, WHO recommends that the reference level should not exceed 300 Bqm^{-3} (WHO 2009).

RADON EXHALATION RATES

The values of radon exhalation rates of soil samples are listed in Table 2. The results illustrate an increased value of radon exhalation rates at increased depths, where the exhalation rates are also found to be relatively large. The average surface exhalation rates (E_A) in soil samples for 0, 20, 40 and 60 cm depths ranged from 91-124, 105-163, 131-191 and 152-228 mBqm^{-2} h^{-1}, respectively. The total average values of radon concentrations for 0, 20, 40 and 60 cm depths are 106, 128, 156 and 184 mBqm^{-2} h^{-1}, respectively. The average mass exhalation rates (E_M) in soil samples for 0, 20, 40 and 60 cm depths ranged from 3.5-4.8, 4.0-6.3, 5.0-7.4 and 5.8-8.8 mBqkg^{-1} h^{-1}, respectively. The total average values of radon concentrations for 0, 20, 40 and 60 cm depths are 4.1, 4.9, 6.0 and 7.1 mBqkg^{-1} h^{-1}, respectively.

The values of radon exhalation rate were found well below the world average value of 57600 mBqm^{-2}h^{-1} (UNSCEAR 2000). Hence it was suggested that for construction purpose this soil may be used, as it does not pose any health hazards due to low radon exhalation rate. A good correlation has been observed between radon concentrations and exhalation rate.

THE RADIATION EXPOSURE

The annual exposure to potential alpha energy E_p (effective dose equivalent) is calculated and listed in Table 3. An exposure to 1 WL for 1 working month (170 h) equals 1 WLM cumulative exposure. A cumulative exposure of 1 WLM is roughly equivalent to living one year in an atmosphere with a radon concentration of 230 Bqm^{-3}. The total average annual exposures in terms of WLM are 1.4, 1.7, 2.0 and 2.4 at the depths 0, 20, 40 and 60 cm, respectively.

The annual effective dose (H_E) is determined and shown in Table 3. The total average values of annual effective dose for 0, 20, 40 and 60 cm depths are 9.3, 11.2, 13.6 and 16.1 mSvy^{-1}, respectively. The values are found to be slightly larger than the action levels (3-10 mSvy^{-1}) recommended by ICRP (ICRP 1993). Moreover, these values seem to be safe from the site of view of health hazards.

The dissolved in soft tissues and dose rate due to alpha-radiation in the lung formed from the surface soil samples is listed in Table 4. The average dissolved in soft tissues range between 10.1 and 13.8 nGyh^{-1} with a total average value of 11.8 nGyh^{-1}. The average dose rate due to alpha-radiation in the lung formed from the surface soil samples varied from 1.27 to 1.73 nGyh^{-1} with a total average value of 1.47 nGyh^{-1}. The values are found to be within the safe limits as recommended by ICRP (1993, 1981). The results showed that these areas are safe from the health hazard point of view as far as the radon is concerned.

CONCLUSION

Radon concentration levels in soil samples collected from different sites in Hebron province were measured at sampling depths of 0, 20, 40 and 60 cm, by using the can technique. The radon exhalation rates, the effective dose equivalent, the annual effective dose, the dissolved

TABLE 2. Surface exhalation rates (E_A) and mass exhalation rates (E_M) in soil samples at specified depths collected from area under investigation

Sample code	E_A (mBqm^{-2} h^{-1})				E_M (mBqkg^{-1}h^{-1})			
	0 cm	20 cm	40 cm	60 cm	0 cm	20 cm	40 cm	60 cm
HcS_1	104	124	188	221	4	4.8	7.2	8.5
HcS_2	135	172	226	258	5.2	6.6	8.7	9.9
HcS_3	124	140	160	204	4.8	5.4	6.2	7.8
Average	121	145	191	228	4.6	5.6	7.4	8.8
DuS_1	149	208	244	312	5.7	8.0	9.4	12
DuS_2	116	153	143	169	4.5	5.9	5.5	6.5
DuS_3	107	128	161	150	4.1	4.9	6.2	5.8
Average	124	163	182	210	4.8	6.3	7.0	8.1
FaS_1	97	119	136	151	3.7	4.6	5.2	5.8
FaS_2	112	135	144	164	4.3	5.2	5.5	6.3
FaS_3	108	127	149	186	4.2	4.9	5.7	7.2
Average	105	127	143	167	4.1	4.9	5.5	6.4
YaS_1	108	124	143	176	4.2	4.8	5.5	6.8
YaS_2	106	123	145	171	4.1	4.7	5.6	6.6
YaS_3	83	95	104	108	3.2	3.7	4.0	4.2
Average	99	114	131	152	3.8	4.4	5.0	5.8
SaS_1	80	103	124	155	3.1	4.0	4.8	6.0
SaS_2	128	151	191	222	4.9	5.8	7.4	8.5
SaS_3	88	106	136	149	3.4	4.1	5.2	5.7
Average	99	120	150	175	3.8	4.6	5.8	6.7
DaS_1	88	104	128	155	3.4	4.0	4.9	6.0
DaS_2	110	148	188	231	4.2	5.7	7.2	8.9
DaS_3	75	88	107	117	2.9	3.4	4.1	4.5
Average	91	113	141	168	3.5	4.3	5.4	6.5
TaS_1	92	108	135	155	3.5	4.2	5.2	6.0
TaS_2	115	140	172	220	4.4	5.4	6.6	8.5
TaS_3	108	136	176	168	4.2	5.2	6.8	6.4
Average	105	128	161	181	4.0	4.9	6.2	7.0
BuS_1	58	52	76	103	2.2	2.0	2.9	4.0
BuS_2	112	135	164	188	4.3	5.2	6.3	7.2
BuS_3	106	127	154	204	4.1	4.9	5.9	7.8
Average	92	105	131	165	3.6	4.0	5.0	6.3
HaS_1	76	96	112	139	2.9	3.7	4.3	5.4
HaS_2	119	143	170	208	4.6	5.5	6.5	8.0
HaS_3	153	184	236	288	5.9	7.1	9.1	11.1
Average	116	141	173	212	4.5	5.4	6.6	8.1
Total average	106	128	156	184	4.1	4.9	6.0	7.1

TABLE 3. The effective dose equivalent (E_p) and the annual effective dose (H_E) in soil samples at specified depths collected from area under investigation

Sample code	E_P (WLM.y^{-1})				H_E (mSvy^{-1})			
	0 cm	20 cm	40 cm	60 cm	0 cm	20 cm	40 cm	60 cm
HcS_1	1.35	1.62	2.45	2.89	9.1	10.8	16.4	19.4
HcS_2	1.76	2.24	2.95	3.37	11.8	15.0	19.8	22.6
HcS_3	1.62	1.83	2.10	2.66	10.8	12.3	14.0	17.9
Average	1.58	1.90	2.50	2.98	10.6	12.7	16.8	19.9
DuS_1	1.95	2.72	3.18	4.07	13.0	18.2	21.3	27.3
DuS_2	1.52	1.99	1.87	2.21	10.2	13.4	12.5	14.8
DuS_3	1.40	1.67	2.10	1.96	9.4	11.2	14.1	13.1
Average	1.62	2.12	2..8	2.74	10.9	14.2	16.0	18.4
FaS_1	1.27	1.55	1.77	1.97	8.5	10.4	11.9	13.2
FaS_2	1.46	1.77	1.88	2.14	9.8	11.8	12.6	14.4
FaS_3	1.41	1.65	1.95	2.43	9.5	11.1	13.0	16.3
Average	1.38	1.66	1.87	2.18	9.2	11.1	12.5	14.6
YaS_1	1.41	1.62	1.87	2.30	9.5	10.8	12.5	15.4
YaS_2	1.39	1.61	1.89	2.24	9.3	10.8	12.7	15.0
YaS_3	1.08	1.25	1.35	1.41	7.2	8.3	9.1	9.5
Average	1.29	1.49	1.71	1.98	8.7	10.0	11.4	13.3
SaS_1	1.05	1.35	1.62	2.03	7.0	9.0	10.8	13.6
SaS_2	1.68	1.98	2.50	2.90	11.2	13.3	16.8	19.4
SaS_3	1.15	1.38	1.77	1.94	7.7	9.3	11.9	13.0
Average	1.29	1.57	1.96	2.29	8.7	10.5	13.2	15.3
DaS_1	1.15	1.35	1.67	2.03	7.7	9.1	11.2	13.6
DaS_2	1.43	1.94	2.46	3.02	9.6	13.0	16.5	20.3
DaS_3	0.98	1.15	1.40	1.53	6.6	7.7	9.4	10.3
Average	1.19	1.48	1.84	2.19	8.0	9.9	12.3	14.7
TaS_1	1.20	1.41	1.77	2.03	8.0	9.5	11.8	13.6
TaS_2	1.51	1.83	2.24	2.88	10.1	12.3	15.0	19.3
TaS_3	1.41	1.78	2.29	2.19	9.5	11.9	15.4	14.7
Average	1.37	1.67	2.10	2.36	9.2	11.2	14.1	15.8
BuS_1	0.75	0.68	1.00	1.35	5.0	4.5	6.7	9.0
BuS_2	1.46	1.77	2.14	2.45	9.8	11.8	14.3	16.4
BuS_3	1.39	1.66	2.01	2.66	9.3	11.2	13.5	17.8
Average	1.20	1.37	1.71	2.15	8.1	9.2	11.5	14.4
HaS_1	0.99	1.25	1.47	1.82	6.6	8.4	9.8	12.2
HaS_2	1.56	1.87	2.22	2.72	10.4	12.5	14.9	18.2
HaS_3	2.00	2.41	3.08	3.77	13.4	16.1	20.6	25.3
Average	16.1	1.84	2.26	2.77	10.1	12.3	15.1	18.6
Total average	1.38	1.68	2.04	2.41	9.3	11.2	13.6	16.1

TABLE 4. The average dissolved in soft tissues (D_{Soft}, $_{tissue}$) and dose rate due to alpha-radiation in the lung (D_{lung}, $_{surface}$) formed from the surface soil samples in the area under investigation

Zone	$D_{Soft,\ tissue}$ (nGyh^{-1})	$D_{lung,\ surface}$ (nGyh^{-1})
Hebron City	1.68	13.4
Dura	1.73	13.8
Al-Fawar	1.47	11.7
Yatta	1.38	11.0
Samou	1.38	11.0
Al-Dahria	1.27	10.1
Tarqumia	1.46	11.7
Beit Umar	1.28	10.2
Halhul	1.61	12.9
Total average	1.47	11.8

in soft tissues and the dose rate due to alpha-radiation in lung were determined to assess the radiological hazards from the soil samples.

The results in the present work indicated that the area under investigation has different radon concentrations according to depth from the ground surface and the locations of the sample site. A systematic increase in soil radon concentration levels with depth is observed for all the locations. Also, it can be concluded that, radon concentration depends upon the radon exhalation rate of soil and to increase at radon exhalation rate of the soil, the radon concentration also increased.

The radon concentration levels in soil samples from the study area showed well within the range reported by other investigators and on average, within the action level recommended by the ICRP (1993) and ICRP (1987), respectively. Moreover, these values seem to be safe from the site of view of health hazards. Hence, human activities would not be at risk in these areas. The results will provide data and information for dose assessment and further studies.

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