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Evaluation of radon concentration and natural radioactivity exposure from the soil of Wadi Hodein region, Egypt

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ABSTRACT

Background: The presence of radon and radioactive nuclei emitted from uranium could result in a radiological hazard. Humans are exposed to natural radiation, which arises from cosmic radiation, radon gas, and radiation from radioactive nuclei of each thorium, uranium, and thorium. ***Methods and Methods:*** This research cares to study the concentration of the natural radioactivity (238-U, 232-Th and 40-K) and radon for fourteen samples of soil from different fourteen location in Wadi Hodein region in Egypt (Southern Eastern Desert). The radon gas was measured using CR-39 detector, while the activity concentration for natural radioactivity measured by HPGD system. ***Results:*** The results of the gamma ray spectroscopy show that main activity concentration of 238-U, 232-Th and 40-K are 13.04±1.15, 12.33±1.54 and 445.33±23.54 Bq/Kg respectively. The 43% form concentration value for K-40 are higher than the exemption level 412 Bq/Kg proposed by the UNSCEAR 2008. Moreover, the 15% of values for absorbed dose D_{ab} were higher than public average 57 nGy/h. But annul effective dose values AED were less than recommended limits for the radiation which reported by UNSCEAR 2000 and 2008. The mean value concentration of radon was 265.96± 25.45 Bq/m^3. The results of samples show that 28.27% of the radon gas concentrations and annul effective dose from radon (AED_R) in soil is higher than allowed limit recommended from International Commission on Radiological Protection agency (ICRP 2007). ***Conclusions:*** Radium, shows good relationship with radon exhalation rate in soil. Good correlation observed between lung cancer per year per million people and radon concentrations for all soil samples.

Keywords: *Radiological hazard, natural radioactivity, SSNTDs, HPGD.*

INTRODUCTION

CR-39 plastic detector is one of the most popular radiation detection, because its high sensitivity to protons and alpha particles (1), CR-39 is used in many fields that contribute to the detection of radioactive materials, including radon gas, which is one of the most dangerous radioactive materials since it is a gas, tasteless and odorless (2).

Radon ^{222}Rn is a noble element produced from the terrestrial elements uranium isotopes ^{238}U, ^{235}U and ^{232}Th.The molecules of radon gas diffuse out through pore spaces in soils and rocks and mix with the atmosphere. The radon gas has three isotopes, ^{222}Rn resulted by the decay of ^{238}U series, ^{220}Rn resulted by the decay of ^{232}Th series and ^{219}Rn a decay produced from the chain originating with U-235 (3). Inhalation of radon gas leads to lung cancer and this occurs in the unventilated environments where the concentration of gas and its daughters increases.

Literature review, from previous studies, it claims that radon gas concentration in soil effects on humans, plants and animals. It is measured in different places such as: Saudi Arabia [4], Bulgaria [5] and Egypt [6]. Radon rates of entry into pore spaces are clearly important to determining and then into atmosphere and the radon rates depend on the concentration of radium in the bedrock and on the permeability of the soil [7.8]. During decay of Radium, radon gas is formed. Long exposure time Radon and his daughters will cause health changes in respiratory functions that may result lung cancer [9].

The activity levels of ^{238}U, ^{232}Th and ^{40}K obtained in the current study were compared with the results of the literature as shown in Table 3 for soil samples in different countries. Moreover, a comparison has been made between the results of the current study and other studies in Egypt.

New studies have shown that the emanation of radon from the soil is dangerous to human health. The UK Health Agency report shows that radon gives higher doses of radiation than any other source [10]. WHO data on radon indicate that 3 to 16 percent of lung cancers are caused by internal radon.

Natural radioactivity (Uranium, Thorium and Potassium) are associated with a huge variety of stones and is mainly due to the supplement minerals they contain. Always human have been exposed to natural ionizing radiation, called extraterrestrial and terrestrial radiation [11, 12]. Extraterrestrial origin of radiation is about 30 $nGyh^{-1}$, while that of terrestrial origin is due to the presence of naturally occurring radionuclides; mainly potassium, rubidium and the radionuclides in the decay chains of thorium and uranium [2].

Ornamental stone is mined by underground and surface mining operations. Decorative stone is used in the decoration work for floors and walls. Therefore, scientists pay great attention to the study of the environment surrounding the places of extracting ornamental stones. Pollution by radioactive atoms that comes from decay of ^{238}U, ^{232}Th and ^{40}K is monitored in order to preserve the environment and public health [13-18].

The aim of this study is to calculate radon concentration and exhalation rates of radon using the CR-39 detector in some kinds of ornamental stones from Wadi Hodein area, Egypt and for the same samples determine the natural radioactivity of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K by using HPGD. These results are of great interest in the study of environmental radiation protection, where marble and granite are widely used as building materials and decorations, including the inner cover.

MATERIALS AND METHODS

The study area

The Wadi Hodein area contains a variety wide of late Precambrian igneous and metamorphic rocks, represented by gneisses, serpentinites, metagabbros, metasediments, metavolcanics, metagabbro-diorite, granodiorite and granitoids. The Wadi Hodein metavolcanics (WHV), including G. Khashab and G. El Anbat, appear for one of the significant metavolcanic suites in the southern part of the Nubian Shield. The Wadi Hodein area is located in the southern extremity of the south Eastern Desert of Egypt and some 20 km west of Shalatin at the Red Sea coast. It is bounded by Latitudes 23° 30 to 23° 50 N and longitude 35° 30 to 35° 41 E covering area about 200 km^2 (figure 1). There are many activities in Wadi Hodein area, such as the reclamation and cultivation of large areas of the valley lands and the establishment of poultry farms and towers for breeding pigeons, to be an urban agricultural community. Therefore, it is important to study the area radio logically to make sure it is free from any radiation danger.

Alpha measurement

At this time, 14 samples of soil were collected from (Wadi Hadin area in the South Eastern Desert of Egypt). Samples were prepared, weighed, and placed in a plastic room for a period of not less than a month, to obtain a radiation balance. A sheet of The CR-39 detector TASTRAK type, (Track Analysis System, Ltd., UK) is cut into a square whose side is 1.5 cm long. This detector features high sensitivity, optical transparency uniformity and uniformity on

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cylindrical cans used to monitor radon gas at the height of 8 cm from the soil. These cans were closed and stored for thirty days. Then the exposed detectors (CR-39) were collected and chemically etched by NaOH at 70 °C for six hours. The track densities (track/cm) on CR-39 detector were counted using the optical microscope [4, 19, 20].

The track density was used to determine the radon concentration C (Bq/m^3) according to the equation 1 [1, 4, 21, 22]:

$$C = \frac{\rho}{Kt} \quad (1)$$

Where; t is the time exposure, and K is the calibration factor for SSNTDs can be determined by the standard Rn-chamber K = 0.045987 cm^{-2} d^{-1} / Bqm^{-3} pathways of radon [23].The equilibrium radon concentration C_{eq} (Bq/m^3) is given by the effective exposure time T_e and is calculated using the equation 2:

$$C_{eq} = \frac{C_i}{T_e} = \frac{\rho}{KT_e} \quad (2)$$

Where; $T_e = t - \frac{1-e^{-\lambda t}}{\lambda}$, λ is the constant decay of radon and C_i ($Bqm^{-3}.d$) is the radon concentration integration. The surface exhalation rate ($mBqm^{-2}\cdot h^{-1}$) of the sample for the release of radon can be calculated by the equation 3 exhalation rate:

$$E_a = \frac{C_i V\lambda}{A\,T_e} \quad (3)$$

Where A is the area of cup (m^2), V is the effective volume of the cup in m^3, λ the decay constant for radon in h^{-1}, and T the exposure time in hours.

The exhalation rate of mass ($mBqkg^{-1}\cdot h^{-1}$) in the samples is measured using the equation 4 [4, 23-25]:

$$E_m = \frac{C_i V\lambda}{MT_e} \quad (4)$$

Where; M is the sample mass (kg) m

The radium content effective Ra_{eff} (Bq/Kg) is calculated using the relation (5) [4, 18, 24]:

$$Ra_{eff} = \frac{E_m}{\lambda} \quad (5)$$

The annual effective dose was calculated by using three factors, which are the dose conversion factor D (9 $nSv/hr/bq/m^3$) and the internal balance factor of radon and its sons F (0.4) and the value of time during the year that passes through exposure to radon gas (8760 hy^{-1}). The equation 6 is used to determine the annual effective dose rate (mSv/year) [2]:

$$AED_R = C \times D \times F \times T \quad (6)$$

The lung cancer cases per year per million person (CPPP), was obtained using the equation 7 [23-26]:

$$(CPPP) = AED_R \times (18 \times 10^{-6}\ mSv^{-1}.y) \quad (7)$$

Gamma measurement

The solid samples for gamma activity analysis we prepare 100 cc from each sample and placed in a polyethylene container, these were completely sealed, weighed, and were left for at least one month to allow radioactive equilibrium. A coaxial hyper pure Ge detector with volume 76.11cm^3 is made of highly pure Germanium crystal, model GMX 60P4 and its electronic circuits. Crystalline dimensions are 69.5 mm in diameter and 86.7 mm in length. Its relative effectiveness is 60% peak to Compton 56: 1. FWHM at 1.33 MeV of ^{60}Co is 2.3 kV, and 1.10 kV at 5.9 kV from 55Fe. Collected spectra are analyzed using the ORTEC Maestro software package with the other measuring components in a singles gamma ray spectrometer and a Maestro, H-EG&G ORTEC MCA card mounted on an IBM compatible PC together with simple programs to estimate quantitatively the elements present in the samples under investigation. The absolute efficiency calibration curve for the spectrometer was carried out together with the energy calibration. To reduce the background radiation the detector was placed surrounded by a lead cylindrical shield lined with a copper layer inside it and covered with a movable cover. The back ground was monitored to be taken in consideration. The γ ray energy transition used to measure the U concentration, Th and K was calculated using the different gamma transitions of every isotope

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present and the average values are given.

The gamma spectra, for the different samples were collected for at least twenty four hours, the back ground was taken in consideration when the quantitative calculations of the uranium, thorium and potassium were made.

The equivalent Radium activity is a widely used hazard index. It is determined by equation 8, (27, 28, 7):

$$Ra_{eq} = A_{Ra} + 1.43\ A_{Th} + 0.077A_K \qquad (8)$$

Where; A_{Ra} is the activity of ^{226}Ra, A_{Th} is the activity of ^{232}Th and A_K is the activity of ^{40}K, in Bq/kg.

The hazardous parameters of radiation

There are two important parameters external hazard radiation and internal radiation hazard obtained from Ra_{eq} expression through the proposition. The maximum value of these parameters must be equal to the unity in order to reduce the risk of radiation. The external hazard index (H_{ex}) is given by the equation 9:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (9)$$

Where ($H_{ex} \leq 1$) is external hazard index. A_{Ra}, A_{Th} and A_K are the activity concentrations, expressed in (Bq/kg) for radium, thorium and potassium respectively. The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and its short-lived progeny and is giving by the equation 10 (27):

$$H_{ex} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (10)$$

Where; ($H_{in} \leq 1$) is internal hazard index. The A_{Ra}, A_{Th} and A_K are the activity concentrations, expressed in (Bq/kg) for radium, thorium and potassium respectively.

The dose conversion factors F are used to convert the activity concentrations of ^{238}U series, ^{232}Th series and ^{40}K into doses (nGy/h per Bq/kg) as 0.427, 0.662 and 0.043, respectively. The absorbed dose rate D (nGy/h) is calculated for each radionuclide using equation 11:

$$Dab = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_k \qquad (11)$$

The annual effective dose AED (mSv/y) in air outdoors was measured by conversion factor F of 0.7×10−6 Sv/Gy and calculated by equation 12 (28,7):

$$AED = Dab \times T \times F \qquad (12)$$

Where: T is the outdoor occupancy time (0.2×24 h×365.25 d=1753 h/y).

The radiation level index of gamma radiation hazard ($I\gamma$) associated with the natural radionuclides. It is assessed by the European Commission (EC), which should be lesser than unity (27) and calculated by equation 13:

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \qquad (13)$$

$I\gamma$ May be used to estimate the level of γ radiation hazard associated with natural radionuclides in the soil used.

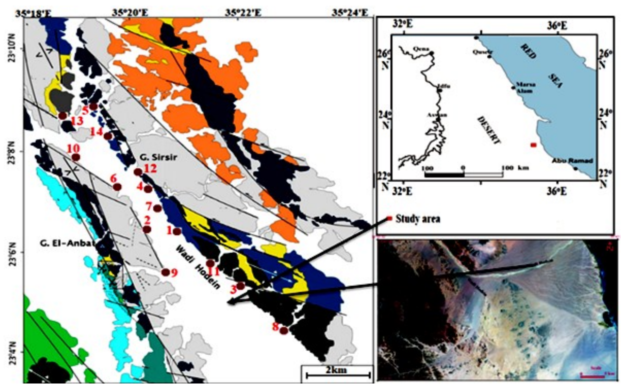

Figure 1. The Wadi Hodein map of the sampling points.

RESULTS

Measurements of Gamma by using HPGD

The concentrations gamma activity of solid samples collected from Wadi Hodein in the southern Eastern Desert of Egypt were measured by HPGD. This activity depends on the gamma ray emitted from radioactive nuclei in the sample. The activity concentration of ^{226}Ra and 222Rn daughter are listed in table 1 for all sample and show that the activity of Ra-226 is ranged from 6.37 to 26.27 Bq/Kg with main

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value 12.88±0.29 Bq/Kg. The activity range of radon daughter Pb-214 and Bi-214 are from 6.72 to 25.57 Bq/Kg and from 6.59 to 25.26 Bq/Kg, respectively. The mean value of radon concentration of is 13.09 ± 1.15 Bq/Kg.

The activity concentrations for ^{238}U, ^{232}Th and ^{40}K are presented in table 1. The results show that the concentration of ^{238}U, ^{232}Th and ^{40}K ranged from 6.64 to 25.50, from 6.62 to 26.30 and from 183.94 to 945Bq/kg respectively. The average concentration for ^{238}U, ^{232}Th and ^{40}K were 13.04±1.15 12.33±1.54 and 445.33±23.54 Bq/Kg, respectively.

Concerning the values of the equivalent radium (Ra_{eq}) were ranged from 30.22±2.12 Bq/kg to 140.26±6.55 Bq/kg, with a mean value of 66.36±9.89 Bq/kg. The value of absorbed dose D_{ab} varies from 14.82±1.04 to 69.45±4.24 nGy/h with an average value of 32.86±2.64 nGy/h. the 15% of these values of absorbed dose D_{ab} are higher than the public average 57 nGy/h [8]. The annual effective dose (AED) was found that in the range 0.02±0.001 to 0.09±0.01 mSv with mean value 0.04±0.003mSv. All values of AED were lower than the recommended limits for the radiation which reported by UNSCEAR [7,8] (for public is 1 mSv/y and for worker 5 mSv/y).

According to report of UNSCEAR [29,7] the representative gamma index (Iγ) , internal hazard index (H_{in}) and external hazard index (H_{ex}) should be less than or equal one. The result shows that the mean value of the representative gamma index (Iγ), internal hazard index (Hin) and external hazard index (H_{ex}) were 0.24±0.02, 0.22±0.02 and 0.04±0.003 respectively. All values of them were less than the recommended values.

The measurement of radon by using CR-39

The radon concentration related their type of soil samples combined from Wadi Hodein in the southern Eastern Desert of Egypt are shown in figure 2. The concentration of radon varied from 777.22±49.83 Bq/m^3 in H_8 to 26.28±9.53 Bq/m^3 in H_2 with an average value of 265.96±25.45 Bq/m^3. It is shown from the results that the concentration of radon changes appreciably in different samples. It is since the samples of soil collected from different sites may have appreciably large uranium contents which results in higher radon emanation rates. The results of samples show that 71.42% of the radon gas concentrations in soil is below the allowed limit while 28.57% of radon concentration were larger than the limited recommended from (ICRP) agency which is (200 Bq/m^3) [30,31].

The annual effective dose has maximum value 24.42±1.57 mSv/y in sample H8 with mean value 8.39±0.80 mSv/y (figure 3). The results show that 28.57 % of AED were higher than the allowable limits recommended from ICRP agency which is (3 -10 mSv/y) [30, 25].

Table 4 summarizes the results of rate of exhalation for radon in soil, lung cancer cases per year per million person (CPPP) and the concentration of Radium. It can be seen from the results that the radon exhalation rate varies from 79.25±5.10 mBq/m^2.h, 4.98±0.32mBq/Kg.h to 2.69±0.98 mBq/m^2.h, 0.17±0.06 mBq/Kg.h with a mean value 27.22±2.60 mBq/m2.h, 1.71±0.16 mBq/Kg. h. The results showed that the radium values detected in the samples were within the permissible limits, which is the internationally recorded safe limit (370 Bq kg^{-1}) [7, 8]. The highest measured radium value was 67.10 ± 4.32 Bq / Kg in the sample H8 and the average value has 23.05±2.21 Bq / Kg. Also, the radium values were within the limit's values measured in the soil of India are (207.00 - 2.50 Bq/kg) [32]. The measured radon exhalation rates were clearly correlated with samples. It is evidence of a change in the concentration of uranium from one sample to another.

The lung cancer cases per year per million person (CPPP) in different sample were yielded from 439.49±28.29 to 14.92±5.41with average value 150.97±14.44 per million persons. The results indicated that H4 and H8 were higher than the internationally permitted limit, while the rest of the samples were less than the permissible limit of 230 - 170 per million people recommended by [33].

Comparison of present study with other studies

The activity levels of ^{226}Ra-, ^{232}Th- and ^{40}K obtained in the current study were compared

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with the results of the literature as shown in table 3 for soil samples in different countries. Moreover, a comparison has been made between the results of the current study and other studies in Egypt. There is a difference between the values shown in the table, depending on the different concentration of radioactive nuclei from one place to another. The mean of the results values in the current study was in agreement with most of the results shown in table 3.

Table 1. The concentration of radioactive level for different radioactive nuclei of different collected sample.

Radioactive elements	Activity concentration of Uranium (Bq/Kg)				Average Activity Bq/Kg		
	Ra-226	Daughter of Rn-222					
		Pb-214	Bi-214	Bi-214			
Energy of gamma KeV	186	352	609	1765	U-238	Th-232	K-40
H1	7.08±0.12	7.73±0.43	7.33±0.34	6.59±0.32	7.18±0.48	7.54±0.32	203.27±8.66
H2	6.37±0.05	6.72±0.12	6.89±0.20	6.59±0.06	6.64±0.22	6.62±0.58	183.94±16.10
H3	7.88±0.05	7.86±0.23	7.76±0.21	7.46±0.05	7.74±0.19	7.79±0.15	213.00±3.97
H4	13.29±0.53	15.69±1.37	18.48±0.97	15.83±0.87	15.82±2.12	10.24±1.35	945±24.42
H5	8.25±0.13	9.01±0.44	8.56±0.36	7.78±0.23	8.40±0.52	9.79±0.07	254.79±1.80
H6	8.64±0.08	8.79±0.27	8.12±0.21	8.19±0.08	8.44±0.33	9.48±0.59	203.37±12.62
H7	9.07±0.08	9.68±0.05	9.73±0.08	9.76±0.07	9.56±0.33	11.24±0.24	230.00±4.88
H8	26.24±0.79	19.33±2.83	23.85±3.03	25.94±0.98	23.84±3.38	27.73±3.89	945.00±32.49
H9	13.29±1.13	13.83±3.33	16.31±3.04	23.18±1.41	16.65±4.84	18.44±1.01	390.00±21.3
H10	11.95±0.22	12.05±1.32	11.13±1.02	9.66±0.35	11.20±1.21	12.53±0.61	254.79±12.43
H11	26.27±0.15	25.57±0.34	25.26±0.37	24.91±0.14	25.50±0.33	26.30±0.69	570.00±14.85
H12	21.63±0.37	18.28±1.78	21.08±0.93	21.58±0.68	20.64±1.78	24.02±1.81	891.00±67.10
H13	12.19±0.23	13.51±0.70	14.45±0.41	13.04±0.63	13.30±0.72	7.21±1.50	738.00±53.88
H14	8.25±0.14	7.24±0.26	7.22±0.09	7.67±0.18	7.60±0.25	7.53±0.40	212.49±11.22
Range	6.37-26.27	6.72-25.57	6.89-25.26	6.59-24.91	6.64-25.50	6.62-26.30	183.94-945
average	12.88±0.29	12.52±0.96	13.29±0.80	13.44±0.43	13.04±1.15	12.33±1.01	445.33±17.07

Table 2. The activity concentration for U-238, Th-232 and K-40 Bq/kg.

Samples	The Hazardous Parameters Radioactive					
	Ra_{eq} (Bq/Kg)	D_{ap} (nGy/h)	AED (mSv/y)	H_{ext}	H_{int}	I_{γ}
H1	33.31±1.25	16.34±0.16	0.02±0.001	0.09±0.02	0.11±0.04	0.12±0.005
H2	30.22±2.12	14.82±1.04	0.02±0.001	0.08±0.03	0.10±0.01	0.10±0.008
H3	35.41±0.56	17.35±0.28	0.02±0.0004	0.10±0.02	0.12±0.002	0.12±0.002
H4	100.69±12.04	51.90±6.25	0.06±0.009	0.27±0.05	0.31±0.03	0.39±0.050
H5	41.83±0.37	20.50±0.18	0.03±0.0002	0.11±0.03	0.14±0.001	0.15±0.001
H6	37.68±1.89	18.28±0.92	0.02±0.001	0.10±0.03	0.13±0.01	0.13±0.007
H7	42.79±0.80	20.73±0.38	0.03±0.001	0.12±0.03	0.14±0.002	0.14±0.003
H8	140.26±6.55	69.45±4.24	0.09±0.01	0.38±0.13	0.45±0.05	0.49±0.066
H9	70.25±14.65	34.10±2.02	0.04±0.002	0.19±0.06	0.23±0.01	0.19±0.016
H10	49.71±2.05	24.02±0.99	0.03±0.001	0.14±0.04	0.17±0.01	0.17±0.008
H11	107.99±2.27	52.34±1.10	0.06±0.002	0.29±0.08	0.36±0.01	0.37±0.009
H12	124.96±8.12	62.23±4.06	0.08±0.006	0.34±0.09	0.40±0.02	0.45±0.033
H13	78.69±14.23	40.61±7.43	0.05±0.010	0.21±0.05	0.25±0.04	0.31±0.060
H14	35.25±1.57	17.29±0.77	0.02±0.001	0.10±0.02	0.12±0.01	0.12±0.006
Range	30.22-140.26	14.82-69.45	0.02-0.09	0.08-0.38	0.10-0.45	0.10-0.49
Average	66.36±9.89	32.86±2.64	0.04±0.003	0.04±0.003	0.22±0.02	0.24±0.02

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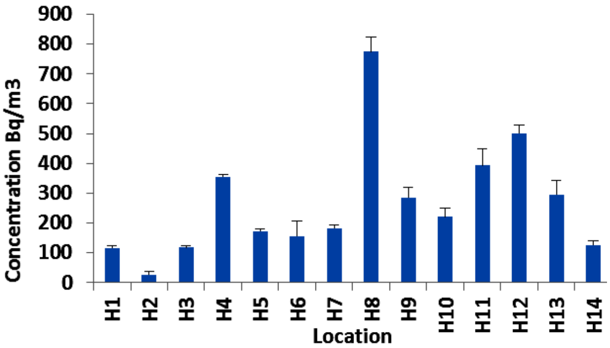

Figure 2. The concentration of radon with different samples by using CR39.

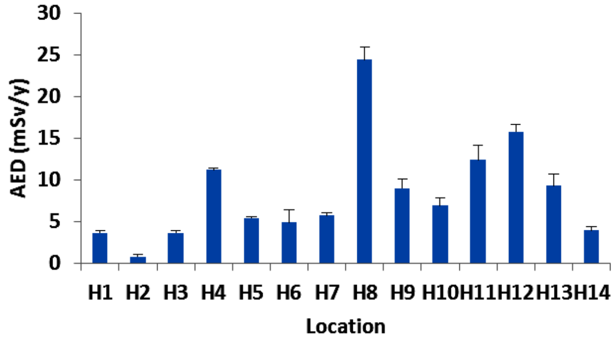

Figure 3. The annul effective dose with different location by using CR39.

Table 3. Comparison of present study with mean value of radioactive concentration of Ra -226, Th-232 and K-40 from other countries.

Country	Mean value of radioactive concentration by (Bq/Kg)			References
	^{226}Ra	^{232}Th	^{40}K	
Egypt	13.04	12.33	445.33	Present work
Egypt	35.17	25.66	187.30	(34)
Egypt	132.00	198.00	236.00	(35)
Egypt	11.30	9.83	411.32	(36)
Egypt	56.00	53.00	120.00	(37)
Vietnam	60.00	95.00	1073.00	(38)
India	8.00	25.00	275.00	(39)
Turkey	290.00	532.00	1160.00	(40)
Saudi Arabia	26.41	10.86	298.50	(16)
Spain	13.00	10.99	451.00	(41)
Thailand	12.00	19.00	344.00	(42)
Brazil	192.00	1673.00	217.00	(43)

Table 4. The exhalation rate for radon in soil, lung cancer cases per year per million person (CPPP) and the concentration of radium.

The Samples	Ra_{eff} Bq/Kg	Lung cancer /10^6 person	The exhalation rate*	
			E_A mBq/m^2.h	E_m mBq/Kg.h
H1	10.05±0.67	65.83±4.36	11.87±0.79	0.75±0.05
H2	2.28±0.83	14.92±5.41	2.69±0.98	0.17±0.06
H3	10.17±0.55	66.60±3.60	12.01±0.65	0.75±0.04
H4	30.78±0.67	201.61±4.36	36.35±0.79	2.28±0.05
H5	14.96±0.55	97.98±3.60	17.67±0.65	1.11±0.04
H6	13.47±4.38	88.21±28.70	15.90±5.17	1.00±0.32
H7	15.86±0.97	103.89±6.34	18.73±1.14	1.18±0.07
H8	67.10±4.32	439.49±28.29	79.25±5.10	4.98±0.32
H9	24.74±2.99	162.01±19.60	29.21±3.53	1.83±0.22
H10	19.12±2.59	125.24±16.97	22.58±3.06	1.42±0.19
H11	34.08±4.91	223.21±32.12	40.25±5.79	2.53±0.36
H12	43.47±2.26	284.68±14.80	51.33±2.67	3.22±0.17
H13	25.64±3.92	167.93±25.66	30.28±4.63	1.90±0.29
H14	10.99±1.28	72.00±8.40	12.98±1.51	0.82±0.10

*EA: Area exhalation rate, Em: Mass exhalation.

DISCUSSION

Characterization of gamma sources in the Wadi Hodein area

Based on the results of the gamma ray measurements of the radionuclides emitted from the samples collected from Wadi Hodein. The results showed a difference in radioactivity based on the values of radioactive nuclei in the soil. It was found that the concentrations of naturally occurring radionuclides for ^{226}Ra and ^{232}Th were lower than the exemption level 32 and 45, respectively. Regarding ^{40}K, the results showed higher values than the exemption levels which is 412 [7]. Samples containing high values of ^{40}K distributed along the valley were (11, 12, 13, 1, 8). This indicates the diversity of the presence of radioactive nuclei in the valley and their lack of concentration in one region. The valley contains multiple activities, including agricultural, industrial and residential, so any increase in the level of radiation is of great importance in preserving the environment.

The obtained results showed that the average dose of absorbed gamma emitted from soil in Wadi Hodein region contains values higher than the permissible international value (i.e. 57 ng / hour) [7] due to the presence of high levels of radionuclide concentration in the soil. Samples containing high doses are (11, 12 ,4, 8), while the sample (13) value was high, but less than permissible. This leads to increased radiation doses towards the public and workers in the valley.

Regarding the average value of the external risk index (H_{ex}), the internal risk index (H_{in}) and

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the representative gamma index (Iγ), the results showed that it was less than one in all samples. This gives the risk rates of gamma in the region safe for workers.

Characterization of radon in the Wadi Hodein area

The amount of radon concentration in the environment depends on the concentration of radionuclides generated from natural sources as well as the permeability of the soil. The results shown in figure 2 showed that the samples (4, 8, 11 and 12) contain high levels of radon. These samples are found in different places in the valley. This means that the possibility of large amounts of radon along the valley is very large, which leads to exposure of workers and residents to high levels of radon gas. The results are consistent with the concentration values of radioactive nuclei (U, Th, Ra). This means that the radon values depend not only on uranium but also with the values of other radioactive nuclei that cause its presence. The results also showed that the values measured with CR-39 were more consistent with the values of the concentrations. Therefore, CR-39 is more accurate in determining and monitoring radon values. Regarding the radiation dose, it was consistent with the radon values that were measured, and this is illustrated in figure 3. The high levels of the radiation dose make the necessity of pursuing research in the Wadi Hodein necessary for maintaining health and the environment.

CONCLUSION

The results show that 62.5% of the radon gas concentrations and AED in soil was below the allowed limit recommended by (ICRP) agency which is (200 Bq/m^3 and 3 -10 mSv/y) respectively. There was a significant correlation between increasing the annual absorbed dose of radon and digestive and respiratory cancer. This relationship was observed between calculated dose values (CPPP) and radon gas concentration in the samples.

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