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Measurements of natural radionuclides in soil samples from Upper Egypt

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Abstract This paper presents the results of natural radioactivity measured for the soil of Qena using gamma-ray spectrometry at ZSR, Hanover University, Germany. Soil samples of radioactive concentrations of ^{238}U-series (^{234}Th, ^{214}Pb, and ^{214}Bi), ^{232}Th-series (^{228}Ac, ^{212}Pb, and ^{208}Tl) and ^{40}K were analyzed. Three objectives were set: (1) activity levels by surface soil sampling at 0~30 cm depth, (2) dose rates of gamma radiation, radium equivalent, index hazard, and effective dose, and (3) ambient dose rates.

Key words Soil, Environmental radioactivity, Gamma spectrometry, Radiation exposure, Ambient dose

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1 Introduction

The Qena governorate in Upper Egypt is best known as the location of some of Egypt's most famous Pharaonic temples. The governorate is located about 535~650 km south of Cairo on the upstream of the Nile River (Fig.1). Qena is bordered on the north by Sohag and on the south by the Aswan governorate. The Nile valley is at its narrowest in Egypt here and the arable land, a green strip only 1 or 4 km on each side of the river, is bordered by barren desert on both sides.

Potential terrestrial sources of naturally occurring elevated radiation levels have been identified in Egypt. Thus, efforts are currently being undertaken to create a natural radiation database, in the form of a radiation level map of natural radioactivity, to be used to assess the associated radiation risk to public. Ambient dose rates were determined with a FH 40 G-L System-Radiometer Instruments dosimeter in many sites in Upper Egypt.

Human beings are exposed to natural gamma radiation emitted by the primordial radionuclide ^{40}K and the radionuclides of the different decay chains that is an omnipresence with ^{238}U and ^{232}Th in soi1 and rocks al1 the time. Humans and other organisms in the environment are exposed to radiation and radionuclides from natural sources, meanwhile people can be exposed to radiation while settling on contaminated soils.

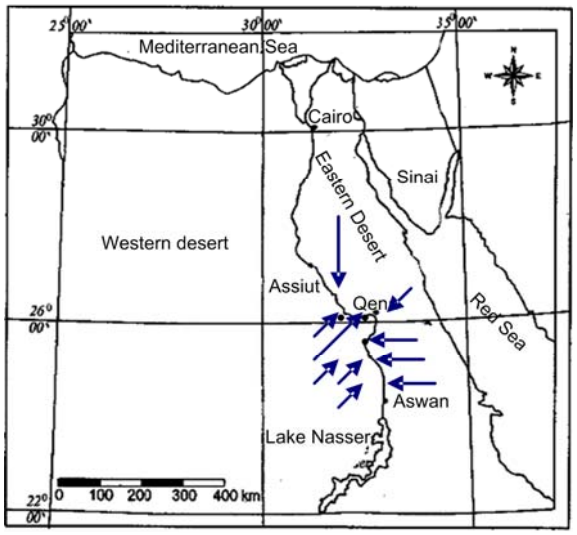

Fig.1 Soil samples locations in Upper Egypt.

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2 Materials and methods

2.1 Soil samples collection and preparation

Soil samples were collected at ten sites (Fig.1). Each sample was taken to a depth of 0~30 cm at a chosen point, data from Global Positioning System (GPS) were used for tracking the data recorded. In order to obtain a representative sample, the collected soil was mixed together, sieved to remove stones and pebbles, and crushed to pass through a 2-mm mesh sieve to homogenize it, then, the soil samples were air-dried for several days, placed in an oven at 100℃ for 72 h and weighed. Finally, a split of each prepared sample was packed in a 250-mL polypropylene bottle, which was sealed and left for at least 4 weeks before counting by gamma spectrometry in order to ensure that radioactive equilibrium was reached between ^{226}Ra, ^{222}Rn, and ^{222}Rn progeny[1].

2.2 Detectors and efficiency calibration

The Gamma spectrometry system, a p-type HPGe coaxial detector, shielded with 10 cm lead and 2 mm copper, was used for bulk counting of environmental samples. The detector is a vertical type, model GEM 50198-P(35% relative efficiency), with an energy resolution of 1.78 keV (FWHM) at E_γ = 1332 keV.

Detector efficiency calibration was carried out by using a mixing radionuclides gamma-ray reference standard QCY48(obtained from Physikalisch-Technische Bundesanstalt PTB, Germany) containing ten γ-emitters in the energy range 59.54 to 1836 keV (Fig.2). The same geometry was used for all the samples[2].

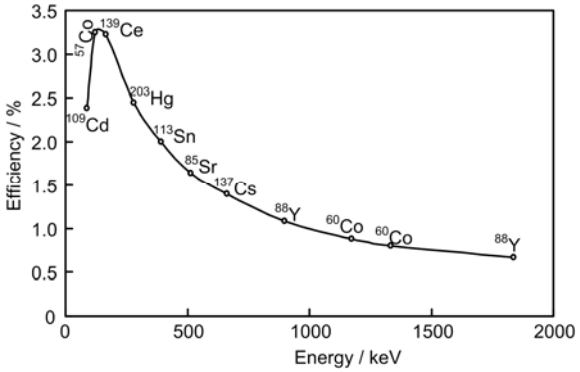

Fig.2 Efficiency calibration for HPGe detector.

2.3 Calculations

2.3.1 Activity concentrations

Following the spectrum analysis, counting rates for each detected photopeak and activity per mass unit (radiological concentration) for each of the detected nuclides are calculated. The specific activity (in Bq·kg^{-1}) is given by

$$A_{\text{specific}} = (N_{\text{s.n}}/t_{\text{s}} - N_{0.\text{n}}/t_0)/(I_\gamma\, \varepsilon\, m) \quad (1)$$

where $N_{\text{s,n}}$ is the net counts in a given peak area for a sample, t_{s}=18~24 h is the counting time for the sample, $N_{0,\text{n}}$ is the net counts in a given peak area for background, t_0=72 h is the counting time for background, ε is the detection efficiency, I_γ is the number of gamma photons per disintegration, and m is the mass in kg of the measured sample.

The ^{238}U activity concentration was calculated from the mean value of gamma transitions obtained from the peaks of ^{234}Th (63.28 and 92.37 keV), and the ^{226}Ra activity concentration was calculated from the mean value of ^{214}Pb (295.22 and 351.93 keV) and ^{214}Bi (609.31 and 1120 keV).

Each tabulated value for the ^{232}Th series concentration was averaged from three measurements of the peaks of ^{212}Pb (238.63 keV), ^{228}Ac (209.25 keV, 338.32 keV, 911.2 keV and 968.97 keV) and ^{208}Tl (583.19 keV). The 1461 keV gamma of ^{40}K was used to determine the ^{40}K concentration in different samples.

The ISO standard[3] is used to estimate the uncertainty of our measurement results such as efficiency and activity of radionuclides in soil samples. The total uncertainty value is composed of the random and systematic errors in all of the factors involved in producing the final nuclide concentration result.

2.3.2 Assessment of radiological hazards

2.3.2.1 Estimation of absorbed dose rate

The conversion factors[4] were used to compute the absorbed dose rate in air per unit of specific activity concentration in soil for ^{40}K, ^{226}Ra and ^{232}Th as in Eq.(2). The conversion factor[5] for photon equivalent dose rate in air kerma is 1.15 Sv·Gy^{-1} in Eq.(3).

$$D(\text{nGy·h}^{-1}) = 0.0417A_{\text{K}} + 0.462A_{\text{Ra}} + 0.604A_{\text{Th}} \quad (2)$$

$$D(\text{nSv·h}^{-1}) = (0.0417A_{\text{K}} + 0.462A_{\text{Ra}} + 0.604A_{\text{Th}}) \times 1.15 \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in $Bq \cdot kg^{-1}$, respectively. The natural radioactivity of building materials is usually determined from ^{226}Ra, ^{232}Th and ^{40}K contents.

2.3.2.2 Radium equivalent activity

Radium equivalent activity is an index that has been introduced to represent the specific activities of ^{226}Ra, ^{232}Th and ^{40}K by a single quantity, which takes into account the radiation hazards associated with them. This first index can be calculated according to[6]

$$Ra_{eq} = C_{Ra} + (10/7)\ C_{Th} + (10/130)\ C_K \quad (4)$$

where C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in $Bq \cdot kg^{-1}$, respectively.

2.3.2.3 Representative level index

Another radiation hazard index called the representative level index ($I_{\gamma r}$) is defined as follows[7]:

$$I_r = (1/150)\ C_{Ra} + (1/100)\ C_{Th} + (1/1500)\ C_K \quad (5)$$

where C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in $Bq \cdot kg^{-1}$, respectively.

2.3.2.4 Annual effective dose rates

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose ($0.7\ Sv \cdot Gy^{-1}$) and outdoor occupancy factor (0.2) proposed by UNSCEAR[8] were used. The effective dose rate in unit of $mSv \cdot a^{-1}$ was calculated by the following formula:

Effective dose rate ($mSv \cdot a^{-1}$) =

$$\text{Dose rate } (nGy \cdot h^{-1}) \times 8760\ h \times 0.2 \times 0.7\ Sv \cdot Gy^{-1} \times 10^{-6} \quad (6)$$

3 Results and discussions

3.1 Terrestrial radionuclides

The activity concentrations of the primordial radionuclides have been detected and measured in the ten locations across the region. ^{137}Cs was not detected in these samples, indicating that the radioactivity in the region is still due to natural radioactive elements. The range and average values of the activity concentration of the natural radionuclides in each site are presented in Tables 1 and 2.

Table 1 Activity concentration of ^{238}U-series (in $Bq \cdot kg^{-1}$) in soil samples

Sample No	^{238}U (^{234}Th)	^{226}Ra		
		Mean (^{214}Pb, ^{214}Bi)	^{214}Pb	^{214}Bi
1	5.5 ± 0.6	8.5 ± 1.5	8.3 ± 1.2	8.7 ± 1.0
2	47.3 ± 15	12.4 ± 1.5	13.0 ± 1.8	11.8 ± 1.0
3	32.5 ± 13	12.5 ± 1.1	13.0 ± 1.2	11.3 ± 1.0
4	46.4 ± 14	16.1 ± 1.5	17.0 ± 1.8	14.8 ± 1.0
5	46.2 ± 15	13.8 ± 1.5	13.0 ± 1.8	14.3 ± 1.0
6	34.3 ± 13	14.1 ± 1.5	13.0 ± 1.8	14.6 ± 1.0
7	47.9 ± 17	11.2 ± 1.6	11.2 ± 2.0	11.1 ± 1.0
8	28.6 ± 15	12.5 ± 1.5	12.9 ± 2.0	12.2 ± 1.0
9	20.0 ± 15	11.3 ± 1.5	12.6 ± 2.0	10.1 ± 1.0
10	24.4 ± 15	12.5 ± 1.5	12.7 ± 2.0	12.3 ± 1.0
Mean	33.3 ± 13.5	12.5 ± 1.5	12.9 ± 1.7	12.1 ± 1.3

Table 2 Activity concentration of ^{232}Th-series and ^{40}K (in Bq·kg^{-1}) in soil samples

Sample No.	^{228}Ra(^{228}Ac)	^{228}Th			^{232}Th	^{40}K
		Mean ^{212}Pb, ^{208}Tl	^{212}Pb	^{208}Tl		
1	12 ± 2	10 ± 1	10 ± 1	8.1 ± 1	10.5 ± 1.3	148 ± 9
2	10 ± 2	11 ± 1	11 ± 1	9.9 ± 1	10.3 ± 1.6	239 ± 14
3	10 ± 1	10 ± 1	11 ± 1	9.1 ± 1	10.1 ± 1.4	189 ± 12
4	14 ± 2	12 ± 1	12 ± 1	11 ± 1	12.7 ± 1.5	224 ± 13
5	13 ± 2	12 ± 1	12 ± 1	11 ± 1	12.2 ± 1.7	249 ± 14
6	13 ± 2	14 ± 1	14 ± 1	13 ± 1	13.7 ± 1.6	191 ± 12
7	16 ± 3	16 ± 1	16 ± 1	16 ± 1	16.0 ± 2.2	291 ± 16
8	14 ± 2	10 ± 1	10 ± 1	10 ± 1	12.4 ± 1.9	238 ± 14
9	13 ± 2	12 ± 1	12 ± 1	12 ± 1	12.9 ± 1.9	237 ± 14
10	14 ± 2	11 ± 1	11 ± 1	11 ± 1	13.0 ± 2.0	229 ± 14
Mean	13 ± 2	11 ± 1	12 ± 1	11 ± 1	12.5 ± 1.7	223 ± 13

3.1.1 Uranium series

^{238}U, ^{226}Ra and other short-lived daughters were detected in all the soil samples. The ^{238}U and ^{226}Ra concentrations (Table 1), which were very low in all cases, are less than reported in different studies[9,10].

3.1.2 Thorium series and ^{40}K

The activity concentrations of ^{228}Ra, ^{228}Th, ^{232}Th and ^{40}K in soil are shown in Table 2. In general, the concentrations of ^{226}Ra and ^{232}Th in the soil are in most cases lower than the data reported by UNSCEAR[11]. World average concentrations are 30 and 25 Bq·kg^{-1} for ^{226}Ra and ^{232}Th, respectively. And the typical concentration ranges are 10~14 Bq·kg^{-1} for ^{228}Ra and 10~13 Bq·kg^{-1} for ^{232}Th. The concentrations of ^{40}K are in most cases lower than the world data of 370 Bq·kg^{-1}[12].

3.2 Ambient dose rate

Ambient gamma dose rates were measured in air at 1.0 m above the ground surface every five minute using the FH 40 G-L System. The measured ambient dose rates due to gamma radiation from the naturally occurring radionuclides in soil in Qena and Aswan governorates are given in Table 3. The dose rate varies from 57 to 130 nSv·h^{-1} with a mean value of 89±18 nSv·h^{-1} in the west site of river Nile. But the value in the east site is 79±18 nSv·h^{-1} excluding the 250 nSv·h^{-1} measured at (32º 48’ 56’’ E, 25º 06’ 44’’ N), where phosphate production is the major industry[13].

3.3 Gamma dose rate and hazard indexes

Table 4 shows the gamma ray activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq·Kg^{-1}in ten positions. It shows mean activity levels of ^{226}Ra, ^{232}Th and ^{40}K measured in the soil from Qena. It can be seen that the ^{226}Ra activity ranges from 8.5 to 16.1 Bq·kg^{-1}, the ^{232}Th from 10.1 to 14.9 Bq·kg^{-1} and the ^{40}K from 148 to 249 Bq·kg^{-1}. The ^{40}K activity is higher than ^{232}Th and ^{226}Ra in all the samples.

The radium equivalent activities of each material were estimated using Eq.(4).The mean value of radium equivalent activities of all soil samples is 47.62±4.96 Bq·kg^{-1}.

Humans are exposed to different sources of radiation in the environment, but natural sources deliver the highest radiation dose that people normally receive. The average annual dose from natural sources is 2.4 mSv which is a reference level representing the range 1~10 mSv·a^{-1} and in extreme cases to 1 Sv or more[8,14].

Table 3 Ambient dose rate measured in both sites of Nile River from Nag-Hamadi to Idfo on November 2, 2006

Site No.	West site of Nile River		Measured $nSv \cdot h^{-1}$	Site No.	East site of Nile River		Measured $nSv \cdot h^{-1}$
	Longitude (E)	Latitude (N)			Longitude (E)	Latitude (N)	
1	32º 17’ 58’’	26º 00’ 43’’	102	1	32º 16’ 49’’	26º 01’ 16’’	60
2	32º 25’ 30’’	26º 03’ 47’’	115	2	32º 20’ 29’’	26º 05’ 07’’	90
3	32º 31’ 02’’	26º 06’ 02’’	85	3	32º 31’ 36’’	26º 07’ 09’’	90
4	32º 34’ 34 ’’	26º 06’ 27’’	95	4	32º 34’ 34’’	26º 06’ 27’’	80
5	32º 37’ 58’’	26º 06’ 30’’	75	5	32º 37’ 58’’	26º 06’ 30’’	75
6	32º 37’ 58’’	26º 09’ 00’’	77	6	32º 37’ 58’’	26º 09’ 00’’	70
7	32º 44’ 45 ’’	26º 11’ 30’’	50.4	7	32º 40’ 14’’	26º 11’ 07’’	60
8	32º 44’ 21’’	26º 06’ 44’’	99	8	32º 44’ 21’’	26º 06’ 40’’	55
9	32º 44’ 22’’	26º 06’ 44’’	57	9	32º 44’ 22’’	26º 06’ 41’’	65
10	32º 46’ 02 ’’	26º 01’ 30’’	77	10	32º 45’ 02’’	26º 01’ 30’’	70
11	32º 45’ 19’’	25º 58’ 29 ’’	75	11	32º 45’ 19’’	25º 58’ 29’’	62
12	32º 43’ 41’’	25º 55’ 32’’	80	12	32º 43’ 31’’	25º 55’ 33’’	68
13	32º 43’ 41 ’’	25º 52’ 19’’	79	13	32º 43’ 41’’	25º 51’ 19’’	77
14	32º 43’ 51’’	25º 49’ 26’’	90	14	32º 43’ 51’’	25º 49’ 26’’	64
15	32º 41’ 37’’	25º 46’ 42’’	77	15	32º 41’ 32’’	25º 48’ 42’’	61
16	32º 39’ 11’’	25º 44’54’’	88	16	32º 39’ 11’’	25º 44’ 50’’	58
17	32º 37’ 32’’	25º 42’ 40’’	72	17	32º 42’ 52’’	25º 42’ 29’’	95
18	32º 33’ 26’’	25º 39’ 26’’	80	18	32º 36’ 12’’	25º 38’ 04’’	90
19	32º 28’ 17’’	25º 36’ 20’’	100	19	32º 30’ 23’’	25º 34’ 42’’	90
20	32º 28’ 29’’	25º 31’ 05’’	98	20	32º 30’ 43’’	25º 29’ 28’’	75
21	32º 32’ 11’’	25º 26’ 00’’	91	21	32º 34’ 08’’	25º 24’ 20’’	53
22	32º 32’ 42’’	25º 20’ 63’’	110	22	32º 34’ 35’’	25º 18’ 50’’	110
23	32º 33’ 27’’	25º 13’ 53’’	80	23	32º 36’ 37’’	25º 15’ 16’’	80
24	32º 36’ 24’’	25º 13’ 53’’	95	24	32º 38’ 58’’	25º 13’ 35’’	100
25	32º 39’ 07’’	25º 12’ 20’’	90	25	32º 42’ 00’’	25º 11’ 52’’	125
26	32º 42’ 01’’	25º 10’ 47’’	100	26	32º 44’ 33’’	25º 09’ 37’’	85
27	32º 44’ 02’’	25º 08’ 19’’	72	27	32º 48’ 25’’	25º 07’ 08’’	75
28	32º 46’ 21’’	25º 06’ 06’’	98	28	32º 48’ 56’’	25º 06’ 44’’	250
29	32º 49’ 25’’	25º 04’51’’	135	29	32º 51’ 02’’	25º 04’ 78’’	95
30	32º 51’ 30’’	25º 02’ 10’’	102	30	32º 52’ 58’’	25º 02’ 25’’	105
31	32º 52’ 29’’	24º 59’ 40’’	130	31	32º 55’ 30’’	24 º 59’ 34’’	80
Mean±SD			89±18	Mean±SD			84±35

Table 4 External gamma dose rate, Ra equivalent activity (R_{aeq}), representative level index (I_γ), and effective dose rate ($mSv \cdot a^{-1}$) from soil samples in Qena, Egypt

Sample No.	$^{226}Ra/Bq \cdot kg^{-1}$	^{232}Th / ^{40}K / $Bq \cdot kg^{-1}$	D / $nSv \cdot h^{-1}$	D / $nGy \cdot h^{-1}$	Ra_{eq} / $Bq \cdot kg^{-1}$	I_γ / $Bq \cdot kg^{-1}$	D_{eff} / $mSv \cdot a^{-1}$
1	8.5 ±1.5	10.5±1.3 148±9	18.9±2.2	16.5±1.9	34.9±4.1	0.26±0.03	0.020±0.002
2	12.4±1.6	10.3±1.6 239±14	25.2±2.6	21.9±2.3	45.6±4.9	0.35±0.04	0.030±0.003
3	12.6±1.2	10.1±1.4 189±12	22.8±2.1	19.8±1.9	41.5±4.1	0.31±0.03	0.020±0.002
4	16.1±1.6	12.7±1.5 224±13	28.1±2.5	24.4±2.2	51.5±4.7	0.38±0.03	0.030±0.003
5	13.8±1.6	12.2±1.7 249±14	27.8±2.7	24.1±2.3	50.4±5.1	0.38±0.04	0.030±0.003
6	14.2±1.6	14.9±1.7 191±12	27.0±2.6	23.5±2.2	50.2±4.9	0.37±0.04	0.030±0.003
7	11.2±1.6	16.0±2.2 292±16	31.1±3.2	27.0±2.8	56.55±6.02	0.43±0.04	0.033±0.003
8	12.5±1.5	12.4±1.9 239±14	26.7±2.8	23.2±2.4	48.64±5.27	0.37±0.04	0.028±0.003
9	11.3±1.5	12.9±1.9 237±14	26.4±2.8	22.9±2.4	48.11±5.24	0.36±0.04	0.028±0.003
10	12.5±1.5	13.0±2.0 230±14	26.7±2.8	23.2±2.5	48.78±5.39	0.37±0.04	0.028±0.003
Mean	12.5±1.5	12.5±1.7 224±13	26.1±2.6	22.7±2.3	47.62±4.96	0.36±0.04	0.028±0.003

4 Conclusion

Activity levels in the soil of Qena, Egypt have been measured. The mean activity of ^{226}Ra, ^{232}Th and ^{40}K were found to be 12.5±1.5, 12.5±1.7 and 224±13 $Bq \cdot kg^{-1}$, respectively. The mean radium equivalent activity Ra_{eq}, representative level index, and terrestrial absorbed dose rate for the area under investigation are 47.62±4.96 $Bq \cdot kg^{-1}$, 0.36±0.04 $Bq \cdot kg^{-1}$, and 22.7±2.3 $nGy \cdot h^{-1}$, respectively. The levels of ^{226}Ra, ^{232}Th, and ^{40}K in the soil of the Qena were comparatively less than the world average whereas radium equivalent activity, external hazard index, internal hazard index and terrestrial absorbed dose rate were below the recommended limits.

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