ESTIMATION OF RADIOECOLOGICAL PARAMETERS OF SOIL SAMPLES FROM A PHOSPHATIC AREA

by

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The activity concentrations of natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) for a set of 31 agricultural soil samples from the Nile River banks in the area of El-Sebaiya city, Aswan Governorate, Egypt were measured by gamma-spectrometry. The study revealed that the average activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were 23.2 2.8Bq/kg, 21.1 2.8 Bq/kg, and 218.6 3.7 Bq/kg, respectively. The obtained results of the activity concentrations are within the range of values reported for neighbouring areas in Egypt.
The values obtained for the hazard indices and the representative level index in all sampling sites were lower than unity, showing that there is no significant risk arising from the exposure to the soil in the studied area.The absorbed dose rate and annual effective dose in air outdoors and indoors were calculated from ^{226}Ra, ^{232}Th, and ^{40}K in soil, the average values being 32.64 nGy/h, 40.06 μSv, and 160.25 μSv, respectively. The absorbed dose rate at the eastof El-Sebaiya city is higher than that obtained for the west because of higher concentrations of tri-calcium phosphate in the soil.The studied area is not significantly affected by the industrial activities, except for a few isolated spots.

Key words: NORM, soil, radioactivity, gamma spectrometry, hazard index

INTRODUCTION

Practically all natural materials contain radioactive nuclides though usually in such a low concentration that they can be detected only by very sensitive analysis. Phosphate rocks contain a relatively high concentration of naturally occurring radioactive materials (NORM) from the uranium and thorium decay series [1]. The average uranium content in phosphate rock is usually around at 50-200 parts per million (ppm) or 0.005-0.020 %, but some commercial rich ores can contain up to 150.000 ppm of uranium [2].

Mining has been identified as one of the potential sources of exposure to NORM [3, 4]. Materials from the deposit may be brought to the surface soil through processes such as weathering of rocks and soil formation [5]. Mining and mineral processing may result in higher concentrations of ^{238}U and ^{232}Th in the surrounding area being spread, distributed in air and deposited on the soil surface [4, 6, 7]. Outdoors,humans are exposed to the natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil only [8]. Edition Soil is widely used as a construction material in Upper Egypt such as in the production of bricks, as filling materials *etc*. Thus the measurement of natural radioactivity in soil, which is the basic indicator of radiological contamination in the environment, is important in estimating the present health risks and establishing the baseline data for future monitoring of exploration and in radiation protection.

El-Sebaiya city (Egypt) is located on both banks of the Nile River (fig. 1). The presence of phosphate mines,the El Nasr Phosphate Factory, and Nile's port used for phosphate transportation, aroused considerable interest to examine whether the cultivated areas around and in El-Sebaiya city contain an excess of NORM which present a potential risk to the population. In the present work, we measured the concentration of ^{226}Ra, ^{232}Th, and ^{40}K in soil samples collected from some different sites of El-Sebaiya city using a gamma ray spectrometer and calculated the associated absorbed dose rates. Previously, similar work has been performed on agricultural soils to assess the radionuclide content and the associated hazards as a results of the production of fertilizers, and these soil samples were collected from around the factories (therefore in the vicinity of the siev-

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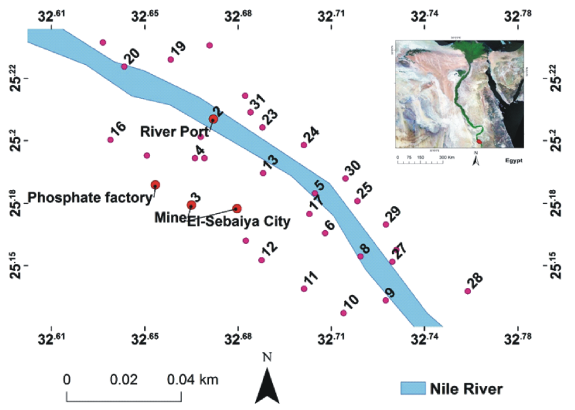

Figure 1. Map of sampling sites in El-Sebaiya city

ing and smelting processes) and these samples contained high amounts of NORM [9, 10]. The present work encompasses a larger area; soil samples were collected not only around the factories but along the pathway of the transportation processes of the phosphate on the way to the Nile port.

MATERIAL AND METHODS

Sampling area

El-Sebaiya city is located between 25.174961°N and 32.678633°E (fig. 1) in the far north of the Aswan Governorate, being famous for its abundance of phosphate ore in the surrounding mountainous areas, whether on the east or west Nile bank, where there are many phosphate mines. El-Sebaiya city is divided into two regions; one region is located on the eastern bank of the Nile River, being characterized by phosphatic soil, phosphate mines, quartz ore, a grinding plant and phosphates factories. On the other Nile bank is the west region of El-Sebaiya city, characterized by cultivated soil, a residential region and some smaller phosphate mines. Thirty one samples were collected from different agricultural soils with sampling sites divided into two zones: 14 samples were collected from the east El-Sebaiya city and 17 samples from the west El-Sebaiya city (fig. 1).

Sampling and sample preparation

The soil samples were collected according to the IAEA TECDOC-1415 [11] and recommendations of the Egyptian Geological Survey and Mining Authority.In the laboratory, soil samples were first cleaned from coarse roots, pebbles, then were dried at 105 °C for 24 hours and mechanically crushed to powder. The powdered samples were sieved through a 560 μm sized sieve to obtain sample homogeneity [12, 13]. The prepared samples were transferred to radon-impermeable plastic containers, weighted and sealed for four weeks to reach the secular equilibrium between ^{226}Ra and its daughters, and ^{232}Th and its daughters, before being taken for gamma spectrometric analysis.

Gamma spectrometry

The radionuclide activity concentrations in the samples were measured using a High-Purity Germanium Detector (HPGD). The gamma spectrometry system consists of an N-type HPGD (CANBERRA), mounted in a cylindrical lead shield (100 mm thick) and cooled in liquid nitrogen, and coupled to a computer based Multi-Channel Analyzer(MCA). The relative efficiency of the detector was 40 %, with an energy resolution of 2 keV at a gamma ray energy of 1332 keV of ^{60}Co. LABSOCS efficiency calibration software, mathematical efficiency calibration software and software program (Genie 2000) were used to calculate the activity concentrations of the samples, taking care to subtract the natural background level.

The most intensive gamma lines for the radionuclides of interest were used for calculations. ^{226}Ra activity was determined from 609.3, 1120.3, and 1764.5 keV gamma ray peaks of ^{214}Bi and from the 351.9 keV gamma ray peaks of ^{214}Pb. On the other hand, the 238.6 keV of ^{212}Pb, the 911.2 keV gamma ray peaks of ^{228}Ac and 2614.7 keV of ^{208}Tl were used to evaluate ^{232}Th. ^{40}K was determined using a 1460.8 keV peak.

CALCULATION OF RADIOECOLOGICAL PARAMETERS

Activity concentrations

The activity concentration A_{iE} (Bq/kg) of a radionuclide i and for a peak of energy E, was calculated using the following formula

$$A_{iE} \quad \frac{N_{iE}}{I_\gamma \varepsilon_E m_s T} \tag{1}$$

where N_{iE} is the net peak area at energy E, ε_E – the detection efficiency at the energy E, T – the counting live time in seconds, I_γ – the gamma ray yield per disintegration of the specific radionuclide for a transition at energy E, and m_s is the mass of the dry weight [kg] of the measured sample [5].

Radium equivalent (Ra_{eq})

The term radium equivalent activity, Ra_{eq}, [Bqkg^{-1}] is normally used to compare the uniformity in radiation of materials containing different amounts of ^{226}Ra, ^{232}Th, and ^{40}K. It was proposed that the activ-

ity concentration of 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K is equivalent to 370 Bq/kg of ^{226}Ra and in these quantities, each of these radionuclides gives an effective dose of 1 mGy/y. Based on these values, Hamilton, 1971 [14] and Beretka 1985 [15] defined Ra_{eq} as

$$Ra_{eq} \quad \frac{A_{Ra}}{370} \quad \frac{A_{Th}}{259} \quad \frac{A_K}{4810} \quad 370 \qquad (2)$$

where A_{Th} is the specific activity of ^{232}Th, A_{Ra} – the specific activity of ^{226}Ra, and A_K – the specific activity of ^{40}K, all activities being in Bq/kg.

Calculation of radiation hazard indices

Standard radiation hazard indices are used to evaluate the effects of radiation on the health condition of people exposed to radiation.

External and internal radiation hazard

The external hazard index (H_{ex}) was calculated from eq. (3) and the internal hazard index (H_{in}) from eq. (4) [3, 16].

$$H_{ex} \quad \frac{A_{Ra}}{370} \quad \frac{A_{Th}}{259} \quad \frac{A_K}{4810} \qquad (3)$$

$$H_{in} \quad \frac{A_{Ra}}{185} \quad \frac{A_{Th}}{259} \quad \frac{A_K}{4810} \qquad (4)$$

Values of H equal to unity correspond to Ra_{eq} (370 Bq/kg)

Representative level index

The representative level index, I, is generally used to assess the hazardous level from radionuclides to the human body when externally (indoor or outdoor) exposed to an amount of annual effective doses of γ – radiations decayed from radioactive nuclides in soils. The representative level index (I_γ) is used to estimate the level of the gamma radiation hazard associated with the natural radionuclides in specific building materials.

Values of I_γ can be calculated according to the following semiempirical formula (5) [9,17,18]

$$I_\gamma \quad \frac{A_{Ra}}{150} \quad \frac{A_{Th}}{100} \quad \frac{A_K}{1500} \qquad (5)$$

Calculation of dosimetric parameters

Absorbed dose rate

The absorbed dose rate is defined as the amount of energy deposited in a substance. By using eq. (6), the absorbed dose rate from the soil samples in air at 1 m above ground was calculated from the activity concentrations [3]

$$D\,[\,\mathrm{mGy/h}\,] \quad 0.462A_{Ra} \quad 0.604A_{Th} \quad 0.042A_K \qquad (6)$$

Annual effective dose outdoors and indoors

The annual effective dose outdoors and indoors must be estimated on the basis of measurable or calculated quantities. To estimate annual effective doses, both the conversion coefficient from the absorbed dose in air to the effective dose (0.7 Sv/Gy) and the outdoor or indoor occupancy factor must be taken into consideration. The effective dose was calculated from [3]

$$D_{out/in} \quad DC_f C_T \qquad (7)$$

where $D_{out/in}$ [μSv] is the annual effective dose outdoors (out) and indoors, C_f – the conversion coefficient from the absorbed dose in air to the effective dose, C_T – the outdoor or indoor occupancy factor (*i. e.* the fraction of time spent outdoors and/or indoors, with the usual values of 0.2 and 0.8, respectively).

RESULTS AND DISCUSSION

Specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/kg of the collected soil samples from El-Sebaiya are shown in tab. 1 and fig. 2. The range of activity concentrations varies from 11.7 3.7 to 59.4 1.7 Bq/kg for ^{226}Ra, from 14. 7 3.2 to 31 2.3 Bq/kg for ^{232}Th, and from 111.7 4.6 to 286.4 3.3 Bq/kg for ^{40}K, with overall mean values of 23.3 ± 2.8 Bq/kg, 21.2 2.8 Bq/kg and 218.6 3.7 Bq/kg, respectively. The highest values of ^{226}Ra and ^{232}Th concentrations in soil samples were observed in samples SE21 and SW11, whereas the highest ^{40}K concentration was registered in sample SE26. Meanwhile, the lowest ^{226}Ra and ^{232}Th concentrations were observed in samples SW10 and SW7, respectively, whereas the lowest ^{40}K concentration was obtained in sample SE21.

The obtained results revealed that the ^{226}Ra and ^{232}Th concentrations in soil samples from the eastern bank of the Nile are higher than those collected from the western bank of the Nile (tab. 1, fig. 2). The explanation may reside in the higher concentrations of tri-calcium phosphate in the east comparatively with those in the west. The Aynahand Mahamid mines on the eastern bank contain around 65 % tri-calcium phosphate and mine content is 64-65 %, while the concentration in the western soilis only about 22-28 % [19].

Average values of activity concentrations are slightly higher than reported worldwide and in the other locations in Egypt, but are comparable with those found in the Aswan province (tab. 2). On the other hand, the measured concentrations for the interest radionuclides in this study are lower than the corresponding ones obtained by [10]. However, there is a pronounced difference in the activity concentration for ^{226}Ra obtained in our previous work [10] and the present one. Previously, the phosphate layer samples were collected from inside and outside the territory of

Table 1. Activity concentration in soil samples from El-Sebaiya, Aswan

Sample no.	Sample texture	Co-ordinates		Activity concentration [Bq kg^{-1}]		
		Lat.	Long.	^{226}Ra	^{232}Th	^{40}K
Western bank of the Nile river						
SW1	Clay	25.20014	32.666	14.1 3.4	16.5 3.2	253.2 3.5
SW2	Clay	25.20645	32.67032	27.3 ± 2.6	22.3 ± 2.9	237.4 ± 3.7
SW3	Clay	25.17627	32.66265	26.5 2.5	17.1 3.0	228.7 3.5
SW4	Clay	25.19271	32.66392	21.6 3.0	21.0 3.0	263.80 3.53
SW5	Clay	25.18038	32.70597	30.8 2.3	24.7 2.5	171.7 3.9
SW6	Clay	25.16638	32.70954	20.0 3.0	21.9 2.8	217.5 3.7
SW7	Clay	25.16372	32.68178	16.8 3.1	14.7 3.2	205.4 3.7
SW8	Clay	25.15821	32.72198	24.1 2.7	19.3 3.0	252.2 3.5
SW9	Clay	25.14278	32.73082	14.4 3.5	18.3 3.2	246.9 3.6
SW10	Mixed (clay and sand)	25.13829	32.71606	11.7 3.7	19.9 2.9	245.3 3.5
SW11	Mixed (clay and sand)	25.14686	32.70215	22.4 2.7	31.0 2.3	175.9 3.9
SW12	Clay	25.1569	32.68731	21.2 2.7	17.6 2.9	204.2 3.7
SW13	Clay	25.18743	32.68783	16.5 3.2	20.4 2.9	255.6 3.5
SW14	Clay	25.19269	32.66726	15.3 3.3	21.9 2.8	247.8 3.6
SW15	Clay	25.19362	32.64708	17.9 3.0	18.9 2.9	230.7 ± 3.6
SW16	Clay	25.19911	32.63435	16.1 3.1	17.7 2.9	246.9 3.4
SW17	Clay	25.17312	32.70403	15.9 3.2	18.4 2.9	237.5 3.5
Average				19.6	20.1	230.6
SD				5.3	3.7	27.2
Min				11.6	14.7	171.6
Max				30.8	31.0	263.8
Eastern bank of the Nile river						
SE18	Clay	25.23335	32.63169	14.0 3.7	19.7 3.2	264.6 3.7
SE19	Mixed (clay and sand)	25.22733	32.65547	21.7 2.8	27.7 2.5	247.6 3.5
SE20	Mixed (clay and sand)	25.22483	32.6392	21.5 2.7	24.5 2.6	209.0 3.6
SE21	Sand	25.2323	32.6691	59.4 1.7	19.4 2.8	111.7 4.6
SE22	Sand	25.21462	32.68157	25.6 2.5	20.8 2.8	187.8 3.8
SE23	Mixed (clay and sand)	25.20351	32.68761	25.2 2.6	23.3 2.7	179.7 3.9
SE24	Clay	25.19729	32.70212	33.9 2.3	27.3 2.5	189.4 3.9
SE25	Clay	25.17767	32.72086	27.7 2.5	25.2 2.6	179.3 ± 3.9
SE26	Clay	25.1605	32.73458	20.3 2.9	20.0 2.9	286.4 3.3
SE27	Clay	25.15636	32.73312	17.5 3.1	20.1 2.9	238.9 3.5
SE28	Clay	25.14601	32.75953	17.5 3.0	18.9 2.9	229.9 3.5
SE29	Clay	25.16944	32.73085	32.1 2.3	22.4 2.7	202.3 3.7
SE30	Clay	25.18557	32.71668	34.6 2.2	23.2 2.6	179.3 3.8
SE31	Sand	25.20884	32.68344	37.3 2.2	21.9 2.8	149.6 4.2
Average				27.7	22.5	204.0
SD				11.6	2.9	46.5
Min				14.0	18.8	111.7
Max				59.4	27.7	286.4
Descriptive statistics of all samples						
Average				23.2	21.2	218.6
SD				2.8	2.8	3.7
Min				11.7	14.7	111.67
Max				59.4	31.0	286.4

the Sebaiya phosphate factory and mine, which could explain the higher concentration of ^{226}Ra when compared to that from cultivated soil samples investigated in the present work.

Table 3 presents the radium equivalent activity (Ra_{eq}), absorbed dose rate (D) and annual effective dose rate in air outdoors (D_{out}) and indoors (D_{in}), radiation hazard indices externally H_{ex} and internally H_{in},

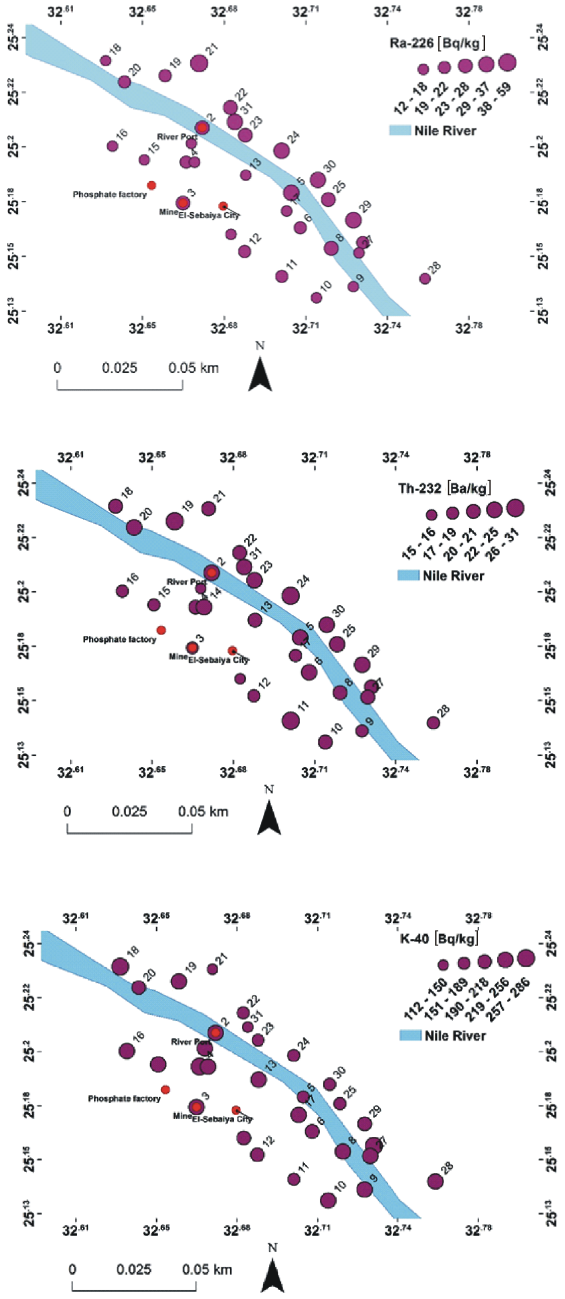

Figure 2. Graduated symbols indicating the activity concentrations [Bq kg^{-1}] of radionuclides

the representative level index (I_r), which were calculated for ^{226}Ra, ^{232}Th, and ^{40}K in the collected soil samples.

The obtained values of Ra_{eq} ranged from 53.6 7.9 Bq/kg to 95.8 6 Bq/kg with an average of 70.4 7.2 Bq/kg. The minimum and maximum values were registered in SW7 and SE21 samples, respectively. All soil samples showed Ra_{eq} far below the limit of 370 Bq/kg. Therefore, the soil from the area where the samples were collected is safe and suitable to be used both for agriculture and building materials.

The calculated external, internal hazard and the representative level index (I_γ) values are shown in tab. 3. The values of external and internal hazardindices are between 0.14 0.02 to 0.26 0.02 (mean 0.19 0.02) and 0.21 0.04 to 0.49 0.02, respectively. The activity index I_γ values ranged from 0.40 0.06 to 0.66 0.04 (mean 0.51 0.05). All values of H_{ex}, H_{in}, and I_γ obtained for all sampling sites are lower than unity. Therefore, there is no significant risk arising from the exposure to the soil of the studied area. Nevertheless, periodic radiation monitoring should be carried out to follow up the dynamics of the radiation background future changes as a result from accumulation of the phosphate processing and transportation operations.

As shown in fig. 3, the absorbed dose rates on the eastern bank are higher than those obtained for the western bank of the Nile, with analmost gradual decrease from east to west. This is due to the higher concentrations of ^{226}Ra and ^{232}Th in the soil samples from the east sites when compared to those from the west sites and geological features [19]. The average absorbed dose rate in the investigated soil samples was 32.64 3.17 nGy/h (25.18 3.51-43.82 2.66 nGy/h), thisvalue being in agreement with the Egyptian average dose due to exposure to these radionuclides in soils, which is 32 nGy/h [3]. The outdoor and indoor annual effective doses ranged from 30.90 4.31 to 53.78 3.26 and from 123.61 17.23 to 215.11 13.04 μSv/y, with mean values of 40.06 3.89 and 160.25 15.55 μSv/y, respectively. It has to be mentioned that the worldwide average annual effective dose is 70 μSv/y (outdoor) and 410 μSv/y (indoor) [3], hence the mean values of doses at investigated sites are generally lower than those reported worldwide [3, 21, 22].

Table 2. Activity concentration in soil samples from El-Sebaiya and other locations

Country	Activity concentration [Bqkg^{-1}]			Ref.
	^{226}Ra	^{232}Th	^{40}K	
Egypt	11.9 8.7-17.9	10.5 3.5-16	1636 1401-1870	[9]
	13.7 7.7-16.9	12.3 10.1-16.1	1233 838-1692	
Egypt	17 5-64	18 2-96	320 29-650	[3]
Ghana	13.6 2.26-30.57	24.2 6.0-93.64	162.1 39.81-551.72	[4]
El-Mahamid, Aswan, Egypt	21.55	18.77	377	[20]
El-Sebaiya, Aswan, Egypt	215.3 69.0-464.8	27.4 20.1-33.8	544.0 249.9-764.5	[10]
El-Sebaiya, Aswan, Egypt	23.3 11.7-59.4	21.2 14.7-31.0	218.6 111.7-286.4	Present work

Table 3. The radioecological (radium equivalent activity, radiation external and internal hazard indices, representative level index) and dosimetric (absorbed dose rate, annual effective dose rates in air outdoors and indoors) parameters calculated in the present work

Sample #	Radioecological parameters								Dosimetric parameters							
	Ra_{eq} [Bqkg^{-1}]		H_{ex}		H_{in}		I		D [nGyh^{-1}]		D_{out} [μSvy^{-1}]		D_{in} [μSvy^{-1}]	
SW1	57.13	8.29	0.15	0.02	0.21	0.04	0.43	0.06	27.01	3.67	33.15	4.50	132.58	18.01
SW2	77.38	7.03	0.21	0.02	0.32	0.03	0.56	0.05	35.94	3.11	44.11	3.81	176.43	15.26
SW3	68.57	7.05	0.19	0.02	0.29	0.03	0.50	0.05	32.11	3.11	39.41	3.82	157.64	15.26
SW4	71.94	7.47	0.19	0.02	0.28	0.03	0.53	0.05	33.66	3.30	41.31	4.05	165.24	16.22
SW5	79.36	6.20	0.21	0.02	0.34	0.03	0.57	0.04	36.32	2.75	44.57	3.37	178.27	13.49
SW6	68.20	7.27	0.18	0.02	0.26	0.03	0.50	0.05	31.60	3.22	38.78	3.96	155.11	15.83
SW7	53.58	7.94	0.14	0.02	0.21	0.03	0.40	0.06	25.18	3.51	30.90	4.31	123.61	17.23
SW8	71.12	7.27	0.19	0.02	0.29	0.03	0.52	0.05	33.31	3.21	40.87	3.94	163.50	15.76
SW9	59.53	8.24	0.16	0.02	0.22	0.04	0.44	0.06	27.98	3.65	34.34	4.48	137.36	17.92
SW10	59.07	8.15	0.16	0.02	0.21	0.04	0.44	0.06	27.66	3.62	33.95	4.45	135.80	17.79
SW11	80.36	6.27	0.22	0.02	0.31	0.03	0.58	0.04	36.45	2.79	44.73	3.43	178.92	13.71
SW12	62.04	7.23	0.17	0.02	0.25	0.03	0.45	0.05	28.92	3.19	35.49	3.92	141.96	15.68
SW13	65.36	7.73	0.18	0.02	0.24	0.03	0.48	0.05	30.60	3.42	37.56	4.20	150.23	16.81
SW14	65.88	7.61	0.18	0.02	0.24	0.03	0.49	0.05	30.71	3.38	37.68	4.15	150.74	16.59
SW15	62.63	7.49	0.17	0.02	0.24	0.03	0.46	0.05	29.28	3.32	35.93	4.07	143.73	16.29
SW16	60.47	7.51	0.16	0.02	0.23	0.03	0.45	0.05	28.45	3.32	34.91	4.08	139.65	16.31
SW17	60.47	7.74	0.16	0.02	0.23	0.03	0.45	0.05	28.35	3.43	34.79	4.21	139.16	16.83
SE18	62.62	8.48	0.17	0.02	0.22	0.04	0.47	0.06	29.43	3.76	36.12	4.61	144.49	18.46
SE19	80.43	6.57	0.22	0.02	0.30	0.03	0.59	0.05	37.10	2.92	45.54	3.58	182.14	14.32
SE20	72.57	6.64	0.20	0.02	0.28	0.03	0.53	0.05	33.42	2.95	41.01	3.62	164.05	14.46
SE21	95.75	6.04	0.26	0.02	0.49	0.02	0.66	0.04	43.82	2.66	53.78	3.26	215.11	13.04
SE22	69.77	6.75	0.19	0.02	0.29	0.03	0.50	0.05	32.21	2.99	39.53	3.66	158.11	14.66
SE23	72.44	6.67	0.20	0.02	0.30	0.03	0.52	0.05	33.25	2.96	40.80	3.63	163.20	14.51
SE24	87.56	6.20	0.24	0.02	0.37	0.03	0.63	0.04	40.07	2.75	49.17	3.37	196.69	13.49
SE25	77.45	6.49	0.21	0.02	0.32	0.03	0.56	0.05	35.46	2.88	43.51	3.53	174.05	14.12
SE26	71.00	7.41	0.19	0.02	0.27	0.03	0.53	0.05	33.42	3.28	41.02	4.02	164.08	16.09
SE27	64.66	7.44	0.17	0.02	0.24	0.03	0.48	0.05	30.20	3.30	37.06	4.04	148.24	16.18
SE28	62.14	7.44	0.17	0.02	0.24	0.03	0.46	0.05	29.05	3.29	35.65	4.04	142.59	16.16
SE29	79.77	6.46	0.22	0.02	0.34	0.03	0.57	0.04	36.82	2.85	45.19	3.50	180.76	14.00
SE30	81.50	6.23	0.22	0.02	0.36	0.03	0.58	0.04	37.44	2.76	45.95	3.38	183.79	13.53
SE31	80.24	6.44	0.22	0.02	0.36	0.03	0.57	0.04	36.75	2.84	45.10	3.49	180.38	13.96
Average	70.35		0.19		0.28		0.51		32.64		40.06		160.25	
SD	7.15		0.02		0.03		0.05		3.17		3.89		15.55	
Min	53.58		0.14		0.21		0.40		25.18		30.90		123.61	
Max	95.75		0.26		0.49		0.66		43.82		53.78		215.11	

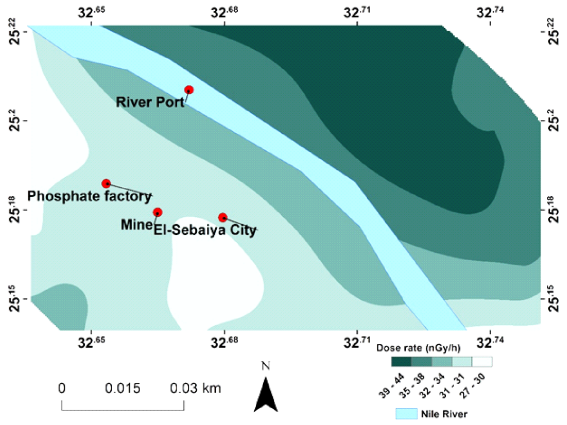

Figure 3. Spatial distribution of the dose rate in nGy/h of the area under investigation

CONCLUSIONS

The concentration of naturally occurring radioactive materials (NORM) from the uranium and thorium decay series in soil samples collected from El-Sebaiya city, Aswan Governorate, Egypt, has been investigated. The area is rich in phosphate ore which usually contains a significant amount of NORM thus presenting a potential health risk for the population. Measurements revealed that the radioactivity concentrations of ^{226}Ra, ^{232}Th in different sampling areas are correlated with the amounts of tri-calcium phosphate in the soil. The radioactivity concentrations of ^{226}Ra and ^{232}Th obtained were close to the results found for soils of similar textures in Egypt and other countries such as Ghana.

All radioecological and dosimetric indices calculated from the radioactivity concentrations were well below a hazardous level indicating the safe usage of this soil in agriculture or as a building material. However, the Republic directions are to establish more industrial facilities dealing with the processing of phosphate ore in the studied area, hence it is highly recommended that periodic radiation monitoring *in situ* (in the field) and *ex situ* (at a laboratory) be carried out to follow up any possible changes of activity concentrations in El-Sebaiya city.

AUTHORS' CONTRIBUTIONS

Samples were collected, prepared, and measured by N. Saad. All the authors have contributed in performing the experimental part. Analysis, data processing, plot graphs, and constructing maps were carried out by W. M. Badawy. The manuscript was discussed and written by all authors.

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ПРОЦЕНА РАДИОЛОШКИХ ПАРАМЕТАРА УЗОРАКА ЗЕМЉИШТА ИЗ ОБЛАСТИ БОГАТЕ ФОСФАТИМА

Помоћу гама спектрометра измерена је концентрација активности природних радионуклида (^{226}Ra, ^{232}Th и ^{40}K) из тридесетједног узорка пољопривредног земљишта крај обала реке Нил, у подручју града Ел-Себаија, у области Асуан у Египту. Резултати мерења показују да просечне концентрације активности природних радионуклида ^{226}Ra, ^{232}Th и ^{40}K износе 23.2 2.8 Bq/kg, 21.1 2.8 Bq/kg и 218.6 3.7 Bq/kg, респективно. Добијене концетрације активности налазе се у опсегу вредности приказаних за околне области у Египту.

Индикатори хазарда и индекс репрезентативног нивоа на свим локацијама узорковања имали су вредности ниже од јединице, што указује да нема значајног повећања ризика од излагања зрачењу из земљишта у испитиваној области. Јачина апсорбоване дозе и годишња ефективна доза у спољашњој средини и унутрашњем простору износиле су 32.64 nGy/h, 40.06 μSv и 160.25 μSv, за ^{226}Ra, ^{232}Th и ^{40}K, респективно. Јачина апсорбоване дозе у источном делу града Ел-Себаија повећана је у односу на западни део града због веће концентрације три-калцијум фосфата у земљишту. Испитивана област није значајно угрожена индустријском активношћу, осим на неколико изолованих места.

Кључне речи: НОРМ, земљиште, радиоактивност, гама спектрометрија, индекс хазарда