Radioactivity levels and hazards of soil and sediment samples collected from Damietta and Rashid branches of the River Nile, Egypt

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Abstract

Forty three soil and thirty nine sediment samples were collected from the banks of different cities located in Rashid and Damietta branches of the River Nile. Natural radioactivity concentrations of ^{238}U, ^{232}Th and ^{40}K have been evaluated for all samples by means of gamma spectrometric analysis using hyper pure Ge detector. The radioactivity levels for both soil and sediments samples fall within the international recommended values. Nevertheless , a high natural background radiation zones are detected at Kafr-Elzayyat region due to the presence of a fertilizer factory and at Rashid region due to the presence of black sand deposits that are dominated there. The radiation hazards (absorbed dose rate, radium equivalent activity, the annual effective dose equivalent, hazard indices, gamma index and excess life time cancer risk) are calculatedand compared with the previously reported data. High values for some of the radiation health parameters are adopted at Kafr-Elzayyat and Rashid regions representing a serious problem to public because they use the soil and sediment as constructing materials for their buildings.

Keywords

Natural radioactivity; River Nile; Soil and sediment; Health hazards.

Introduction

Natural radionuclides are components of earth since its existence and widely spread in earth's environment. There are many naturally occurring radionuclides in environment, such as uranium and thorium series radioisotopes and natural ^{40}K. These natural radionuclides exist in water, soil, sediment, plants and air.

Natural environmental radioactivity associated with external exposure due to gamma radiation depends primarily on the geological conditions formations of each region in the world **(1).** Hence it plays a role in accumulating and transporting contaminants within the geographic area, as well as it is considered environmental host of the waste, which is charged by natural or artificial processes (2). A long - term exposure due to uranium and radium through inhalation has several health effects such as chronic lung diseases, acute leucopoenia, anemia, necrosis, hepatic bone, kidney cancer and leukemia **(3).**

The assessment of the activity concentrations of natural radionuclides is of particular importance because it embodies an important contribution to the external dose of population. In this range, the United Nation Scientific committee on the effects of the Atomic Radiation (4) provides a direct correlation between the activity of ^{226}Ra, ^{232}Th and ^{40}K in water, soil and sediments and the external doses absorbed by the population.

The study area has many industries such as chemical, organic fertilizers and construction materials on both sides of the banks of the river. The discharge wastes and toxic metals from such industries and living residents are directly let out into the river.

The Nile River has supported many civilizations of Egypt throughout history and continues to play a vital role in supplying precious water for drinking, irrigation and industry to the people of Egypt. It plays an essential role in Egyptian life. The study of the natural radioactivity of the water, soil and sediment from its banks is very important and the assessment of natural dose rates deserves great interest to regional health. Also, the Nile is a major north-flowing river in north-eastern Africa, generally regarded as the longest river in the world. It is 6650 Km long. It runs through ten countries. These countries are Sudan, South Sudan, Burundi, Rwanda, The Democratic Republican Congo, Tanzania, Kenya, Ethiopia, Uganda, and Egypt.

On the other hand, soil acts as a medium of migration for the transfer of radionuclides to the biological system and hence, it is the basic indicator of radiological contamination in the environment. Moreover, the soil radioactivity is usually important for purposes of establishing baseline data for future radiation impact assessment. The radionuclides present in soils can pass on to the food chain and the air, contributing to the internal dose received by the population.

Natural radionuclides in river sediment generate significant components of the background radiation exposure of the population (5). Therefore, the knowledge of the concentrations and distributions of the radionuclides in the deposited samples are of great interest since it provides useful information in monitoring of environmental contamination and the associated human health impacts by natural radioactivity. Accordingly, the aim of the present work is to reinvestigate the radioactivity concentrations in soil and sediments collected from the two branches of the northern part of River Nile where several big cities along with many industrial projects area situated. The health hazard parameters are to be accurately extracted and discussed.

Material and method

Study area

The present study covered an area in the Nile Delta region along Rashid and Damietta branches that includes different districts. Rashid branch is one of the Nile bifurcates which starts 23 Km north of Cairo and runs about 236 Km northward along the west boundary of the Nile-Delta and pours its water in the Mediterranean sea 12 Km north of Rashid city. Damietta branch is very important for navigation and irrigation in Egypt. It extends from downstream Delta Barrages at Km 26.5 behind El-Roda Gouge station to Mediterranean Sea having 245 Km length.

Sample collection and preparation

Fourty three soil and thirty nine sediment samples were collected from different sites of the selected study area. These samples were precisely identified by its longitude and latitude axes using Global positioning system (GPS).

Samples were collected from Rashid and Damietta branches from different location near big cities and factories over a distance one kilometer for each location and they were taken at depth (5-10) cm from the surface.

The recently deposited soil and sediment samples were manually collected with the help of a plastic spade in polyethylene bags. These samples were oven dried at a temperature of 105℃ for 24 h and sieved through 1mm. The dried samples were transferred to polyethylene Marinelli beakers of 350 cm^3 capacity left at least 4 weeks to reach secular equilibrium between members of both ^{238}U and ^{232}Th chains [6, 7].

Radioactivity measurements:-

For gamma measurements, a closed end-coaxial Canberra N-type HPGe detector of vertical configuration (model GC5019), with 40% relative efficiency and 2.0keV energy resolution at 1.33 MeV photons of ^{60}Co. This detector is shielded by 4 mm Pb, 1mm Cd and 1 mm Cu.

The activity of ^{226}Ra and ^{228}Ra were obtained indirectly from the gamma-rays emitted by their progenies which are in secular equilibrium with them while ^{40}K was estimated directly by its gamma-line of 1460.8 keV. ^{226}Ra activities were determined using the gamma-lines 295.2 keV from ^{214}Pb, 609.3 and 1120.3 keV from ^{214}Bi. ^{232}Th activities were determined using gamma-lines 583.1 and 2614.4 keV from ^{208}Ti and 338.7 and 911.2 keV from ^{228}Ac.

Results and discussion:-

Radioactivity analysis

The activity concentration of soil and sediments samples along Rashid and Damietta branches of the River Nile are shown in tables 1, 2, 3 and 4.

Table (1): Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for soil samples (Rashid branch).

Location	Sample code	^{226}Ra	^{232}Th	^{40}K
Banha	N1	15± 1.2	15±1.3	285±9.4
	N2	18.8±1.5	16.2±1.5	355±11.2
	N3	12±1	9±0.8	265±10.1
Mean		15.2±1.23	13.4±1.2	301±10.23
Quesna	N4	12.2±1.1	11.5±1.1	390±12.2
	N5	15.8±1.5	14.2±1.3	409±13
	N6	5.5±0.4	7.1±0.6	308±10.5
Mean		11.1±1	10.9±1	369±11.9
Berket-Elsaba	N7	10.2±0.9	5.5±0.45	271±9.4
	N8	13.1±1.2	10.1±0.9	293±9.6
	N9	9.5±0.9	8.2±0.76	191±8.1
Mean		10.9±1	7.9±0.7	251.6±9

Kafr-Elzayyat	N10	70.1±4.1	12±1.1	139±7.1
	N11	259±12	17.4±1.6	180±8.5
	N12	12±1	3.2±0.2	79±6.8
Mean		113±5.7	10.8±0.96	132±7.4
Rashid	N13	45±4.2	71±6.1	85±7.9
	N14	66±5.8	82±7	99±9.2
	N15	42±4.1	45±4.1	79±6.9
Mean		51±4.7	66±5.7	87.6±8
Mean (all regions)		33.74±2.7	21.82±1.9	228.53±9.3
Worldwide average		**32**	**45**	420

Table (2) : Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for soil samples (Damietta branch).

Location	**Sample code**	**^{226}Ra**	**^{232}Th**	**^{40}K**
Mansoura	N1	4.26±0.39	4.7±0.5	77.4±7.6
	N2	4.15±0.4	3.87±0.4	74.2±7.3
	N3	5.40±0.51	4.09±0.4	76.1±7.5
	N4	6.70±0.6	4.72±0.5	78.4±7.9
	N5	3.98±0.4	2.76±0.3	51.09±5
	N6	3.89±0.4	2.23±0.2	50.2±5
	N7	5.88±0.6	2.64±0.3	52.1±5.2
	N8	6.81±0.7	2.51±0.25	51.7±5.1
	N9	3.58±0.4	3.79±0.4	59.07±6
	N10	3.09±0.3	3±0.3	61.91±6.1
	N11	4.20±0.41	3.49±0.3	58.13±5.5
	N12	5.69±0.6	3.13±0.3	60.09±6
Mean		4.80±0.5	3.41±0.3	62.53±6
Kafr-shokr	N13	4.31±0.4	4.06±0.4	69.71±7
	N14	3.49±0.3	2.89±0.3	68.13±6.8
	N15	4.28±0.4	3.42±0.3	70.14±7
	N16	6.04±0.6	3.31±0.3	66.91±6.6
Mean		4.53±0.41	3.42±0.33	68.72±6.5
Damietta	N17	3.94±0.4	4.52±0.5	62.30±6.2
	N18	3.68±0.4	3.66±0.4	60.2±6
	N19	5.22±0.5	4.24±0.4	63.13±6.3
	N20	6.13±0.6	4.1±0.4	64.5±6.4
	N21	2.88±0.3	2.85±0.3	60.21±6

	N22	2.58±0.3	2.08±0.2	62.3±6.2
	N23	3.50±0.4	2.81±0.3	59.09±5.5
	N24	5.20±0.5	2.52±0.2	61.4±6
	N25	3.98±0.4	5.11±0.5	78.83±8
	N26	4.14±0.4	4.31±0.4	75.14±7.5
	N27	5.55±0.6	5±0.5	79.1±8
	N28	7.30±0.7	3.81±0.4	76.±7.5
Mean		4.50±0.42	3.75±0.35	66.85±6.5
Mean (all regions)		4.61±4.3	3.52±3.1	66.03±6.1
Worldwide average		**32**	**45**	**420**

Table (3): Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K given in Bq/Kg for sediments samples (Rashid branch).

Location	Sample code	^{226}Ra	^{232}Th	^{40}K
Berket-Elsaab	D1	17.8±1.7	17±1.66	355±25
	D2	12±1.1	13±1.2	300±24
	D3	14±1.3	9±.85	246±23.4
Mean		14.6±1.41	13±1.25	300.33±22.5
Kafr-Elshekh	D4	20±1.5	30±2.6	290±26.1
	D5	26±2.1	20±2	305±23.3
	D6	8±0.7	11±1	198±16.4
Mean		18±1.6	20.33±2.03	264.33±24.4
Desouk	D7	10±1	12.8±1.3	370±26.1
	D8	9±0.8	6±.56	227±21.4
	D9	18±1.7	10±1.1	409±28.3
Mean		12.33±1.12	6.6±.67	335.33±27.5
Kafr-Elzayyat	D10	14.7±1.3	8.8±.75	250±24.4
	D11	15±1.4	8.1±.77	280±26.8

	D12	5±0.45	4.5±0.44	217±18.9
Mean		11.5±1.11	7.13±0.67	249±22.7
Elbehera	D13	28.8±2.1	19.1±1.8	390±30
	D14	20±2	21.5±2	424±34.2
	D15	14.2±1.2	8.8±0.78	305±28.9
Mean		21±2	16.46±1.55	373±30.1
Rashid	D16	15.2±1.3	20.1±2.1	214±18.2
	D17	126±10,.2	141±12.3	91±8.9
	D18	145±12.3	191±18.6	103±9.2
	D19	91±8.7	109±9.6	89±6.8
Mean		94.3±8.5	153.7±12.8	124.25±11.6
Mean (all regions)		28.62±2.5	36.20±3.3	212.20±18.8
Worldwide average		**32**	**45**	420

Table (4): Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K given in Bq/Kg for sediment samples (Damietta branch).

Location	**Sample code**	**^{226}Ra**	**^{232}Th**	**^{40}K**
Damietta	D1	4.10±0.34	3.98±0.29	73.46±7
	D2	3.85±0.28	3.40±0.3	70.99±6.7
	D3	7.21±0.67	3.60±0.35	74.01±7.1
	D4	4.79±0.37	3.25±0.3	75.16±7.2
	D5	6.14±0.55	3.97±0.4	64.99±6.1
	D6	3.09±0.28	3.12±0.29	66.14±6.2
	D7	3.61±0.32	3.65±0.33	63.61±6
	D8	3.62±0.34	3.55±0.3	65.33±6.5
	D9	4.08±0.38	5.12±0.49	80.15±7.9
	D10	4.39±0.41	3.92±0.38	82.31±8
	D11	3.94±0.38	4.19±0.4	78.88±8.1
	D12	6.46±0.63	4.5±0.4	81.19±8
	D13	3.02±0.28	2.20±0.22	85.81±8.4
	D14	2.25±0.19	1.99±0.2	80.88±7.8

	D15	4.55±0.39	2.43±0.23	88.91±8.5
	D16	2.211±0.21	2.16±0.21	83.18±8
Mean		4.20±0.37	3.43±0.31	70.93±6.8
Mansoura	D17	5.52±0.49	4.71±0.39	65.76±6.4
	D18	3.82±0.36	3.67±0.32	60.61±6
	D19	7.22±0.68	3.74±0.33	67.31±6.5
	D20	4.30±0.38	4.51±0.38	62.21±5.8
Mean		5.21±0.5	4.15±0.4	63.97±6.1
Mean (all regions)		4.7±0.45	3.79±0.35	67.46±6.5
Worldwide average		**32**	**45**	**420**

For soil samples the largest value are found in Rashid and Kafr-Elzayaat city. The activity concentration ranges of ^{238}U (^{226}Ra), (^{232}Th) and ^{40}K in Rashid city are 42±4.1 to 66±5.8 Bq/Kg with an average 51±4.7 Bq/Kg, 45 ±4.1to 82±7 Bq/Kg with an average 66±5.7 Bq/Kg and 79±6.9 to 99± 9.2 Bq/Kg with an average 87.6 ± 8 Bq/Kg respectively. Also, the activity concentration ranges of ^{238}U (^{226}Ra) in Kafr-ELzayat city are 12± 1 to 259±12 Bq/Kg with an average 113±5.7 Bq/Kg. It represents about three orders of magnitude more than the international mean value.

The corresponding results for sediments samples are found high in Rashid city where the activity concentrations ranges of ^{238}U (^{226}Ra), (^{232}Th) and ^{40}K are 15.2± 1.3 to 145± 12.3 Bq/Kg with an average 94.3± 8.5 Bq/Kg, 20.1 ±2.1 to 191± 18.6 Bq/Kg with an average 153.7± 12.8 Bq/Kg and 91± 8.9 to 214± 18.2 Bq/Kg with an average 124.25±11.6 Bq/Kg respectively.

The average activity concentrations varied from location to location, because the river bottom can exhibit large variations in chemical and mineralogical properties and rare-earth elements [(8)]. The combined effect of weathering, rivers, streams, morphological features of the river basins and their interaction with the sea influences the distribution of the radioactive elements in the beach sectors along the coastal zone [(9-11)].

The world average concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil samples reported by (UNSCEAR 2008) [(12)], are 32,45,420 Bq/Kg, respectively. Our results show that the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in our soil and sediment samples in the studied region are below the worldwide averages except that soil samples collected from Kafr-ELayaat that are close to the phosphate fertilizer plant. This may be attributed to the fallout of phosphate dust generated during loading and processing of phosphate inside the phosphate fertilizers plant. Also, the samples collected from Rashid coast along Rashid city are characterized by high radioactivity levels for both soil and sediment samples as shown in tables (1 and 3).These high values are consequences of the existence of the black sand along Rashid coast which is highly rich with natural radionuclides. The presence of magnetite, ilmenite and monazite may be the reason of the black coloration of the sand [(13)].

Evaluation of radiological hazard effects in soil and sediment samples:

Absorbed dose rate

Calculating the absorbed dose rate is the first major step for evaluating the health risk. With regard to biological effects, the radiological and clinical effects are directly related to the absorbed dose rate [(8)]. The measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are converted into doses by applying the conversion factors 0.462, 0.604, and 0.0417 for uranium, thorium and potassium, respectively. These factors are used to calculate the total dose rate (D) (nGyh^{-1}) using the following equation [(14)] :-

$$\mathbf{D = 0.462\ C_{Ra} + 0.604\ C_{Th} + 0.0417\ C_K\ (nGyh^{-1})}$$

Where $\mathbf{C_{Ra}}$, $\mathbf{C_{Th}}$, $\mathbf{C_K}$ are the activity concentrations (Bq/Kg) for **^{226}Ra**, **^{232}Th** and **^{40}K**in soil and sediment, respectively. The calculated values for soil and sediment samples are presented in table (3a, 3b, 4a and 4b) respectively.

Previous studies have indicated an average absorbed dose rate of 59 nGyh^{-1} in the world ranging from 10 to 200 nGyh^{-1} [(12)]. The present study determined that the absorbed dose rate varied from 5.04 to 9.02 and 10.77 to 137.67nGyh^{-1} for soil samples at Damietta and Rashid, respectively.

The absorbed dose rate varied from 5.61 to 9.08 and 14.07 to 186.64 nGyh^{-1} for sediment samples at Damietta and Rashid, respectively. Generally, the average absorbed dose rate of the investigated samples is lower than the world average value except those of soil samples collected from Rashid and Kafr – Elzayyat where their values are 67.07 and 64.62 nGyh^{-1}, respectively .The corresponding average value for sediment samples at Rashid city is118.36 nGyh^{-1}.

The annual effective dose equivalent

Annual estimated average effective dose equivalent (AEDE) received by an individual was calculated using a conversion factor of 0.7 Sv/Gy which was used to convert the absorbed dose rate to the human effective dose equivalent with an outdoor occupancy of 20% [15]. The outdoor annual effective dose could be determined using the following equations:-

$$\text{AEDE (outdoor) (mSv/y)} = \text{absorbed dose (nGyh}^{-1}) \times 8760\text{h} \times 0.7\ \text{SvGy}^{-1} \times 0.2 \times 10^{-3}$$

From the calculated values of AEDE table (3a, 3b, 4a and 4b) it is clear that the average values of outdoor AEDE for all samples are lower than the world average values (70 µSv/y),[16] except the AEDE values for sediment samples from Rashid coast that have higher values than the world average values. Also, the average outdoor AEDE values for soil samples in Kafr-Elzayyat and Rashid coast are slightly higher than the world average values.

Radium equivalent activities

Ra_{eq} is a widely used hazard index and it is calculated through the relation given by Beretka and Mathew [17]. It is assumed that 370 Bq/Kg of ^{226}Ra, 259 Bq/Kg of ^{232}Th and 4810 Bq/Kg of ^{40}K produce the same gamma-ray dose rate. Ra_{eq} can be obtained by means of the following relation:-

$$Ra_{eq}(\text{Bq/Kg}) = C_{Ra} + 1.43C_{Th} + 0.077C_K$$

Where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/Kg, respectively. The range of Ra_{eq} values were estimated for the collected samples and are given in table (5, 6, 7 and 8).

The estimated average values are lower than the recommended maximum value of 370 Bq/Kg except those from Rashid, ElBehera and Kafr-Elzayyat regions. As a consequence, soil and sediment samples are safe to be used as construction materials except those from Rashid, El-Behera and Kafr-Elzayyat regions.

Table (5): Dose rates, outdoor AEDE and Ra_{eq} for soil samples in Damietta branch.

Location	Sample Code	Dose rates (nGy/ h)	AEDE (µSv/year) Outdoor	Ra_{eq} (Bq/ kg)
Mansoura	N1	8.03	9.84	16.94
	N2	7.3	9	15.39
	N3	8.1	9.97	17.10
	N4	9.2	11.30	19.48
	N5	7.1	8.75	15.20
	N6	6.4	7.87	13.54
	N7	7.6	9.32	16.14
	N8	7.9	9.79	16.95
	N9	7.1	8.81	15.48
	N10	6.1	7.59	12.86
	N11	6.9	8.53	14.57
	N12	7.5	9.28	15.92
Mean		7.43	9.17	15.79
Kafr-Shokr	N1	6.4	7.84	13.54
	N2	5.8	7.13	12.14
	N3	6.4	7.93	13.66
	N4	7.02	8.60	14.79
Mean		6.40	7.87	13.53
Damietta	N1	5.6	6.90	11.86

	N2	5.2	6.41	10.94
	N3	6.4	7.94	13.66
	N4	6.8	8.35	14.38
	N5	5.5	6.81	11.59
	N6	5.04	6.18	10.35
	N7	5.7	7.07	12.06
	N8	6.4	7.94	13.53
	N9	8.2	10.06	17.35
	N10	7.6	8.40	16.08
	N11	8.8	10.89	18.79
	N12	8.8	10.86	18.63
Mean		6.67	8.15	14.10

Table (6): Dose rates, outdoor AEDE and Ra_{eq} for soil samples in Rashid branch.

Location	Sample Code	Dose rates (nGy/ h)	AEDA (μS v/ year) Outdoor	Ra_{eq} (Bq/ kg)
Banha	N1	27.87	34.17	85.39
	N2	33.27	40.80	69.30
	N3	22.03	27.01	45.27
Mean		27.72	33.99	66.65
Quesna	N1	28.84	35.36	58.67
	N2	32.93	40.38	67.59
	N3	23.88	29.28	39.36
Mean		28.55	35.0	55.20
Berket-Elsaba	N1	19.33	23.70	38.93
	N2	24.37	29.88	50.10
	N3	17.30	21.21	35.93
Mean		20.33	24.93	41.65
Kafr- Elzayaat	N1	45.43	55.71	97.96
	N2	137.67	168.83	297.74
	N3	10.77	13.20	22.65
Mean		64.62	79.24	139.45
Rashid	N1	67.21	82.42	153.07
	N2	84.14	103.18	190.88

	N3	49.87	61.16	112.43
Mean		67.07	82.25	152.12

Table (7): Dose rates, outdoor AEDE and Ra_{eq} for sediment samples along Damietta branch.

Location	Sample Code	Dose rates (nGy /h)	AEDE (µS v/ year) Outdoor	Ra_{eq} (Bq/ kg)
Damietta	D1	7.36	9.02	15.44
	D2	6.86	8.41	13.96
	D3	7.47	9.16	15.63
	D4	8.51	10.43	17.85
	D5	6.78	8.31	14.30
	D6	6.07	7.44	12.64
	D7	6.52	7.99	13.72
	D8	7.70	9.44	16.24
	D9	8.31	10.19	17.57
	D10	7.62	9.34	15.88
	D11	7.84	9.61	16.45
	D12	9.08	11.13	19.14
	D13	5.92	7.26	11.96
	D14	5.61	6.88	11.32
	D15	6.57	8.05	13.34
	D16	6.87	8.42	14.04
Mean		7.19	8.81	14.96
Mansoura	D1	7.57	9.28	16.09
	D2	6.50	7.97	13.73
	D3	7.61	9.33	16.05
	D4	8.65	10.60	18.45
	D5	7.48	9.17	15.95
	D6	6.94	8.51	14.66
	D7	8.91	10.92	19.07
	D8	8.79	10.78	18.70
Mean		7.80	9.57	16.58

Table (8): Dose rates, outdoor AEDE and Ra_{eq} for sediment samples along Rashid branch.

Location	Sample Code	Dose rates (nGy/ h)	AEDE (μS v /year) Outdoor	Ra_{eq} (Bq/ kg)
Berket – Elsaab	D1	33.29	40.82	69.44
	D2	25.90	31.76	53.69
	D3	22.10	27.10	45.81
Mean		27.09	33.22	56.31
Kafr-Elshekh	D1	39.45	48.38	86.38
	D2	36.81	45.14	69.84
	D3	18.59	22.79	52.22
Mean		31.61	38.77	69.48
Desouk	D1	27.78	34.06	45.77
	D2	17.24	21.14	49.07
	D3	31.41	38.52	46.53
Mean		25.47	31.24	47.33
Kafr-Elzayyat	D1	22.53	27.64	48.14
	D2	23.49	28.80	28.13
	D3	14.07	17.25	86.14
Mean		20.03	24.56	54.13
Elbehera	D1	41.10	50.40	83.38
	D2	39.90	48.93	50.26
	D3	24.59	30.15	60.41
Mean		35.19	43.16	64.68
Rashid	D1	28.08	34.43	60.44
	D2	147.17	180.48	334.63
	D3	186.64	228.89	426.89
	D4	111.58	136.84	134.64
Mean		118.36	145.16	240.21

Hazard indices (H_{ex} and H_{in})

Beretka and Mathew (1985) defined two indices that represent external and internal radiation hazards. The prime objective of these indices is to limit the radiation dose to a dose equivalent limit of 1mSv/y. The external and internal hazard index (H_{ex} and H_{in}) can be calculated using the following equation [16-17].

$$H_{ex} = (C_{Ra} /370 + C_{Th} /259 + C_K /4810) \leq 1,$$

$$H_{in} = (C_{Ra} /185 + C_{Th} /259 + C_K /4810) \leq 1,$$

Where C_{Ra}, C_{Th}, and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/Kg, respectively.

H_{ex} must not exceed the limit of unity for the radiation hazard to be negligible. Also the value of H_{in} must also is less than unity to have negligible hazards effects of radon and its short-lived progeny to the respiratory organs. [14]

The calculated values of H_{ex} and H_{in} ranged from 0.027 to 0.052 and 0.034 to 0.070 for soil samples and 0.030 to 0.051 and 0.036 to 0.069 for sediment sample (Damietta branch), respectively as shown in table 9 and 12.

The calculated values of H_{ex} and H_{in} ranged from 0.06 to 0.80 and 0.09 to 1.50 for soil samples and 0.07 to 1.15 and 0.08 to 1.54 for sediment sample (Rashid branch), respectively.

From the tables, it is clear that there are certain samples at Kafr-Elzayyat and Rashid regions have remarkable H_{in} values that are greater than the international recommended limits.

Gamma index (I_γ)

Another radiation hazard, called the gamma activity concentration index (I_γ), has been defined by the European commission [18-19]. I_γ can be obtained by the following relation;

$$I_\gamma = (C_{Ra}/300 + C_{Th}/200 + C_k/3000),$$

Where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Bq/Kg, respectively.

I_γ is correlated with the annual dose rate due to the excess external gamma radiation caused by superficial material. Values of I_γ of ≤ 2 correspond to a dose rate criterion of 0.3 mSv/y, whereas $I_\gamma \leq 6$ correspond to a criterion of 1 mSv/y.[18-20] Thus, I_γ should use only as a screening tool for identifying materials that might be of concern to be used as construction materials. Materials with $I_\gamma > 6$ should be avoided [21] since these values correspond to dose rates higher than 1 mSv/y. [18]

Based on the calculated indices for Rashid, it is certain that use of construction materials mined from some of the study locations may lead to elevated external exposure to residents from building based on those materials. Therefore, use of the studied sediment materials for construction should be properly regulated. The calculated values of I_γ values are presented in tables (9, 10, 11 and 12) for soil, and sediment samples respectively.

Annual gonadal dose equivalent

The bone marrow activity, the gonads and the bone surface cells are considered as organs of interest [4, 22] because they are characterized by rabidly dividing cells. Therefore; the annual gonadal dose equivalent **(AGDE)** due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was calculated using the following formula [22, 23]:

$$AGDE\ (\mu Sv/y) = 3.09\ C_{Ra} + 4.18\ C_{Th} + 0.314\ C_k$$

The average AGDE values varied from 36.22 to 91.06 µSv/y and 75.26 to 929.56 µSv/y for soil samples at Damietta and Rashid, respectively. Also it varied from 40.66 to 60.69µSv/y and 102.39 to 1278.77 µSv/y for sediment samples at Damietta and Rashid, respectively. Tables 5and 6 show that the highest average AGDE value was 929.56 µSv/y in Kafr-El-Zayaat for soil samples and 1278.77 µSv/year in Rashid for sediment samples. The obtained results are less than the recommended international mean value (The UNSCEAR value of 300 µSv/year)[4] except those at Kafer-El-Zayaat for soil samples and at Rashid for sediment samples.

In other words, it is about three times higher than the world average for Kafr-El-Zayaat soil samples and about four times higher than world average for Rashid sediment samples.

Excess life time cancer risk (ELCR)

Excess life time cancer risk (ELCR) is calculated using the following equation;

$$ELCR = AEDE \times DL \times RF$$

Where AEDE, DL, and RF are the annual effective dose equivalent, duration of life (70 years) and risk factor (Sv^{-1}). For stochastic effects, ICRP 60 uses values of 0.05 for public [3].The calculated range of ELCR is 21.63×10^{-6} to 39.55×10^{-6} and 46.2×10^{-6} to 590.90×10^{-6} for soils samples at Damietta and Rashid branches, respectively. Also it is 24.08×10^{-6} to 38.95×10^{-6} and 60.3×10^{-6} to 801.1×10^{-6} for sediment samples at Damietta and Rashid branches respectively. The average values of ELCR are less than the world average (0.29×10^{-3}) [14] except the average value for soil samples at Kafr-Elzayyat, soil and sediment samples at Rashid city.

Table (9): Hazard indices (H_{ex}, H_{in}, I_γ, AGDE, and ELCR) for soil samples in Damietta branch.

Location	Sample code	Hazard indices				
		H_{ex}	H_{in}	I_γ (mSv/year)	AGDE	ELCR X 10^{-6}
Damietta	N1	0.031	0.039	0.043	39.71	23.83
	N2	0.027	0.034	0.0390	36.22	21.63
	N3	0.042	0.042	0.045	41.11	24.74
	N4	0.036	0.050	0.050	45.88	27.79
	N5	0.046	0.057	0.051	58.41	35.21
	N6	0.043	0.054	0.060	54.40	29.4
	N7	0.050	0.065	0.069	62.88	38.11
	N8	0.050	0.07	0.025	62.50	38.01
	N9	0.041	0.051	0.056	50.63	30.62
	N10	0.036	0.046	0.050	45.57	27.54
	N11	0.043	0.057	0.059	53.67	32.62
	N12	0.045	0.062	0.062	56.33	34.26
Mean		0.04	0.052	0.050	50.60	30.31
Mansoura	N1	0.036	0.046	0.050	45.45	27.44
	N2	0.032	0.0411	0.045	41.52	24.95
	N3	0.036	0.048	0.050	45.81	27.75
	N4	0.039	0.055	0.020	91.06	30.1
	N5	0.045	0.057	0.063	57.11	34.44
	N6	0.041	0.052	0.05	52.29	31.5
	N7	0.046	0.06	0.063	57.67	34.89
	N8	0.052	0.070	0.072	65.05	39.55
	N9	0.032	0.042	0.044	39.87	24.15
	N10	0.029	0.040	0.016	37.10	22.43
	N11	0.036	0.052	0.050	45.56	27.79
	N12	0.038	0.057	0.052	47.76	29.22
Mean		0.038	0.051	0.047	52.18	29.51
Kafr-Shokr	N1	0.041	0.053	0.057	52.17	30.83
	N2	0.034	0.044	0.022	44.25	26.56
	N3	0.039	0.050	0.054	49.54	29.85
	N4	0.043	0.059	0.022	53.50	32.48
Mean		0.039	0.051	0.155	49.86	50.96

Table (10): Hazard indices (H_{ex}, H_{in}, $I_γ$, AGDE, and ELCR) for soil samples in Rashid branch.

Location	Sample code	Hazard indices				
		H_{ex}	H_{in}	$I_γ$ (mSv/ year)	AGDE	ELCR x 10^{-6}
Banha	N1	0.15	0.19	0.22	198.54	119.59
	N2	0.18	0.23	0.26	237.27	142.8
	N3	0.12	0.15	0.17	157.91	94.53
Mean		0.15	0.19	0.21	197.90	118.97
Quesna	N1	0.15	0.19	0.22	208.22	123.76
	N2	0.18	0.22	0.26	236.60	141.33
	N3	0.10	0.12	0.15	143.38	102.48
Mean		0.14	0.17	0.21	196.06	122.52
Berket-Elsaba	N1	0.10	0.13	0.15	139.60	82.95
	N2	0.13	0.17	0.19	174.69	104.58
	N3	0.09	0.12	0.13	123.60	73.92
Mean		0.106	0.14	0.15	145.96	87.15
Kafr- Elzayaat	N1	0.26	0.45	0.34	310.41	194.98
	N2	0.80	1.50	1.01	929.56	590.90
	N3	0.06	0.09	0.082	75.26	46.2
Mean		0.37	0.68	1.43	438.41	277.36
Rashid	N1	0.41	0.53	0.53	462.52	288.47
	N2	0.51	0.69	0.66	577.78	361.13
	N3	0.30	0.41	0.39	342.68	214.06
Mean		0.40	0.54	0.52	460.99	287.88

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Table (11): Hazard indices (H_{ex}, H_{in}, I_γ, AGDE, and ELCR) for sediments samples in Damietta branch.

Location	Sample code	Hazard indices				
		H_{ex}	H_{in}	I_γ (mSv /year)	AGDE	ELCR X 10^{-6}
Damietta	D1	0.041	0.052	0.011	52.37	31.57
	D2	0.037	0.048	0.023	47.77	29.43
	D3	0.042	0.055	0.024	53.08	32.06
	D4	0.048	0.067	0.042	60.09	36.50
	D5	0.038	0.048	0.021	48.18	29.08
	D6	0.033	0.042	0.047	43.35	26.04
	D7	0.037	0.046	0.021	46.38	27.96
	D8	0.043	0.060	0.059	54.32	33.04
	D9	0.047	0.058	0.065	59.17	35.66
	D9	0.042	0.053	0.060	54.40	32.69
	D10	0.044	0.056	0.026	55.84	33.63
	D11	0.051	0.069	0.049	64.26	38.95
	D12	0.032	0.038	0.028	42.97	25.41
	D14	0.030	0.036	0.04	40.66	24.08
	D15	0.036	0.044	0.029	47.40	28.17
	D16	0.037	0.050	0.038	49.20	29.47
Mean		0.039	0.051	0.036	51.21	30.85
Mansoura	D1	0.043	0.055	0.059	53.62	32.48
	D2	0.037	0.047	0.051	46.17	27.89
	D3	0.043	0.058	0.059	53.82	32.65
	D4	0.049	0.069	0.067	60.69	37.1
Mean		0.043	0.057	0.059	53.57	32.53

Table (12): Hazard indices (H_{ex}, H_{in}, I_γ, AGDE, and ELCR) for sediments samples in Rashid branch.

Location	Sample code	Hazard indices				
		H_{ex}	H_{in}	I_γ (mSv/ year)	AGDE	ELCR X 10^{-6}
Berket – Elsaab	D1	0.18	0.23	0.26	237.5	142.8
	D2	0.14	0.17	0.16	185.6	111.1
	D3	0.10	0.16	0.17	158.12	94.8
Mean		0.14	0.18	0.19	193.74	116.23
Kafr-Elshekh	D1	0.23	0.28	0.31	278.2	169.3
	D2	0.21	0.28	0.28	259.7	157.9
	D3	0.10	0.12	0.14	132.87	79.7
Mean		0.18	0.22	0.24	223.59	135.63
Desouk	D1	0.15	0.18	0.22	200.58	119.2
	D2	0.09	0.11	0.13	124.16	73.9
	D3	0.17	0.22	0.24	225.84	134.8
Mean		0.13	0.17	0.19	183.52	109.3
Kafr-Elzayyat	D1	0.12	0.16	0.17	160.70	96.7
	D2	0.13	0.17	0.18	168.12	100.8
	D3	0.07	0.08	0.11	102.39	60.3
Mean		0.10	0.13	0.15	143.73	85.93
Elbehera	D1	0.23	0.31	0.32	291.29	176.4
	D2	0.22	0.27	0.31	284.8	171.2
	D3	0.13	0.17	0.19	176.43	105.5
Mean		0.19	0.25	0.27	250.84	151.03
Rashid	D1	0.16	0.20	0.21	198.18	120.5
	D2	0.90	1.24	1.15	1007.29	631.6
	D3	1.15	1.54	1.47	1278.77	801.1
	D4	0.68	0.93	0.87	764.75	478.9
Mean		0.72	0.97	0.925	812.24	508.02

Conclusion

The present work is devoted to calculate the radioactivity values of both soil and sediment samples collected from the banks and bottoms of the two branches of the River Nile. The experimental technique has been performed making use of a hyper pure Ge detector. The obtained results of the natural radioactivity contents indicate that their values are lower than the recommended average levels (32, 46, 420 Bq/kg) except those samples collected from Kafer-Elzayaat (sample: N11) and Rashid (samples: N13, N14 and N15). The health hazard indices (Ra_{eq}, D, H_{in}, H_{out}, AEDE, I_γ and ELCR) have been calculated and discussed. Higher values have been found in Kafr-Elzayaat and Rashid regions that exceed the upper international average limits. The reasons for these higher values are the existing chemical factories such as the fertilizer factory near Kafr-Elzayaat or the black sands that covers large domains in Rashid region. As a consequence, precautions and strictly rules should be applied to control the use of soil or sediment from those regions as constructing materials. The crops, agricultural and animal products, and drinking water taken from there should be accurately investigated against their radioactivity contents in order to have safe products along with precious water for local consumption.

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