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Measurements for Natural Radioactive Materials at the East & West banks of The River Nile

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Abstract: Soil samples were collected along the East and West banks of the River Nile region starting from Bait Al-mal in the West side and the second East bank of the River Nile Shambat. Gamma radiation measurements were performed using high resolution HPGe detector with low background PC multichannel spectrometer. The gamma measurements of the soil revealed the presence of the natural long-lived radioisotopes ^{238}U, ^{232}Th and ^{40}K. The ranges of their activity concentrations were 3.32±1.1~6.3±2.1 $Bqkg^{-1}$, 5.61±1.7~10.76±2.13 $Bqkg^{-1}$ and 180±7.77~291±11.6 $Bqkg^{-1}$ 'respectively'. The other factors controlling the distribution of the detected natural radioisotopes have been discussed. Absorbed dose rates have been calculated for each location with range 15.27±0.82~21.07±1.53 $nGyh^{-1}$. Also, the estimated activity utilization indexes have been presented. The ratios between the detected radioisotopes have been calculated.

Keywords: Uranium, Thorium, Potassium, Absorbed Dose Rate, Radiation Exposure

1. Introduction

There are two kinds of radiation according to their origin: natural and artificial radiation. Natural radiation comes from cosmic rays from outer space and naturally occurring radioactive materials (NORMs) that exist in food, air and our natural habitat while exposure in medical practice mostly due to diagnostic X-rays, contributes the largest fraction of human's exposure to artificial radiation. About 90% of human radiation exposures arise from natural sources [3].

Significant naturally occurring radionuclides present in the soil are ^{238}U, ^{232}Th and ^{40}K [4].

These radionuclides are not uniformly distributed hence, the knowledge of their distribution in soil plays an important role in radiation protection.

Soil not only acts as a source of continuous radiation exposure to humans but also as a medium of migration for transfer of radionuclides to biological systems [5]. Hence, the basic indicator of radiological contamination in the environment is the soil [6]. The understanding of the decay chain where series of stepwise decay in terms of half-lives of nuclei of unstable radionuclides lead to stable states in form of other nuclides is very paramount. Alpha (α) and beta (β) particles are still emitting with the gamma but their travel distance in the air is limited while gamma (γ) radiation is emitted. High levels of uranium and thorium and their decay products in rock and soil are the main sources of high natural background radiation. There is a continuous bombardment of human and his environment by these (radionuclides) ionizing radiations [7]. The long term exposure to uranium and its daughters such as radium and radon through inhalation has several health effects such as chronic lung diseases, acute leucopoenia, anemia and necrosis of the mouth. Radium causes bone, cranial and nasal tumors. Thorium exposure can cause lung, pancreas, hepatic, bone, kidney cancers and leukemia [8].

Therefore, gamma dose rates and radionuclides activity concentrations should be monitored because of their health implications.

The Nile River is the longest river in the world. In ancient times, the Nile River flooded annually, caused by rains in central Africa and in Ethiopian highlands carrying great quantities of silt in its water. [12].

The Nile River has supported many civilizations of Egypt and Sudan throughout history and continues to play a vital role in supplying precious water for drinking, irrigation, and

industry to the people of the Sudan. The Nile River plays an essential role in Sudanese life; it is the life line of Egypt and Sudan, the study of the natural radioactivity of the coasts of the River Nile is very important, and the assessment of natural dose rates will be of some interest to regional health.

The Nile is a major north-owing river in north eastern Africa. It is 6650 km long. It runs through the 10 countries of Sudan, South Sudan, Burundi, Rwanda, the Democratic Republic of the Congo, Tanzania, Kenya, Ethiopia, Uganda, and Egypt. During the last decades, there has been an increasing interest in the study of radioactivity in River Nile soil [9 ,10, 11].

2. Materials and Methods

2.1. Sampling

A total number of 30 surface soil (dry and out of the Nile water) samples were collected along the East and West banks of the River Nile region from 30 successive locations at a chosen point, data from Global Positioning System (GPS) were used for tracking the data recorded starting from Bait Al-mal in the West (15°39'0.20"N ~ 32°30'25.30"E) to the Shambat at East side (15°38'57.30"N~ 32°30'44.40"E).

The samples locations are listed in Table 1 and showed in(Figure. 1)and (Figure 2) The study area was divided into Two sections First the East bank and second West bank of the River Nile.

2.2. Study Area Description

The study area is located on the banks of the Nile River north of Khartoum, starting from Bait Al-mal in the West (15°39'0.20"N ~ 32°30'25.30"E) to the Shambat at East side (15°38'57.30"N~ 32°30'44.40"E). This area was chosen because it is an agricultural area and provide the Khartoum markets with the necessary vegetables and the agricultural land at two sides are used fertilizers from originally from Phosphate.

The significance of the current study relies on its contribution to the efforts being done to generate a radiation map for Sudan and on the targeted area, The River Nile which is of great importance due to the heavy agricultural activities involved. Level of natural radioactivity in surface soil samples collected along the east and west banks of the River Nile will be evaluated using high resolution HPGe detector. The study measures the activity concentrations of ^{238}U, ^{232}Th and ^{40}K across all of the soil samples. The radiological hazard to humans due to the radioactivity arising from radionuclides contained in soils samples is to be assessed and the absorbed dose rates based on soil radioactivity is to be estimated.

Figure 1. *Map for samples' location.*

Figure 2. *Site area under study for a map of Sudan.*

Table 1. *Sample codes, locations and types.*

Code no.	N (Degrees)	E (Degrees)	Code no	N (Degrees)	E (Degrees)
SW1	15°39'0.20"N	32°30'25.30"E	SE1	15°38'41.90"N	32°30'35.40"E
SW2	15°39'1.60"N	32°30'26.00"E	SE2	15°38'44.40"N	32°30'36.30"E
SW3	15°39'2.90"N	32°30'26.70"E	SE3	15°38'44.90"N	32°30'36.70"E
SW4	15°39'4.30"N	32°30'27.20"E	SE4	15°38'46.70"N	32°30'37.80"E
SW5	15°39'5.60"N	32°30'27.40"E	SE5	15°38'47.80"N	32°30'38.40"E
SW6	15°39'6.40"N	32°30'27.50"E	SE6	15°38'48.90"N	32°30'39.00"E
SW7	15°39'11.90"N	32°30'29.10"E	SE7	15°38'50.00"N	32°30'39.90"E
SW8	15°39'13.20"N	32°30'29.40"E	SE8	15°38'50.10"N	32°30'40.40"E
SW9	15°39'14.50"N	32°30'29.70"E	SE9	15°38'52.20"N	32°30'41.20"E
SW10	15°39'15.80"N	32°30'30.00"E	SE10	15°38'53.40"N	32°30'41.70"E
SW11	15°39'17.10"N	32°30'30.40"E	SE11	15°38'53.90"N	32°30'41.80"E
SW12	15°39'18.20"N	32°30'30.50"E	SE12	15°38'55.60"N	32°30'41.90"E
SW13	15°39'19.50"N	32°30'30.80"E	SE13	15°38'55.90"N	32°30'42.70"E
SW14	15°39'20.90"N	32°30'31.20"E	SE14	15°38'56.50"N	32°30'43.80"E
SW15	15°39'22.20"N	32°30'31.50"E	SE15	15°38'57.30"N	32°30'44.40"E

2.3. Radioactivity Measurements

The soil samples were collected from the upper layer at depth 0–30 cm using plastic cup and then placed in plastic bags and prepared. These were first placed a dry area for few minutes and then placed in an oven to be heated at a temperature of 60°C for 24 hours. This was to remove all moisture found in the samples. The samples were then sieved using 2mm 500µm mesh to differentiate particle size. A Marinelli beaker (size 500ml) was used to seal the soil samples, weighted and labelled. The samples were stored for at least one whole month to reach secular equilibrium. The samples filled in the beaker are of the same volume and are assumed to be homogenous with respect to parameter to be measured. Marinelli beakers are chemically resistant polypropylene, light weight and seamlessness which eliminate leaks. They are used for gamma-spectral analysis because of their high counting efficiencies and because they minimize gamma-ray attenuation. The details of the sample characteristics are shown in Table 2 [40].

Table 2. *Show sealing date at weights for two samples as ex.*

Sample ID	Sealing Date	Beaker Weight (g)	Sample Weight (g)
SE1	12th March 2014	83.61	1250.61
SW1	30th March 2014	83.45	1250.73

For gamma analysis, the soil samples were placed directly over the detector. The measured activity concentrations were presented as $Bqkg^{-1}$.

The (1460.83 keV) gamma transition was used to determine the concentration of ^{40}K in different samples. The gamma transitions used to determine the concentrations of

^{238}U and ^{232}Th were listed in Table 3.

The gamma ray measurements were performed with a low background spectrometer with PC multichannel analyzer and HPGe detector high resolution.

The details of the coaxial hyper-pure germanium detector (HPGe) and the parameters used for this experimental project are as follows:

1. Model name: GCW2021
2. Cryostat Model: 7500-RDC-4ULB
3. Operating Voltage: 3000 Volt
4. Serial number: 06308
5. Preamplifier Model: 2002C
6. Standard calibration Sources use are ^{152}Eu, ^{226}Ra, ^{232}Th and NG3

2.4. Quality Control

Three types of calibrations were carried out for HPGe detector. These are energy, resolution and efficiency calibrations. Efficiency calibration was performed using ^{152}Eu standard source. ^{152}Eu was manufactured by Amersham International plc. Precision and accuracy were checked by parallel measurements of IAEA inter comparison soil samples; IAEA-300 and IAEA-315. In order to determine the background due to the existence of natural radionuclides in the environment, an empty polyethylene container with the same geometry and the same measuring conditions as for the samples, was used. The uncertainties in the calibration of the peak areas of these photo peaks were within ±2%.

2.5. Energy Calibration

The initial energy calibration was performed using a standard source (^{152}Eu) with an activity of 2.549kBq. Source is placed on the detector for a preset time and counts for seconds. The energies of ^{152}Eu source, ranging from 121.78, 244.96, 344.27, 778.90, 964.07 and 1408keV were used to calibrate the detector. The linear relationship between energy and channel is shown in Figure 2.1. The displayed equation on the plot is used to find other peaks that do not belong to standard source ^{152}Eu. The equation relates to the gamma energy at any given channel x. The spectra energy lines corresponding to the counts are shown in Figure 3.

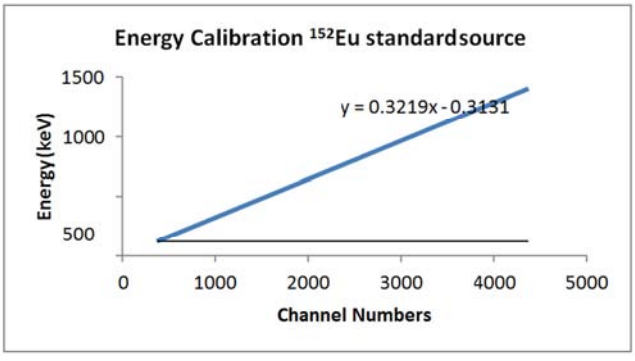

Figure 3. *Linear relationship between channel numbers corresponding to Energy.*

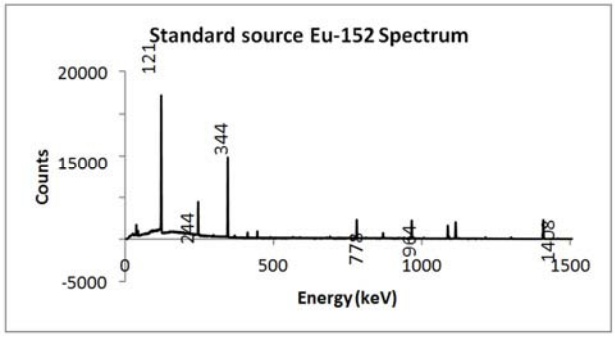

Figure 4. *Spectra lines from the 152Eu calibration source.*

2.6. Efficiency Calibration

In efficiency calibration, four standard sources ^{226}Ra, ^{232}Th, NG3 and ^{152}Eu were used. The gamma ray energy lines ranges from ~100 to 2.6MeV were used to analyze the absolute full energy peak detection efficiency. The NG3 source consisting of ^{241}Am, ^{57}Co, ^{60}Co, ^{85}Sr, ^{88}Y, ^{109}Cd, ^{137}Cs, ^{139}Ce, and ^{203}Hg provided by Hi-tech sources. The values obtained are used to plot the efficiency curve as shown in Figure 5.

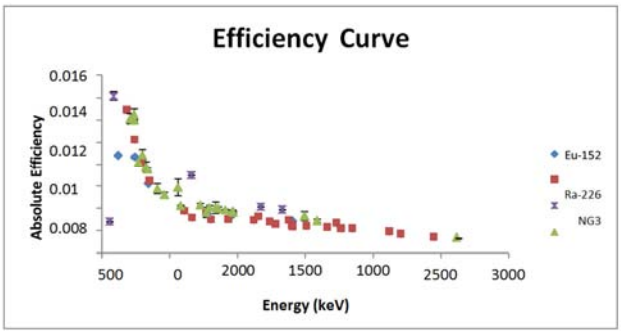

Figure 5. *The absolute full-energy peak efficiency measurement using the Standard sources ^{226}Ra, ^{232}Th, ^{152}Eu and NG3.*

Table 3. *Gamma rays and their related isotopes used to calculate the activity concentrations of ^{238}U, ^{232}Th and ^{40}K.*

Nuclide	Half-life (years)	Gamma ray energy (keV)	Isotope
^{238}U	4.468 ± 0.003 × 10^{9}	63.290 ± 0.02	^{234}Th, ^{234}Pa
		295.224 ± 0.002	^{214}Pb
		351.932 ± 0.002	^{214}Pb
		609.312 ± 0.007	^{214}Bi
		1120.287 ± 0.01	^{214}Bi
^{232}Th	1.405 ± 0.006 × 10^{10}	238.632 ± 0.002	^{212}Pb
		338.320 ± 0.003	^{228}Ac
		727.330 ± 0.009	^{212}Bi
		968.971 ± 0.017	^{228}Ac
^{40}K	1.277 ± 0.008 × 10^{9}	1460.83	Single

Table 4. *The ORETICAL Gamma ray exposure rates and gamma dose rate 1 m above a plane and infinite homogeneous soil medium per unit radioelement concentration assuming radioactive equilibrium in the U and Th decay series (IAEA, 1989, IAEA, 1991, Lovborg, 1984).*

Radioelement concentration	Exposure rate (μR/h)	Dose rate (nGy/h)
1% K	1.505	13.078
1 ppm U	0.653	5.675
1 ppm Th	0.287	2.494

Table 5. *The global average annual effective dose from natural radiation sources (UNSCEAR, 1988).*

Source of irradiation	External (mSv)	Internal (mSv)	Total (mSv)
Cosmic rays	0.410 (17)		0.410 (17)
Cosmo genic radionuclides		0.015 (1)	0.015 (1)
Natural sources:			
^{40}K	0.150 (6)	0.180 (7)	0.330 (13)
^{238}U – series	0.100 (4)	1.239 (51)	1.339 (55)
^{232}Th – series	0.160 (7)	0.176 (7)	0.336 (14)
Total	0.820 (34)	1.616 (66)	2.436 (100)

Note: relative values are given in brackets (%).

3. Results and Discussion

3.1. ^{238}U, ^{232}Th and ^{40}K Activity Concentrations

The activity concentrations of the detected radionuclides ^{238}U, ^{232}Th and ^{40}K are presented in Table 6 and showed in Figure 6

Elemental concentrations are calculated from measured radiological concentrations in the soil samples. First, the radiological concentration of nuclide i, *C,* in units of Bq kg^{-1} of soil, is calculated using,

$$C=\frac{ci}{Yi.Mx.\varepsilon i} \quad (1)$$

where *Ci* is the measured count rate [cts/sec], *Yi* is the yield of gamma rays per disintegration, *εi* is the efficiency [cts/gamma] of the detector at the energy of the nuclide i gamma ray, and *Mx* is the dry mass of the soil sample being analyzed.

The activity concentration ranges for ^{238}U, ^{232}Th and ^{40}K were at East side 3.91±0.44 ~ 5.72±2.15 Bqkg^{-1} with average 4.5±1.23 Bqkg^{-1}, 5.61±1.7~10.76±2.13 Bqkg^{-1} with average 7.8±1.99 Bqkg^{-1} and 180±7.77~ 291±11.6 Bqkg^{-1} with average 240.26±7.9Bqkg^{-1}, 'respectively'. At West side 3.32±1.1 ~ 6.3±2.1 Bqkg^{-1} with average 4.7±1.85Bqkg^{-1}, 6.92±2.06~ 9±1.3 Bqkg^{-1} with average 7.92±1.42 Bqkg^{-1} and 197.5±4.77 ~ 267±9.68 Bqkg^{-1} with average 231.34±6.47 Bqkg^{-1} 'respectively'.

Table 6. *Activity concentrations (Bqkg^{-1}) of ^{238}U, ^{232}Th and ^{40}K with their uncertainties, absorbed dose (nGyh^{-1}), in the coasts of the Nile River Soil samples collected from west and east side.*

sample code no	^{238}U	^{232}Th	^{40}K	absorbed dose	^{238}U/^{232}Th	^{232}Th/^{238}U	^{232}Th/^{40}K	^{238}U/^{40}K	AEDR out (mSv/y)	AEDR in (mSv/y)
SE1	5.31±1.52	10.76±1.93	277±9.82	21.07±1.53	0.5	2.02	0.04	0.02	0.026	0.10
SE2	4.74±1.32	6.92±1.2	232±5.3	16.38±0.63	0.7	1.46	0.03	0.02	0.02	0.08
SE3	4.74±0.7	8.53±1.07	180±7.77	15.27±0.82	0.55	1.8	0.05	0.03	0.019	0.074
SE4	4.45±0.5	6.15±1.1	240±7.19	16.08±0.57	0.72	1.4	0.026	0.02	0.02	0.08
SE5	4.8±1.2	7.07±2.06	252±12.24	17.43±0.8	0.7	1.5	0.03	0.02	0.021	0.085
SE6	5.07±1.6	9.23±1.42	252±8.2	18.9±1.03	0.55	1.82	0.04	0.02	0.023	0.092
SE7	4.18±0.35	8±2.07	227±7.29	16.65±0.73	0.52	1.91	0.035	0.02	0.02	0.081
SE8	5.72±2.15	5.61±1.7	232±3.77	15.92±0.67	1.01	1	0.024	0.024	0.02	0.08
SE9	4.6±0.71	7.76±2.07	291±11.6	19.35±1.03	0.6	1.7	0.026	0.015	0.023	0.094
SE10	4.51±1.6	6.23±2.5	223±4.04	15.44±0.44	0.72	1.4	0.03	0.02	0.02	0.075
SE11	3.91±0.44	10±1.7	223±11.08	17.69±1.2	0.4	2.56	0.045	0.02	0.021	0.086
SE12	5.07±1.15	10.76±2.13	202±11.82	17.82±1.39	0.5	2.12	0.053	0.025	0.022	0.09
SE13	5.04±1.43	6.54±1.02	257±5.83	17.30±0.66	0.77	1.3	0.025	0.02	0.021	0.084
SE14	5.34±2.12	6.54±2.5	277±6.63	18.27±0.72	0.81	1.3	0.024	0.02	0.022	0.09
SE15	5±1.6	6.77±1.5	239±6	16.68±0.64	0.74	1.35	0.03	0.02	0.02	0.081
SW1	5.5±2.32	6.92±2.06	257±5.31	17.75±0.75	0.8	1.25	0.027	0.021	0.022	0.087
SW2	3.32±1.1	8.46±1.18	242±7.74	17.22±0.79	0.4	2.54	0.035	0.013	0.021	0.084
SW3	4±1.2	8.46±1.3	267±9.68	18.56±0.95	0.5	2.11	0.032	0.015	0.023	0.091
SW4	5.64±2.19	7±2	237±3.87	17.03±0.81	0.8	1.24	0.03	0.024	0.02	0.083
SW5	4.5±1.45	7.7±1.15	197.5±4.77	15.35±0.67	0.6	1.71	0.04	0.022	0.018	0.075
SW6	4.8±2.1	8.5±1.3	208±5.31	16.45±0.83	0.6	1.77	0.04	0.023	0.02	0.08
SW7	5.34±2.8	7.7±2.15	247±6.82	17.8±0.85	0.7	1.44	0.031	0.022	0.022	0.087
SW8	5.46±1.2	9±1.3	208±5.31	17.06±0.71	0.6	1.64	0.043	0.026	0.02	0.084
SW9	4.15±1.97	7.7±1.08	210±7.17	15.72±0.91	0.54	1.85	0.04	0.02	0.02	0.077
SW10	6.3±2.1	7.7±1.2	222±2.65	17.15±0.6	0.82	1.22	0.034	0.03	0.021	0.084
SW11	4.24±1.97	6.92±2	263±5.31	17.47±0.7	0.61	1.63	0.026	0.016	0.021	0.086
SW12	4.6±2.1	6.92±2.1	232.6±7.44	16.35±0.9	0.66	1.5	0.03	0.02	0.02	0.08
SW13	4±1.2	8±1.2	204±6.29	15.6±0.62	0.5	2	0.04	0.02	0.02	0.076
SW14	4.5±1.45	9.23±1.14	217±8.78	17.19±0.86	0.48	2.05	0.042	0.02	0.021	0.084
SW15	4±1.2	8.61±1.4	258±10.68	18.28±1.02	0.46	2.15	0.033	0.015	0.022	0.09
Average	4.6±1.54	7.86±1.705	235.8±7.185	17.175±0.83	0.602	1.69	0.0345	0.0205	0.0216	0.0835
Stand. Dev.	9.22	6.23	200.21	7.3	1.34	0.58	0.03	0.05	0.04	0.46
Max.	6.3	10.76	291	21.07	1.01	2.56	0.053	0.026	0.026	0.01
Min.	3.32	5.61	180	15.27	0.4	1	0.024	0.015	0.018	0.074

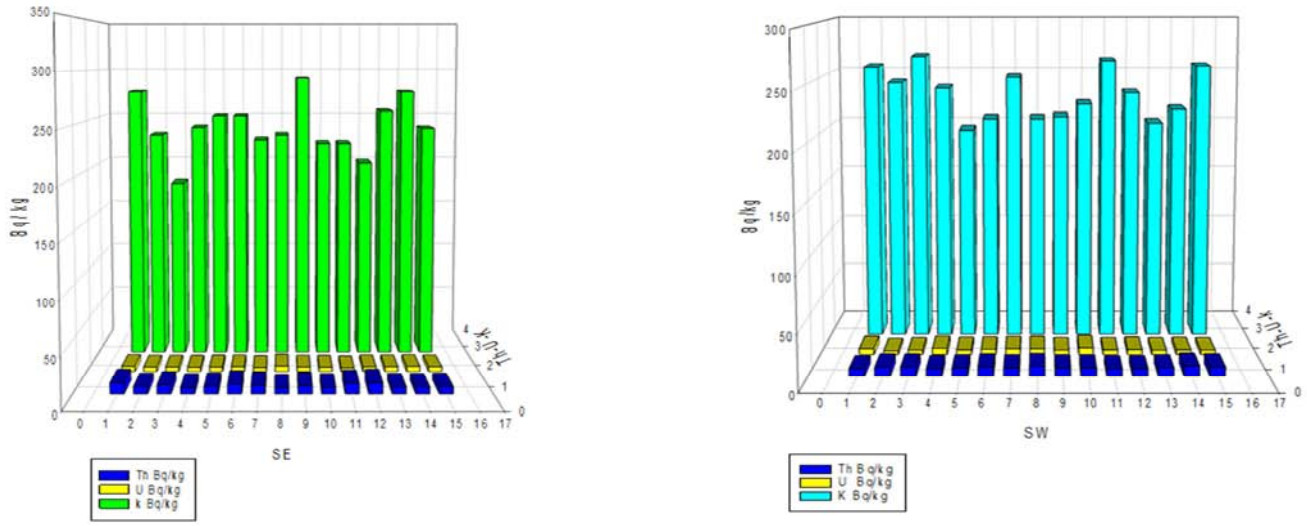

Figure 6. *^{238}U, ^{232}Th and ^{40}K concentrations (Bq kg^{-1}) in the east and west coasts of the Nile River soil samples.*

Table 7. *Comparison data between the present study ranges of the measured ^{238}U, ^{232}Th and ^{40}K in the two sections with the other national and international Soil and Sediments samples data.*

Location Reference	^{238}U	^{232}Th	^{40}K	
Present study ranges				
SE	3.91±0.44~5.72±2.15	5.61±1.7~10.76±1.93	180±7.77~291±11.6	
SW	3.32±1.1 ~6.3±2.1	6.92±2.06~ 9±1.3	197.5±4.77~267±9.68	
Upper Egypt soil	-	12.5±1.7	224±13	Shaban et al. (2008)
Nile Delta and Middle Egypt sediments				
Clay loam silt	15.5	17.9	317	Ibrahiem et al. (1993)
Sandy loam	14.8	15.5	288.6	Ibrahiem et al. (1993)
Nile Estuaries				
Damietta Eastern shore sediments	193.2	267.4		El-Tahawy et al. (2001)
Damietta Western shore sediments	3.3–10.5	2.9–12.7		El-Tahawy et al. (2001)
Other rivers				
Danube River, Bezdan, Serbia	31 ±6	26 ± 4	395 ± 17	Bikit et al. (2006)
Danube River, Petrovaradin, Serbia	34 ± 10	34 ± 4	430 ± 40	Bikit et al. (2006)
Danube River, Novi Sad (2006)	25 ±6	23 ± 3	331 ± 23	Bikit et al.
Krka River, Croatia		1.9–29.4	18–45	Cukrov and Bariši´c (2006)
Loco Bayon basin	20.6–47.	6 24.7–70.5		Yeager et al. (2002)

Table 8. *Natural radionuclide content in soil Data not referenced are from UNSCEAR 2000 Survey of Natural Radiation Exposures.*

Region / country	Concentration in soil (Bqkg^{-1})					
	^{40}K		^{238}U		^{232}Th	
Africa	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Algeria	370	66- 1150	30	2- 110	25	2 -140
Egypt	320	29 -650	37	6- 120	18	2- 96

Table 9. *External exposure rates calculated from various concentrations of terrestrial radionuclides in soil.*

Radionuclide	Concentration in soil (Bqkg^{-1})		Dose coefficient [I20, S49] (nGyh^{-1} per Bqkg^{-1})	Absorbed dose rate in air (nGyh^{-1})	
	Median value	Population-weighted value		Median value	Population-weighted value
^{40}K	400	420	0.0417	17	18
^{238}U	35	33	0.462	16	15
^{232}Th	30	45	0.604	18	27
Total				51	60

Table 10. *External exposure rates from terrestrial gamma radiation Data not referenced are from UNSCEAR Survey of Natural Radiation Exposures (UNSCEAR2000).*

Region / country	Population in 1996 (10^6)	Absorbed dose rate in air ($nGyh^{-1}$)			
		Outdoors		Indoors	
Africa		Average	Range	Average	Range
Algeria [B4]	28.78	70	20- 133		14-2 100
Egypt [H9, I13]	63.27	32	8- 93		
Namibia [S12]	1.58				
Sudan	27.29	53	26- 690		

The study area was divided into two sections along the East and West banks of the River Nile.

Table 6 summarizes the activity concentration ranges for the radionuclides under considerations in each section.

A. The first section: the East bank of the Nile River

The first section is extended from station SE1 to SE15 as listed in Table 6. This section includes the highest and lowest concentration values of ^{232}Th on the whole study area. Relatively high level of ^{238}U concentration has been observed at SE8. This is could be due to the soil type. Irregular spatial distribution has been observed for ^{238}U and ^{232}Th radioisotopes.

The first section was characterized by wide ranges of ^{238}U and ^{232}Th; from 3.91±0.44 to 5.72±2.15 $Bqkg^{-1}$ with average 4.5±1.23 $Bqkg^{-1}$, and from 5.61±1.7 to 10.76 ±1.93 $Bqkg^{-1}$ with average 7.8 ±1.99 $Bqkg^{-1}$ 'respectively'.

Decline trends of ^{40}K values were observed in the first at SE3 and second sections SW5 as shown in Figure 6

The first section showed the decline trend of ^{40}K values decreasing from SE9 *(*291 $Bqkg^{-1}$*)* to

SE3 (180Bq kg^{-1}).

This could be due to the change of the soil type with the increase of the river flow.

B. The second section: the West bank of the Nile River

This section is extended from station SW1 to SW15 as listed in Table 6.

Relatively high level of ^{238}U concentration has been observed at SW10. This is could be due to the presence of phosphate fertilizers in the soil because it is an agricultural area.

This section was characterized by irregular distribution patterns for ^{238}U, ^{232}Th and ^{40}K radioisotopes.

The second section was characterized by wide ranges of ^{238}U and ^{232}Th; from 3.32±1.1 to 6.3±2.1 $Bqkg^{-1}$ with average 4.7±1.85 $Bqkg^{-1}$, and from 6.92±2 to 9±1.3 $Bqkg^{-1}$ with average 7.92±1.42 $Bqkg^{-1}$ 'respectively'.

The second section showed the decline trend of ^{40}K values decreasing from SW3 *(*267 $Bqkg^{-1}$*)* to SW5 *(*197.5 $Bqkg^{-1}$*)*.

This could be due to the change of the soil type with the increase of the river flow. The confluence of two Niles (blue and white Niles) play an important role for increase the levels of ^{238}U and ^{232}Th due to the erosion processes.

C. Effective factors: Many factors could be distinguished to play an effective role in the distribution of the detected natural radioisotopes along the study area. The First and the most important that the presence of fertilizers in the soil because it is an agricultural area. The Second factor the soil types. Thirdly could be the locations of the soil sample. The samples collected along the East and West banks of the Nile River.

The other factor could be due to the human activities and its corresponding waste. Moreover, the contamination from the drainage of fertilizers hold radioactive materials, the mineralogical of the sites such as the presence of calcium carbonate and the chemistry of the Nile water could be added as another factors controlling the distribution of the radioisotopes under consideration.

The geographical features of the Nile are also considered as important factors controlling the distribution of the radioactive isotopes under consideration. Radioactive materials could be transported with the flow of the Nile water from the central Africa and Ethiopia such as the black sand, which is characterized by relatively high radioactivity concentrations [14]; [13].

The other factor erosion processes can play important role to remove the upper light sediments layer and expose the old soils, which contains black sand.

Table 7 shows the concentration ranges obtained from each section compared with the other referenced values. The detected ranges of ^{238}U and ^{232}Th are in agreement with the other referenced data for the other parts of Nile River [16]; [18]; [14]; [17]; [20].

3.2. Absorbed Dose Rate (DR)

The absorbed dose rates due to gamma radiations in air at 1 m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) were calculated which based on the guidelines provided by UNSCEAR [11]. The conversion factors used to compute the absorbed gamma dose rate (DR) in air per unit activity concentration in $Bqkg^{-1}$ (dry weight) corresponds to 0.428 $nGyh^{-1}$ for ^{238}U, 0.666 $nGyh^{-1}$ for ^{232}Th and 0.042 $nGyh^{-1}$ for ^{40}K. Therefore DR can be calculated as follows:

$$DR(nGyh^{-1}) = 0.428A_U + 0.666\ A_{Th} + 0.042A_K \quad (2)$$

Table 6 shows the absorbed dose rates calculated from ^{238}U, ^{232}Th and ^{40}K activity concentrations for each location based on the conversion factors given by [20]. The range of the total absorbed dose rates was from at East side 15.27±0.82 ~ 21.07±1.53 $nGyh^{-1}$with average 17.35±0.86 $nGyh^{-1}$.

At West said 15.35±0.67 ~18.56±0.95 $nGyh^{-1}$ with

average 17±0.8 nGyh^{-1}. The lowest values for the absorbed dose rate due to natural radionuclides were detected for sandy soil.

The population-weighted average is 84 nGyh^{-1} with national averages ranging from 20 to 200 nGyh^{-1}. [2]

The values are decreased according to the fractional utilization of the materials. This could be due to the spatial variations of minerals holding in the soil.

All the samples exhibit dose rates that range from 15 to 21 nGyh^{-1}.

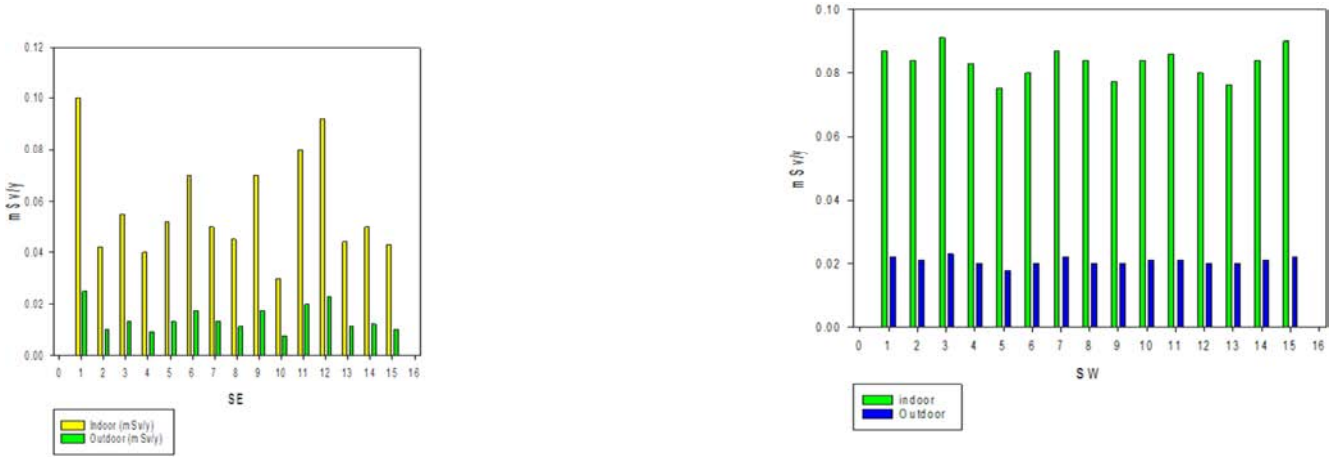

Figure 7. *The contribution of the annual effective dose rate (AEDR) for the east and west banks of the Nile river soil (indoor) (outdoor).*

3.3. Annual Effective Dose Rate (AEDR)

The annual effective dose rate (AEDR) in mSvy^{-1} resulting from the absorbed dose values (DR) was calculated using the following formula. The annual effective dose (Table 6) ranged between at East side (outdoor) 0.019 ~0.026 mSvy^{-1} (indoor) 0.074 ~ 0.1 mSvy^{-1}. And at west side (outdoor) 0.018 ~ 0.023mSvy^{-1} (indoor) 0.075 ~ 0.091 mSvy^{-1} with a mean value of 0.04 mSvy^{-1}. In normal background areas, the average annual indoor effective dose from terrestrial radionuclides is0.46 mSvy^{-1}. Therefore, the obtained mean value from this study (0.052 mSvy^{-1}) is lower than the world average value.

Ann. Eff. dose rate(mSvy^{-1}) = DR(nGyh^{-1}) ×8760h y^{-1} × 0.7 × 10^3 mSv / 10^9 nGy × 0.2 (outdoor)

AEDR = DR × 1.2264 × 10^{-3} [2] (outdoor)

Ann. Eff. dose rate(mSvy^{-1}) = DR(nGyh^{-1}) ×8760h y^{-1} × 0.7 × 10^3 mSv / 10^9 nGy × 0.8 (indoor)

AEDR = DR × 4.9056 × 10^{-3} [2] (indoor)

The resulting worldwide average of the annual effective dose is 0.48 mSvy^{-1}, with the results for individual countries being generally within the 0.3 - 0.6 mSvy^{-1} range Therefore the obtained mean value from this study (0.052 mSvy^{-1}) is lower than the world average value.

3.4. ^{238}U and ^{232}Th Activity Ratios

The investigation of ^{238}U:^{232}Th activity ratio calculations revealed that ^{232}Th activity concentrations are seen to be on the average 1.6 times higher than the ^{238}U activity concentration in the measured at East bank of the Nile River soil and at the West bank of the Nile River the investigation of ^{238}U:^{232}Th activity ratio calculations revealed that ^{232}Th activity concentrations are seen to be on the average 1.7 times higher than the ^{238}U activity concentration.

SE8 showed the highest U/Th ratio (1.01).

This indicated that relatively equal amount of ^{238}U (5.72 Bqkg^{-1}) exist than ^{232}Th (5.61 Bqkg^{-1}). This is could be due to the presence of the human activities and its corresponding waste. Moreover, the contamination from the drainage of fertilizers hold radioactive materials, and the soil type loamy soil at SE8 which have relatively high amount of ^{238}U. On the other hand, SE11 showed the lowest U/Th ratio (0.4). This indicated that this location has ^{232}Th activity concentration (10 Bqkg^{-1}) higher than ^{238}U (3.91 Bqkg^{-1}). At one samples (SE8), equality has been detected between ^{238}U and ^{232}Th activity concentrations. This could be due to the differences of the mineralogy of the soil type. Also, it could be due to the geological and solubility differences between ^{238}U and ^{232}Th.

From the other side, Th/U ratios have been calculated and listed in Table 6. The presence of calcium carbonate sediments could be playing an important role for depletion of the ^{232}Th relative to ^{238}U [16]. [30] have mentioned that 0.7–0.4 is the typical range for igneous zircon. [31] enlarge the previously mentioned range to 0.3–2 for xenolith zircon. All soil samples of the coasts of the Nile River have Th/U ratio within this range. The majority of the measured samples have Th/U ratios match with this range. This could be indicated that the present study confirmed the presence of zircon in the banks of the Nile River soil.

4. Conclusion

a) The detected natural radionuclides ^{238}U, ^{232}Th and ^{40}K showed irregular distribution patterns along the study area. The investigation of the spatial distribution of the banks of the Nile soil revealed that there are many factors affecting the distribution of the natural radioisotopes in the area under consideration.

These factors could be as the following:

(1) The phosphate fertilizers contain high concentrations

of uranium compared with other types of Fertilizers, because there is a companion uranium phosphate.

(2) the presence of fertilizers in the soil because it is an agricultural area;

(3) the geographical feature of the stream such as the confluence of two Niles; (blue and white Niles)

(4) chemistry of the Nile water

(5) human activities and its corresponding waste.

b) The significance of the current study relies on its contribution to the efforts being done to generate a radiation map for Sudan and on the targeted area, The River Nile which is of great importance due to the heavy agricultural activities involved.

c) The activity concentrations and the absorbed dose rates, due to ^{238}U, ^{232}Th and ^{40}K, and annual effective dose rate (AEDR). These values obtained from the coastal soil were less than the recommended safe and criterion limits given by UNSCEAR.

d) The activity concentration measurements showed that ^{232}Th activities are higher than ^{238}U activity concentrations by 1.4 fold along the study area.

e) The study uses Spectral HPGe detector to evaluate the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in 30 soil samples taken from the Nile east and west banks northern Khartoum. The activity concentrations may be limited to the randomly taken samples and the results may not be generalized to the whole Nile banks. More samples are needed to evaluate

f) Results of the study could serve as an important baseline radiometric data for future epidemiological studies and monitoring initiatives in the study area. The statistical methods were applied to study the relationship between all the calculated natural radionuclides

g) The Absorbed Dose Rate in Air, Effective dose rate in Air and was calculated from the activity concentrations of (^{238}U) series, ^{232}Th series and ^{40}K. All results were found to be less than world maximum values.

h) All soil samples of the banks of the Nile River have Th/U ratio within this range (1 – 2.56). The majority of the measured samples have Th/U ratios match with this range. This could be indicated that the present study confirmed the presence of zircon in the coasts of the Nile River soil.

The data collected in this experiment could be used for various purposes. It could be used to determine whether or not the radiation levels in the River Nile basin pose a health hazard to the local population or to wildlife. It could also be used to determine the chemical composition of the soil, and by comparison to soil samples that are not subject to the effects of fertilizers, the effects of fertilizer on the chemical composition of soil could be determined.

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