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Assessment of Radiological Hazard Indices in Abu Rusheid Area, South Eastern Desert, Egypt, Using Gamma Ray Spectroscopy

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The radiological hazard indices were determined using NaI(Tl) detector for twenty six collected rock samples from Abu Rusheid area, South Eastern Desert, Egypt. The Eastern Desert of Egypt is a source of granitic rocks used for uranium mining and also used as raw materials for building.For this reason cataclastic (mylonitic) rock samlpes were investigated to evaluate the radiation hazard indicators and compare them with the world average values.The results show that the distribution of radionuclides activity concentrations in the rock sample varieties affects the values of the absorbed dose rate in the studied rocks to be higher than the worldwide limit that are not safe for human. The average values of the total annual effective dose varied from 3.30 to 7.51 $mSvy^{-1}$ and the lifetime cancer risk ranged from 2.31to 5.25. From the radiation protection point, the results were found above the worldwide average. These data record the radioactivity background levels in rock samples and could be used as reference information to assess any changes in the radioactivity background level due to different geological processes in the investigated area.

Keywords: Gamma *ray spectroscopy, Annual effective dose, Hazard indices, Rock samples*

Introduction

The study of radionuclides and their generation in natural samples has become one of the most important issues due to its impact on human health, plant and animal. Gamma ray surveys are used in geological, geochemical and environmental mapping for mineral exploration, Natural radioactive elements such as uranium, thorium can be found everywhere in the world [1]. Natural radioactive materials such as uranium and thorium chains in addition to potassium are found in different percentages in soil, water, animal, human, oil and phosphate [2,3]. The variation in radionuclides concentrations of soil depends on the mineralogical composition, chemical composition, and physical properties [4]. All raw materials and products derived from rock and soil contain various amounts of mainly natural radionuclides elements.

Exposure to radiation is classified into: the external exposure as a result of gamma rays and the internal exposure due to the inhalation of radon, thoron and their progeny. These radionuclides are the sources of the external and the internal radiation exposures in dwellings, mining sites, nuclear facilities. The activities of radionuclides depend on geological and geographical conditions as well as geochemical characteristics of those materials. The importance of studying the radiation level and radionuclides distributions in our environment comes from the continuing human population growth and man made nuclear activities. The earth's natural

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radiation comes from the presence of radioactive elements such as thorium, uranium and potassium in the environment at different levels due to geological and geographical conditions and is the main cause of external exposure due to the emission of gamma rays [5].

Many previous works have linked cancer with radiation from natural and non-natural sources. This includes lung cancer, breast and thyroid glands. Long exposures lead to a greater the risk of cancer, although it appears after decades of exposure and is no different from cancer caused by other factors [6]. Various human activities involving the use of radioactive materials and radiation tend to cause radiation exposure in addition to the natural exposure. An example of such activities includes mining, processing and the use of raw materials, which NORM. Many studies have investigated the radioactive elements in different rock samples. From the radiological point, the area under study attracted the attention of several authors [5, 7, 8].

The present work aimed to assess the natural radionuclides and the radiological hazard indices in samples collected from Abu Rusheid area, which is used as an exploration area for uranium mining, and may also be used as building materials in the future, using [NaI(Tl)] gamma ray spectroscopy, to assess the radiological risk associated with among processing and the accumulated effluent in the investigated area.

Geology of Abu Rusheid

The area of Wadi Abu Rusheid, Wadi Nugrus and Wadi Sikait comprises two napes (ophiolite rocks and arc assemblage), separated by ophiolitic mélange. These rocks associations are intruded by intracratonic gabbroic and granitic rocks [9, 10]. The rocks are generally intensively deformed and show clear gradual variation from low grade green schist facies, through the medium grade amphibolite facies (staurolite - kyanite - silliminite facies) [11]. It is mainly constituted of meta-peridotites, meta-pyroxenites, layered metagabbros and ortho-amphibolites [12]. The detailed geologic of the study area (3.0 km^2) is characterized by low to moderate topography.

Abu Rusheid granitic pluton is elongated in north west to south east (12 km in length) and is thinning in north east to the south west (3 km in width). The cataclastic rocks occupy the core of that granitic pluton. The granitic rocks are represented from the NW direction by porphyritic biotite granites followed by deformed biotite granites and two mica granites (abundant garnet and kyanite crystals), whereas the muscovite granites occupy the SE part of the pluton [7, 13].

Materials and Methods

Twenty six cataclastic (mylonitic) rock samples were collected from Abu Rusheid, South Eastern Desert, Egypt. The samples were analyzed by gamma ray spectroscopy [NaI(Tl)] to determine the natural radionuclides concentration and the radiological hazard indices for the studied area. The samples were collected at an equal distance of 50 m between each other, then dried in air for four days and Then dried at 105 ° Cfor 4 hours to remove moisture completely.The samples were homogeneously crushed down to 200 mesh, which is the most suitable size for heavy minerals, and were put in circular plastic containers 10 cm diameter and 3cm height, it is then closed for four weeks until equilibrium occurs between the parent and daughter nucleus [14]. To ensure that radon and radon decay products exist within the same sample. The measuring system consists of NaI(Tl) crystal, 76x76 mm detector housed in thick lead shield. The detector is also connected with PCA-8000 computer based, 8192 multichannel analyzer. The gamma ray spectroscopy system was calibrated before it is used. The 1460 KeV photo peak was used to evaluate the ^{40}K activity, 1764 KeV gamma line of ^{214}Bi for ^{226}Ra and 2610 KeV gamma line of ^{208}Tl for ^{232}Th. The conversion values of Ra, Th in ppm, as well as K%, were converted to activity concentration in $Bqkg^{-1}$, by using the conversion factors given by the Polish Central Laboratory for Radiological Protection [15]. The spacific activity for 1ppm sample of ^{226}Ra equalized 11.1 $Bqkg^{-1}$, 1ppm ^{232}Th is 4.06 Bq kg^{-1} and 1 K % equal 313 $Bqkg^{-1}$ [16, 17]. Using radiation activity of radionuclides, the risk factor was calculated including ; radium equivalent activity, absorbed dose, annual effective dose, gamma index, external and internal hazard index, excess lifetime cancer risk and annual gonadal equivalent dose. These parameters are indicators of the health status of the human beings and environment.

Radium equivalent activity (Ra_{eq})
The distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil has been defined in terms of radium equivalent (Bqkg^{-1}), and it given by:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

Ra_{eq} is radium equivalent (Bqkg^{-1}) and (A_{Ra} - A_{Th} - A_K) are the specific activities of (^{226}Ra - ^{232}Th - ^{40}K) in Bqkg^{-1} [18,19].

Absorbed dose rate (D)
The absorbed dose rate in air (D) depends on the specific activity of ^{226}Ra, ^{232}Th and ^{40}K , was calculated using the following equation:

$$D\left(nGyh^{-1}\right) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (2)$$

Where D is the absorbed dose rate (nGyh^{-1}) [6, 20].

Annual effective dose equivalent (AEDE)
In this case, a conversion coefficient from the absorbed dose in air to the effective dose must take into account value of 0.7 SvGy^{-1} a conversion factor from air intake to the effective dose received by adults, where the outdoor occupancy factor 0.2 and 0.8 for indoor occupancy factor. It was calculated using the equations **[**6]:

$$AEDE_{OUT} = D\left(nGh^{-1}\right) \times 8760hy^{-1} \times 0.7 \times 10^{-6} \times 0.2 \quad (3)$$

$$AEDE_{In} = D\left(nGh^{-1}\right) \times 8760\ hy^{-1} \times 0.7 \times 10^{-6} \times 0.8 \quad (4)$$

$$Tottal\ Annual\ effective\ dose\ \left(mSvy^{-1}\right) = AEDR_{Outdoor} + AEDR_{Indoor} \quad (5)$$

Representative level index (I_γ):
Representative level index ***(I_γ)*** is the estimation of gamma radiation associated with the natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the soil by this equation [21]:

$$I(\gamma) = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (6)$$

External (H_{ex}) and Internal hazardous index:
In the case of constructing a building using materials with a percentage of radionuclides produced by an external radiation(external hazard index) dose and calculated from the following relationship.

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Another hazard index, called the internal hazard index (H_{in}) that controls the internal exposure to radon and its radioactive progeny, was calculated using the equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (8)$$

In order to ensure that there is any harmful effect, the value of internal and external indices should not exceed 1 mSvy^{-1} to the population, and to keep the radiation hazard negligible[22, 23].

Excess lifetime cancer risk (ELCR):
Is the possibility of cancer development due to exposure to radiation, taking into account the average age of human 70 years was calculated from the following relationship**:**

$$ELCR = AEDE \times DL \times RF \quad (9)$$

Where DL is the average duration of a lifetime (estimated to be 70 years) and RF is the risk factor (Sv), for stochastic effects, assigned by ICRP as 0.05/Sv for the public [1].

Annual Gonadal equivalent dose (AGED):
Measurement of the threat resulting from the effect of a certain level of radiation on the gonads called annual gonadal equivalent dose and calculated from the following relationship[24].

$$AGED\left(mSvy^{-1}\right) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (10)$$

Results and Discussion
The location of the collected samples and the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and radium equivalent activity are evaluated and given in Table (1). The large variation of activity concentrations observed at different locations in study area refers to variables in the mineralogical content present in soil due to regional geology of the study area. Based on UNSCEAR recommendations for the activity values of ^{226}Ra, ^{232}Th and ^{40}K are 50, 50, and 500 Bqkg^{-1}, respectively, and also the value of radium equivalent activity is 370 Bqkg^{-1} [25]. The average values in ppm for three natural nuclides equal 64.65 , 178.73 ppm and 3.04% for ^{226}Ra , ^{232}Th and ^{40}K respectively. However, the activity concentration of ^{226}Ra ranged from 133.2 to 1542.9 Bqkg^{-1} and the average value equal 717.66 Bqkg^{-1} . Also the activity concentration of ^{232}Th ranged from 682.08 to 2457.27 Bqkg^{-1} , and the average value equals 732.80 Bqkg^{-1}. But for ^{40}K varied from 71.99 to 1521.18 Bqkg^{-1} , and the average value 1307.02 Bqkg^{-1}. The values of activity concentrations are higher than the world average of 35 Bqkg^{-1} for ^{226}Ra, 30 Bqkg^{-1} for ^{232}Th and 340 Bqkg^{-1} for ^{40}K **[**6]. The comparison between the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}Kfor

the collected samples is shown in Figure1, which presents that the values of activity concentration of ^{232}Th are higher than the values of ^{226}Ra and ^{40}K, but the activity concentration of ^{226}Ra is lower than ^{232}Th and ^{40}K. Sample number 23 has a high value of ^{232}Th and sample number 1 has the lowest value of ^{232}Th. Also sample number 22 has a high value of ^{226}Ra and the lowest value was found in sample 26.

The higher value of ^{40}K was found in sample, number 21 and the lowest value in sample 20. The results are useful for environmental mapping for mineral exploration. The values of radium equivalent activity varied from 1199.44 to 2725.41 Bq kg^{-1} with an average value 1838.84 Bq kg^{-1}. The obtained results indicate that the values of radium equivalent activity for all samples are above the permissible limit of 370 Bq kg^{-1} which recommended by UNSCEAR. This may be attributed to the enrichment with ^{238}U **[**6]. The distribution of radionuclides activity concentrations in the rock samples are higher than the worldwide limit and not safety for human.

The correlation relation between radium equivalent activity and external hazard is shown in Figure (2), where the correlation factor (R^2 = 1) this is a positive relation and this is referred to the values of external hazard depend on gamma radiation, which emitted from ^{226}Ra, ^{232}Th and ^{40}K.

The external, internal hazard index, representative level index, absorbed dose rate, annual effective dose, excess lifetime cancer risk and annual gonadal dose equivalent rate of the collected samples are given in Table (2). The representative level index ranges from 8.15 to 16.91 with an average value of 12.75. The average of ($\boldsymbol{I_\gamma}$ **)** is higher than the international accepted value of 1 Bqkg^{-1}. The average external hazardous (H_{ex}) value for the investigated samples was 4.97, which higher than unity **[**23]. The average internal hazardous (H_{in}) value for the investigated samples was 6.46, this value is higher than unity **[**26]. It should be taken into consideration that the H_{ex} and H_{in} risk values must be less than unity **[**14]. The external, internal hazard index and the representative gamma index are higher than the world permissible value of unity **[**27]. The average values of calculated absorbed dose rates in cataclastic rock samples under investigation range between 537.62 to 1223.95 nGyh^{-1} with an average value 813.86 nGyh^{-1} is higher than the value 55 nGyh^{-1}, which recommended by UNSCEAR **[**6]. The worldwide average values ranged from 18 to 93 nGy h^{-1}. The measured absorbed dose rate in outdoor air ranged from 10 to 200 nGy h^{-1}. The population average value of absorbed dose of terrestrial gamma radiation equal 55 nGyh^{-1}. The average annual dose (oudoor) from the collected samples was 1 *m*Sv y^{-1} , while for the indoor value was 3.35 *m*Sv y^{-1} with a total average annual dose of 4.99 *m*Sv y^{-1}. It is found that the average annual dose is higher than the recommended value. The comparison between the sample number and total annual effective dose for the collected samples given by Figure3, since sample number 22 has a high value but the lowest value found in sample number 20. If the excessive gamma radiation due to those materials causes the increase of the annual effective dose received by an individual with a maximum value.

An effective dose exceeding the dose criterion of 1*m*Svy^{-1} should be taken into account in terms of radiation protection. The correlation between representative level index and excess lifetime cancer risk is given in Figure4. This is a positive correlation, which equal R^2=1. The figure indicates that lifetime cancer risk increases with increasing exposure to level index of gamma. The average excess lifetime cancer risk equal 3.49 exceeded the global average of 0.29×10^{-3}. The AGED is higher than the permissible limit of 300 mSvy^{-1}[28]. Positive correlation was found between representative level index and annual gonadal dose equivalent rate (R^2= 0.99) as shown in Figure (5). No dose should exceed 50 mSvR based on the recommendations of the International Committee for Radiation Protection from all sources, whether industrial or nature, as well as the recommendations of the International Atomic Energy Agency[29]. The permissible levels of dose reaches up to 5 *m*Sv y^{-1} for public members and up to 20 *m*Sv y^{-1} for the occupational members. The obtained results agree with the published data of different authors[6,16,18, and 30-38], and it is given in Table (3).

Table (1): Position, content in (ppm), activity concentration and radium equivalent in (Bqkg^{-1}) for the collected rock samples

S. No.	Lat.	Long.	Ra-226		Th-232		K-40		Ra_{eq} Bq kg^{-1}
			ppm*	Bq kg^{-1}	ppm*	Bq kg^{-1}	ppm*	Bq kg^{-1}	
1	678917E	2725791N	44	488.4	168	682.08	3.12	976.56	1548.58
2	678945E	2725783N	51	566.1	251	1548.58	4.1	1283.3	2136.53
3	679006E	2725804N	79	876.9	209	2136.53	2.15	672.95	2154.08
4	679029E	2725785N	69	765.9	244	2154.08	2.74	857.62	2262.51
5	678971E	2725785N	31	344.1	156	2262.51	2.52	788.76	1319.46
6	678941E	2725811N	50	555	252	1319.46	2.47	773.11	2092.01
7	678897E	2725824N	103	1143.3	214	2092.01	2.46	769.98	2457.27
8	678935E	2725751N	85	943.5	200	2457.27	2.35	735.55	2172.74
9	678890E	2725721N	49	543.9	125	2172.74	2.67	835.71	1341.12
10	678860E	2725764N	59	654.9	245	1341.12	3.83	1198.79	2183.64
11	678748E	2725729N	62	688.2	225	2183.64	2.64	826.32	2071.00
12	678739E	2725757N	55	610.5	213	2071.00	3.32	1039.16	1939.33
13	678722E	2725809N	61	677.1	117	1939.33	2.87	898.31	1432.24
14	678676E	2725838N	74	821.4	129	1432.24	2.64	826.32	1641.35
15	678964E	2725252N	105	1165.5	115	1641.35	3.72	1164.36	1929.40
16	679067E	2725233N	72	799.2	122	1929.40	3.52	1101.76	1599.32
17	679119E	2725188N	45	499.5	181	1599.32	3.39	1061.07	1642.41
18	679189E	2725255N	55	610.5	272	1642.41	2.57	804.41	2267.18
19	678999E	2725175N	53	588.3	102	2267.18	2.39	748.07	1243.93
20	679131E	2725036N	69	765.9	73	1243.93	0.23	71.99	1199.44
21	679073E	2725065N	41	455.1	123	1199.44	5.00	1565	1296.75
22	679113E	2724964N	139	1542.9	185	1296.75	4.06	1270.78	2725.41
23	679069E	2724856N	94	1043.4	117	2725.41	4.86	1521.18	1846.50
24	679028E	2724855N	57	632.7	173	1846.50	2.52	788.76	1707.73
25	678978E	2724784N	67	743.7	248	1707.73	3.95	1236.35	2292.92
26	679023E	2724736N	12	133.2	188	2292.92	2.97	929.61	1307.02
Average			64.65	717.66	178.73	732.80	3.04	1307.02	1838.84

*****The percentage of error in the content in ppm equal ±10 %

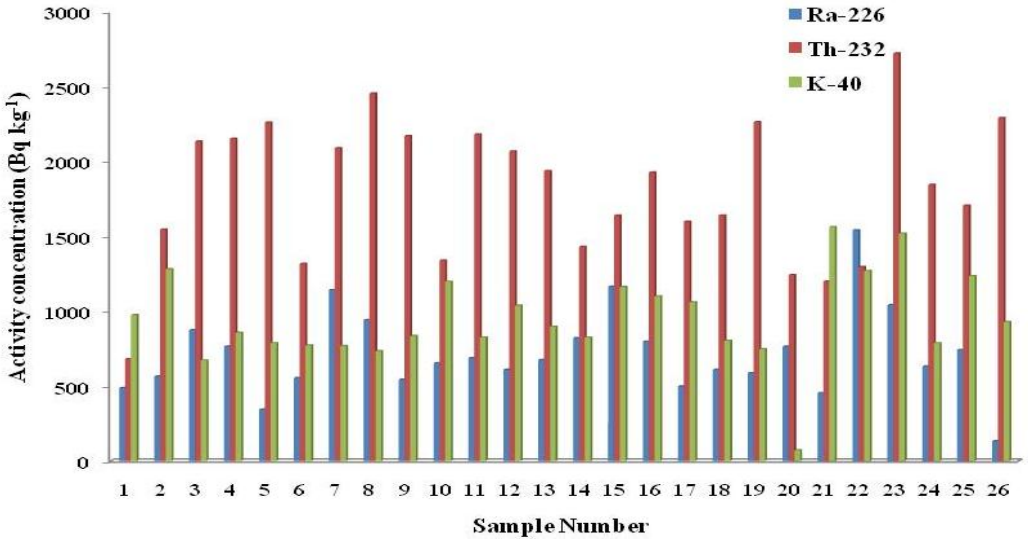

Figure (1): The comparison between specific activity of Ra, Th and K for the collected samples

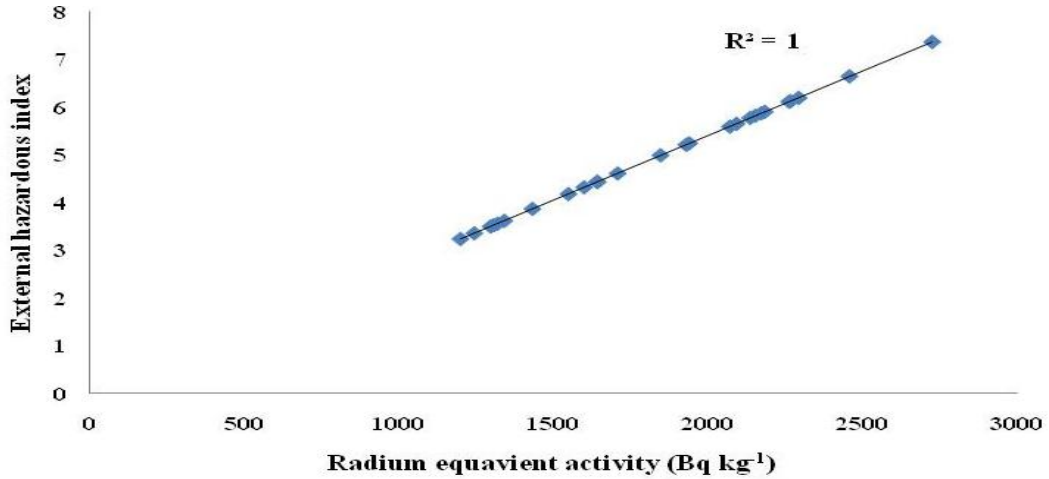

Figure (2): The relation between radium equavlent activity and external hazard index for the collected samples

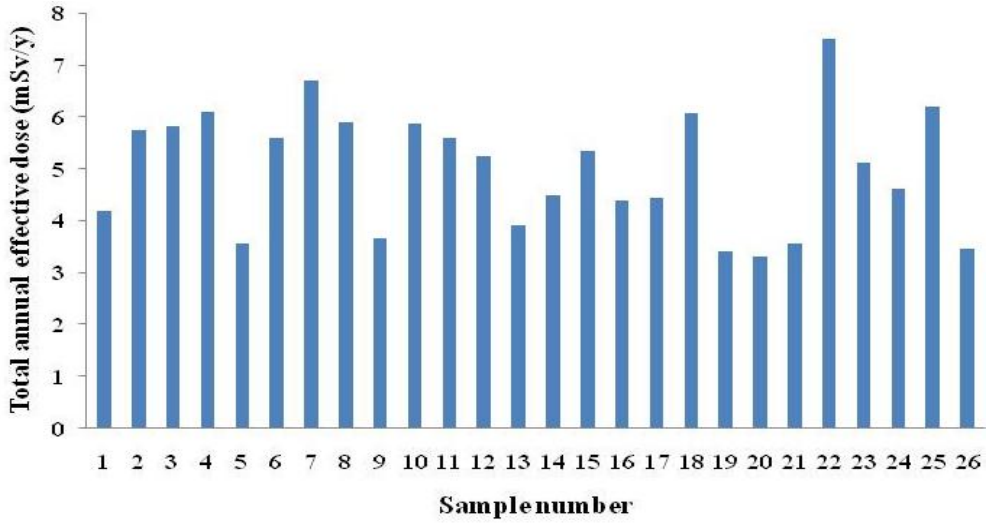

Figure (3): The comparison between the values of the total annual effective dose for the collected samples

Table (2): External, internal hazard index, representative level index, D_R, AED, ELCR and AGED of the collected samples

Sample No.	Hazard index		I (ɣ)	D_R ($nGyh^{-1}$)	Annual Effective dose ($mSvy^{-1}$)			ELCR	AGED
	H_{in}	H_{ex}			A_d outdoor	A_d indoor	A_d total		
1	5.50	4.18	10.80	682.40	0.84	3.35	4.18	2.93	4694.98
2	7.30	5.77	14.92	936.63	1.15	4.59	5.74	4.02	6453.84
3	8.19	5.82	14.86	950.76	1.17	4.66	5.83	4.08	6502.77
4	8.18	6.11	15.68	993.85	1.22	4.88	6.09	4.27	6817.60
5	4.49	3.56	9.22	578.18	0.71	2.84	3.55	2.48	3984.47
6	7.15	5.65	14.55	912.70	1.12	4.48	5.60	3.92	6276.48
7	9.73	6.64	16.91	1090.26	1.34	5.35	6.69	4.68	7442.10
8	8.42	5.87	14.98	961.85	1.18	4.72	5.90	4.13	6573.98
9	5.09	3.62	9.31	595.68	0.73	2.92	3.65	2.56	4085.31
10	7.67	5.90	15.21	959.27	1.18	4.71	5.88	4.12	6598.87
11	7.45	5.59	14.36	909.60	1.12	4.46	5.58	3.90	6242.05
12	6.89	5.24	13.50	852.86	1.05	4.18	5.23	3.66	5863.14
13	5.70	3.87	9.91	640.02	0.78	3.14	3.92	2.75	4379.45
14	6.65	4.43	11.32	733.40	0.90	3.60	4.50	3.15	5008.39
15	8.36	5.21	13.26	871.80	1.07	4.28	5.35	3.74	5937.87
16	6.48	4.32	11.06	717.29	0.88	3.52	4.40	3.08	4906.32
17	4.84	4.44	11.46	723.24	0.89	3.55	4.43	3.10	4978.61
18	4.58	6.12	15.76	989.18	1.21	4.85	6.07	4.25	6800.57
19	4.34	3.36	8.60	555.58	0.68	2.73	3.41	2.38	3800.82
20	3.22	3.24	8.15	537.62	0.66	2.64	3.30	2.31	3640.31
21	6.03	3.50	9.12	580.11	0.71	2.85	3.56	2.49	4005.64
22	9.53	7.36	18.72	1223.95	1.50	6.00	7.51	5.25	8337.12
23	8.23	4.99	12.77	835.22	1.02	4.10	5.12	3.59	5706.90
24	4.63	4.61	11.84	753.62	0.92	3.70	4.62	3.23	5167.59
25	6.28	6.19	15.95	1009.29	1.24	4.95	6.19	4.33	6936.47
26	3.04	3.53	9.22	565.87	0.69	2.78	3.47	2.43	3925.43
Avg.	6.46	4.97	12.75	813.86	1.00	3.35	4.99	3.49	5579.50

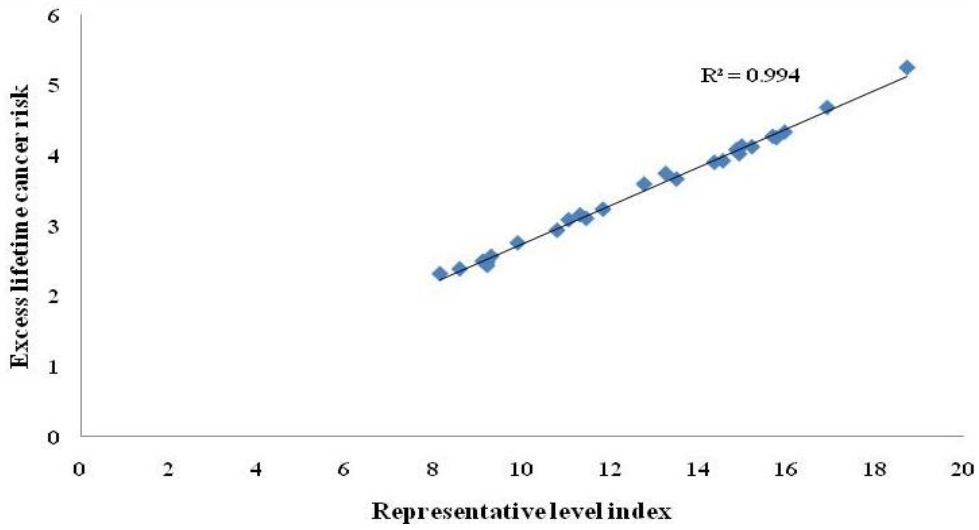

Figure (4): The relation between representative level index and life time cancer for the collected samples

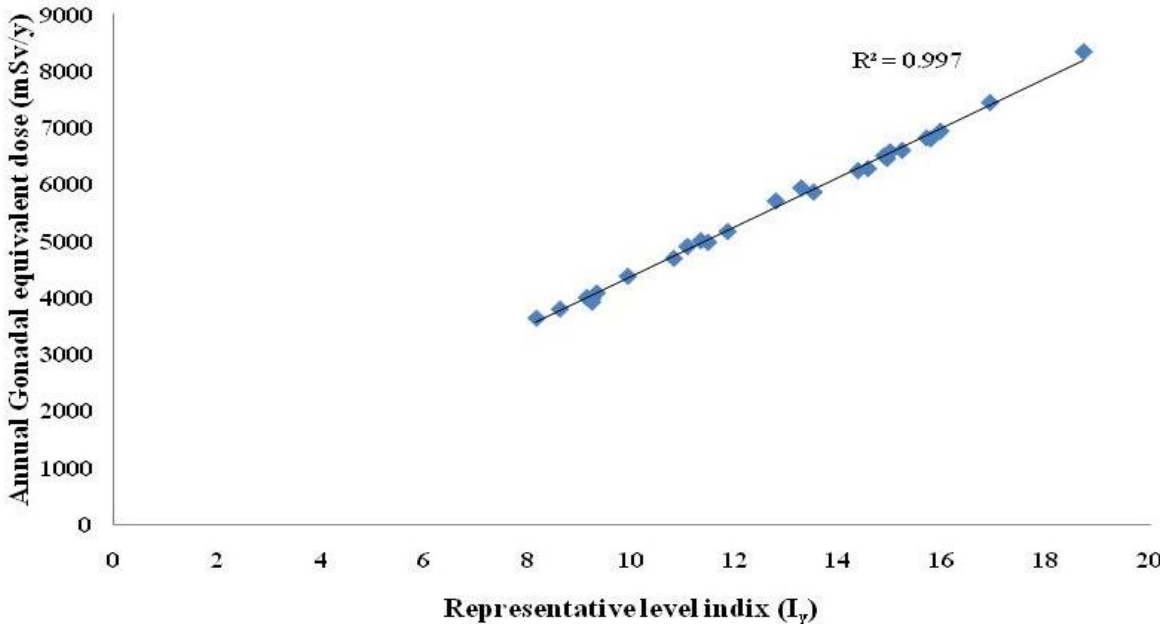

Figure (5): The relation between representative level index and annual gonadal equivalent dose for the collected samples

Table (3): A comparison between the obtained results and the published data from different countries

Country/Org.	^{226}Ra	^{232}Th	^{40}K	D_R	References
	Bq kg^{-1}			(nGyh^{-1})	
Egypt (Granite) Gabal El Majal Gabal El Misikat Gabal El Aradia	239.96 1308.78 197.41	30.3 40.4 24.5	681.2 704.7 480.1	134.1 90.5 569.9	[30]
Egypt (Granite)	14.12	14.46	405.73	32.50	[31]
Egypt (Soil - rocks) Wadi Sahu	378.47	65.75	243.05	222.71	[16]
Egypt (Rocks)	98.8	15.23	77.86	61.9	[32]
Egypt (Granite)	199.97	36.39	1051.61	150.53	[33]
Saudi Arabia (Granite)	76.4	81	1099	28-120	[34]
Bangladesh (Soil)	55.25	125.27	497.9	124.12	[35]
Iran (Rocks)	14.8	5.5	148.41	14.39	[36]
Nigeria (Rocks)	310	147.26	719.90	260	[18]
IAEA	50	50	500		[37]
ICRP	35	30	400		[38]
UNSCEAR	35	30	400		[6]
Egypt	717.66	732.80	1307.02	826.31	Present work

Conclusions

Radioactivity levels of the environment depend on the geological aspects of rock samples, where they are found in varying concentrations. The chemical and physical properties play an important role in the redistribution of radionuclides in different rock types. This distribution of radionuclides reflects its impacts on the environment. The Eastern Desert of Egypt is a source of granitic rocks used in uranium mining and also used as raw materials for building, and for that reason cataclastic (mylonitic) rock samples were investigated to evaluate the radiation

hazard indicators and compare the values of the world average values. The present work contributes in establishing a database reference of natural radionuclide concentrations. The average activity concentration of radionuclides ^{238}U, ^{232}Th and ^{40}K are higher than the world average values. The distribution of radionuclides activity concentrations in the rock sample varieties affects the values of the absorbed dose rate in the studied rocks and it is higher than the worldwide limit and are not safe for human. The annual effective dose rate exceeded the public permissible values in the studied rock samples, consequently, personal protective masks should be used to protect working personnel from inhalation of alpha particles. This means that these rocks are not safe for human beings from the environmental point of view. From the obtained results we can conclude that the area under study can be used as a mine of natural radioactive elements, and for point of safety, we must protect ourselves from radiation and don't live near the area under study to minimize the exposure time of radiation, and we must repeat the measurements to detect the variation in the concentration of radioactive radionuclides that affect the environment and human.

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