Middle East Journal of Applied Sciences
Volume: 13 | Issue: 02| April – June | 2023

EISSN: 2706 -7947 ISSN: 2077- 4613
DOI: 10.36632/mejas/2023.13.2.20
Journal homepage: www.curresweb.com
Pages: 257-271

Assessment of Natural Radioactivity and its Radiation Hazards in Abu Diab Area in Central Eastern Desert of Egypt

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Received: 17 April 2023 **Accepted:** 15 May 2023 **Published:** 20 May 2023

ABSTRACT

Sixteen samples from Abu Diab granite in the Central Eastern Desert of Egypt are investigated radiometrically using scintillation detector (NaI (Tl)) to determine U, Th and K contents. The obtained results of activity concentrations are ranged from 2 to 22 ppm for U with mean value 8.625 ppm, from 11 to 16 ppm for Th with mean value 13.75 ppm and from 2.89 % to 3.32% for K with mean value 3.12 %. Accordingly, the radiological effects from these rocks are estimated through the calculation of some radiological hazard indices : radium equivalent activity (Ra_{eq}), internal absorbed dose rate indoor (D_{in}), external absorbed dose rate outdoor (D_{out}), annual effective dose equivalent outdoors ($AEDE_{out}$) and indoors ($AEDE_{in}$), alpha index (I_{α}), gamma index (I_{γ}), external hazard index (H_{ex}), internal hazard index (H_{in}), annual gonadal dose equivalent (AGDE) and total excess lifetime cancer risk) $(ELCR)_{total}$. The estimated average values are 261.55 Bq/kg , 237.70 nGy/h , 123.74 nGy/h , 0.152 mSv/y, 1.167 mSv/y, 0.960, 0.533 ,0.707, 0.995, 0.870 mSv/y and 4.616 $x10^{-3}$, respectively. Our granite samples from Abu Diab area have a higher activities and radiological hazard than that of the permissible of the worldwide limits. Accordingly, these granite samples are not suitable for decoration or building materials.

Keywords: radiometrically, scintillation detector, radiation hazards, U, Th and K

1. Introduction

Natural radioactivity is widespread in the Earth's environment; it exists in soil, rocks, plants, water, air, coal and phosphate (Pimpl *et al.,* 1992). The natural radioactivity in rocks comes mainly from the uranium, U, and thorium, Th, series and natural potassium, K (Merdanoğlu and Altınsoy, 2006). Radionuclides in rocks generate a significant component of the background radiation exposure of the population. Since granite rocks are mostly present as a substructure for buildings, its contribution to the overall activity is significant. Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions and appear at different levels in granite rocks of each region in the world (UNSCEAR, 1988; UNSCEAR, 2000). The radiation dose comes from gamma-rays, which are emitted from rocks, soil and some other building materials composed of the Earth's crust (Sabharwal *et al.,* 2012). So, knowing of radioactivity present in these building materials enables one to assess any possible radiological hazard to mankind, as most people spend about 80% of their life inside houses and office buildings. Moreover, they can also be a source of indoor radon. It has been demonstrated in various studied that, if building materials with high natural radioactivity concentration are employed dose rates indoors will be elevated accordingly (Righi & Bruzzi, 2006). Consequently, granitic rocks can cause significant gamma dose indoors, due to their natural radionuclide content.

The specific activity of building materials has been reported for many countries in the world and different locations in Egypt. Furthermore, it is beneficial in setting the standards and national guidelines with regard to the international recommendations (Medhat, 2009; Sonkawade *et al.,* 2008; Stoulos *et al.,* 2003). In the primary goal of the present work, granitic samples are collected from Abu Diab

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granites in the Central Eastern Desert, Egypt and then measured the concentration of natural radionuclides ^{238}U, ^{232}Th, and ^{40}K to assess their contents and other radiological hazard.

2. Geology Description

Abu Diab graites, which attains an elevation of (~ 1160 m at the sea level) covering an area of about 40 km^2 representing about 12% of the total mapped area, (Fig.1). Gabal Abu Diab consists of two loops; the eastern one is manly of greyish pink colour and composed of biotite granites while the western loop is of pink red colour. The pink red granites are highly dissected by quartz and feldspar veinlet especially along the north western peripheries of the mass. It outcrops in the north western corner of the mapped area forming an oval shaped body elongated in N 40° W - S 40° E direction. It is surrounded from the western and southern side by a vast sandy plain and intrudes the country granodiorites from the northern side with sharp intrusive contact.

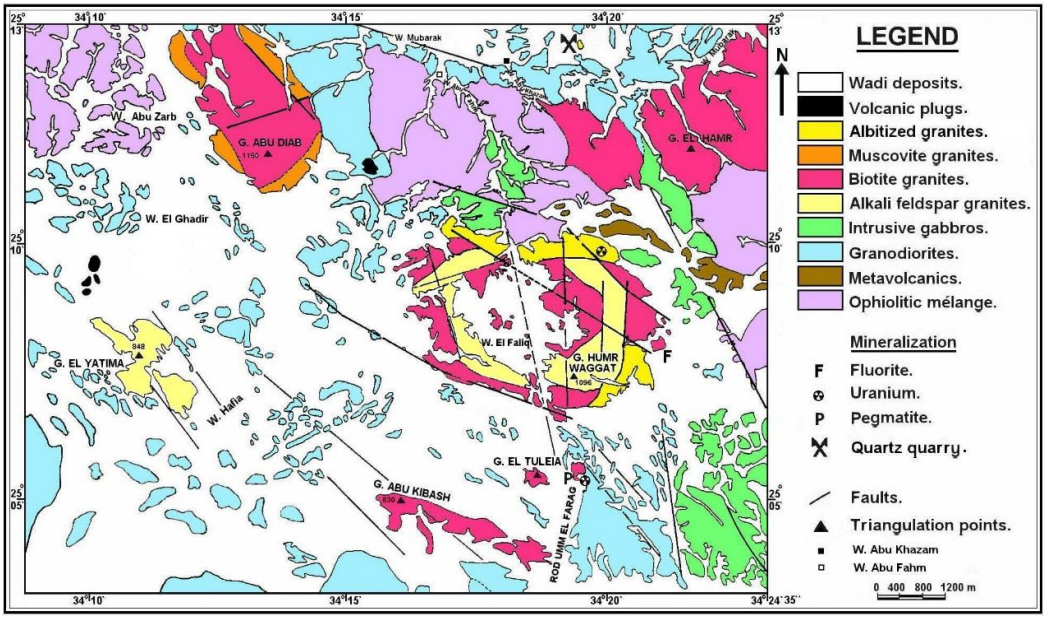

Fig. 1: Total mapped area of some granitic masses in the Central Eastern Desert of Egypt.

This granite is massive, medium- to coarse - grained, being fine- grained in some places. It ranges from greyish pink, pinkish red and reddish, buff colour and is characterized by well-developed joints in different directions (Fig 2a). It is composed mainly of two types of granites with gradual contact between each other. The outer zone is mainly composed of greyish pink to pinkish red muscovite-bearing granite and the inner zone is mainly composed of whitish to reddish pink biotite granite (Fig 2b). Generally, this granite is characterized by the presence of alteration and exfoliation due to high weathering along the periphery of the pluton. Silicification, hematitization and kaolinitization represent the main alteration features exhibited in this granite. Many basic and acidic dykes and veins dissect this pluton (Fig 2c). Also, pegmatite pockets and feldspar veinlets intruded this granite especially along the periphery of the mass. Three major sets of joints in descending order of abundance, striking E-W, NW-SE and WNW-ESE and dipping 85º to N, 10º to SW and WNW-ESE dipping 75º to NE, respectively are recognized traversing Abu Diab granite.

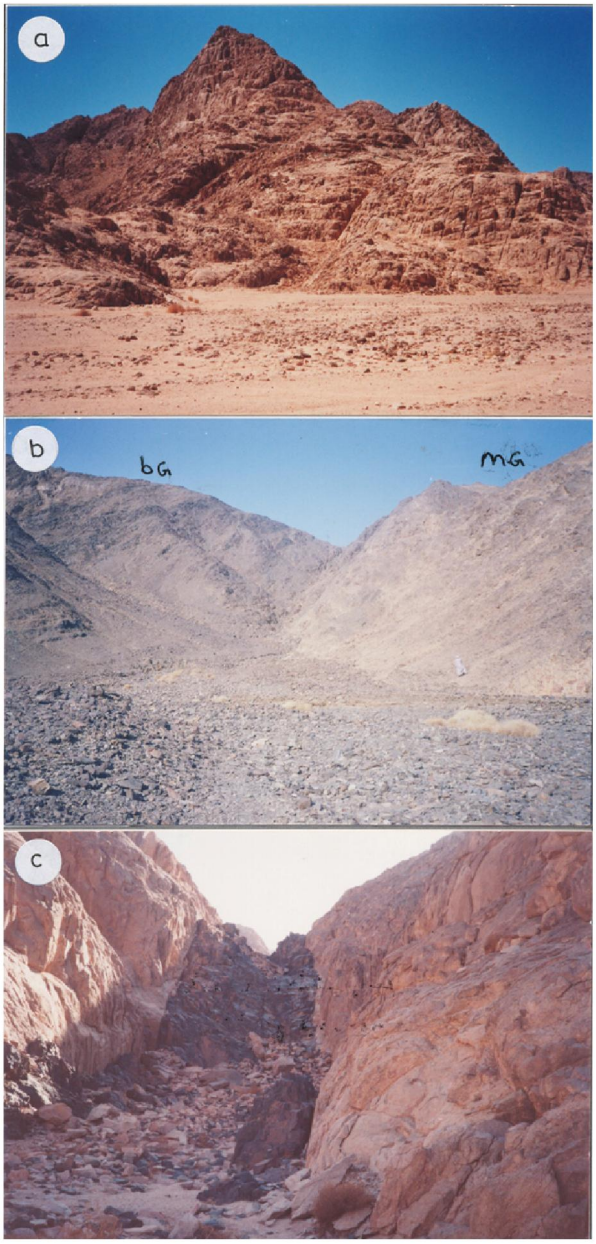

Fig. 2: a) General view of the highly jointed Abu Diab pluton exhibiting reddish colour and dissected by well-developed sets of joints in different directions.
(Looking N)
b) Gradational contact between biotite- and muscovite- bearing granites of Abu Diab pluton. (Looking E)
c) Basic dyke cutting Abu Diab pluton at its northern part (Looking E)

3. Materials and Methods

3.1. Samples preparation

Each sample was dried in an oven at about 110 °C for 12 h to ensure that moisture is completely removed, crushed and mixed well to avoid non-homogeneous distribution of minerals, then proper weight (300-350 gm) of each sample was placed in standard size polyethylene container (cylindrical in shape of volume 212.65 cm^3. with 9.5 cm average diameter and 3 cm height). These containers are carefully sealed to prevent contamination of the spectrometer. The homogenizing process liberates the

radon contained in the sample and therefore much of its gamma radioactivity. For correcting the loss of radon, the samples in the sealed containers are stored for at least four weeks, where the radon is back to normal state and attains radioactive equilibrium between U, Th and their short lived daughter products (El-Arabi, 2007; Matolin, 1991; Mollah *et al.,* 1986).

3.2. Measurements and Calibration

About sixteen granitic rocks samples are collected from Abu Diab region in the Central Eastern Desert of Egypt. The samples are considered to investigate their natural radioactivity due to ^{238}U (ppm), ^{232}Th (ppm) and ^{40}K (%). The studied rocks are investigated using a scintillating NaI (Tl) detector, with crystal (76 mm x76 mm). The measurement of the radionuclides is based on choosing four energy regions of interest (ROIs) representing ^{234}Th, ^{212}Pb, ^{214}Pb and ^{40}K for U, Th, Ra and K, respectively. Uranium is estimated both as eU and Ra (eU) and thorium as eTh. The values of eU represent the concentration of U using ^{234}Th energy peak (92.6 KeV) which is the first daughter isotope in the ^{238}U decay series with very low possible loss. Radium is measured at the ^{214} Pb energy peak (352 KeV) which is considered as a measure for concentration of the U only in case of the secular equilibrium state between ^{238}U and all its daughter isotopes. Thorium is measured at the ^{212}Pb energy peak (238.6 KeV) while the ^{40}K was determined directly by means of the γ-energy line of ^{40}K at (1460 KeV).

To ensure that the instrument accurately records the gamma radiation energy of the radioactive elements, permanent calibration process is applied by using radioactive point sources like ^{137}Cs and ^{57}Co. Meanwhile the gamma-ray spectrometer is used as a geochemical prospecting, it must be calibrated in terms of the isotopic sensitivity (i.e., conversion from counts per unit of time into isotopic concentration in part per million, ppm or percent %). The calibration was carried out using four artificial standard sources (NMA-U, IAEA-Ra, IAEA-Th, IAEA-K). Assaying of the samples by long period count, 1000 second for each, in the shielded environment then determination of the gross count rate for U, Th, eU (Ra) and K at their selected energy regions as well. After measurement and subtraction of the background, the specific activity was calculated by the equation (Eissa *et al.,* 2005):

$$A = N / \varepsilon \times I\gamma \times m \times t \qquad (1)$$

where : A = activity concentrations of the sample (Bq/kg)
N = the total net counting peak area of the radioisotope
Ɛ = the absolute efficiency of the detector for the radioisotope at gamma ray energy
m = the mass of the measured sample (Kg)
t = the counting time (in seconds)
Iγ = gamma intensity

4. Results and Discussion

4.1 Natural Activity Concentration

Activity concentration of ^{238}U, ^{232}Th, and ^{40}K have been measured for 16 different Egyptian granite samples. The measured activities are estimated in ppm and are presented in table (1). In order to evaluate the radiological parameters, the calculated activity concentrations (ppm) are converted into Bq/kg (^{238}U; 1 ppm = 12.35 Bq/kg) (^{232}Th; 1ppm=4.06 Bq/kg), whereas (1% of ^{40}K=313 Bq/kg) (IAEA, 1989). The values of activity concentrations of the three radionuclides in 16 granite samples under investigation are illustrated in figure (3). From these results it can be seen that the ^{238}U activity concentration is attained to vary from (24.7±5.113) Bq/kg for sample number (10) to (271.7±10.323) Bq/kg for sample number (14). The ^{232}Th activity concentration ranged from (44.66±0.698) Bq/kg for sample number (1) to (64.96±0.571) Bq/kg for sample number (10). While ^{40}K activity concentration be between (904.57±4.634) Bq/kg for sample number (4) and (1039.16±3.778) Bq/kg for sample number (16).

It is found that mean value for ^{238}U concentration is (106.518±2.870) Bq/kg, for ^{232}Th is (55.825± 0.293) Bq/kg and for ^{40}K is also recorded as (978.711±1.822) Bq/kg, and all these values are higher than that the worldwide average (50, 50, and 500) Bq/kg, respectively (UNCEAR, 2000).

Table 1: Activity concentration of ^{238}U, ^{232}Th (in both ppm & Bq/kg) and ^{40}K(% & Bq/kg) .

Sample Number	Activity (Bq/Kg)			Activity (ppm)		
	^{238}U	^{232}Th	^{40}K%	^{238}U	^{232}Th	^{40}K%
1	111.15±0.289	44.66±0.698	1010.99±2.017	9±0.023	11±0.171	3.23±0.0064
2	135.85±1.833	56.84±0.063	948.39±1.895	11±0.148	14±0.0156	3.03±0.006
3	111.15±0.289	52.78±0.190	979.69±0.061	9±0.023	13±0.0468	3.13±0.00019
4	123.5±1.061	52.78±0.190	904.57±4.634	10±0.085	13±0.0468	2.89±0.0148
5	49.4±3.569	56.84±0.063	970.3±0.526	4±0.289	14±0.0156	3.1±0.00168
6	148.2±2.605	48.72±0.444	1014.12±2.213	12±0.210	12±0.1093	3.24±0.007
7	111.15±0.289	60.9±0.317	1032.9±3.387	9±0.023	15±0.0781	3.3±0.0108
8	37.05±4.341	60.9±0.317	970.3±0.526	3±0.351	15±0.0781	3.1±0.00168
9	37.05±4.341	52.78±0.190	1004.73±1.626	3±0.351	13±0.0468	3.21±0.0051
10	24.7±5.113	64.96±0.571	989.08±0.648	2±0.414	16±0.1406	3.16±0.00207
11	37.05±4.341	48.72±0.444	973.43±0.330	3±0.351	12±0.1093	3.11±0.001055
12	86.45±1.254	60.9±0.317	935.87±2.678	7±0.101	15±0.0781	2.99±0.0085
13	148.2±2.605	60.9±0.317	945.26±2.091	12±0.210	15±0.0781	3.02±0.0066
14	271.7±10.323	60.9±0.317	948.39±1.895	22±0.835	15±0.0781	3.03±0.006
15	123.5±1.0613	56.84±0.063	992.21±0.844	10±0.085	14±0.0156	3.17±0.002695
16	148.2±2.605	52.78±0.190	1039.16±3.778	12±0.210	13±0.0468	3.32±0.01207
Minimum	24.7±5.113	44.66±0.698	904.57±4.634	2±0.414	11±0.1718	2.89±0.014805
Maximum	271.7±10.323	64.96±0.571	1039.16±3.778	22±0.835	16±0.1406	3.32±0.01207
Average	106.518±2.870	55.825± 0.293	978.711±1.822	8.625±0.232	13.75±0.0722	3.12±0.00582
Worldwide acceptable	50	50	500	4	12.3	1.6

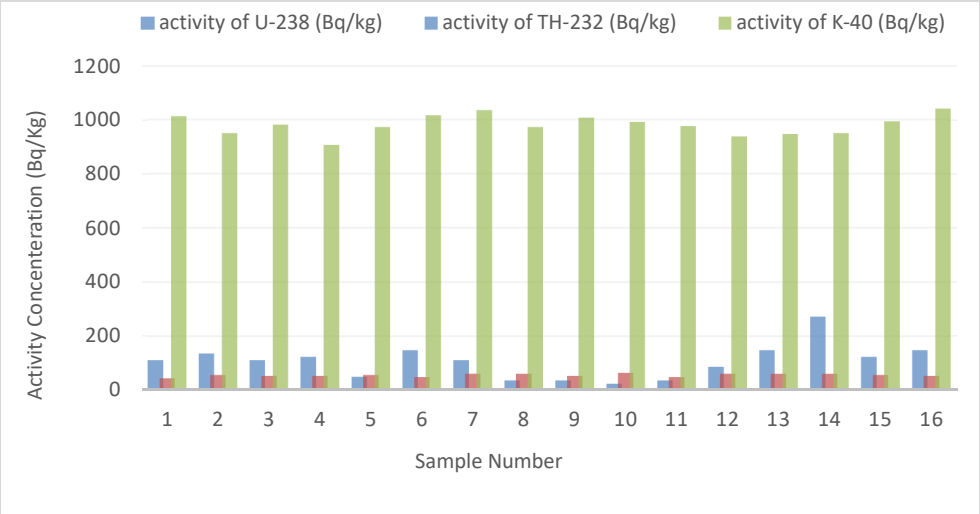

Fig. 3: Activity concentrations of the radioelements (in Bq/kg) , Abu Diab area.

4.1.2 Comparison between the Mean Activity Concentrations of our Granite samples with that of other Countries of the World

The present results for mean specific activities of ^{238}U, ^{232}Th, and ^{40}K in various samples of Egyptian granite are compared in table (2) with the results for other Egyptian granite studies and some world countries. As shown in that table, the radioactivity in granite samples varied from one country to another, this depends on the nature of the region from which samples are collected. The activity concentrations of these radionuclides for the samples of granite are higher compared to results from Egypt (El-Taher, 2010). The mean specific activities of ^{238}U, ^{232}Th, and ^{40}K for granite samples

recorded in this study are lower than that values obtained in Hong Kong (Yu *et al.,* 1992) which have the most radiant level among them.

Table 2: Comparison between the mean activity concentrations of our granite samples from Abu Diab area with that of other different countries of the world.

Countries	Radioactivity concentration (Bq/ kg)			References
	^{238}U	^{232}Th	^{40}K	
Egypt	**106.518±2.870**	**55.825± 0.293**	**978.711±1.822**	**Our present work**
Brazil	48.6	288.2	1335	Malanca *et al.* (1993)
Egypt	18±1.4	24 ± 1.3	350±4	El-Taher, (2010)
France	90	80	1200	NEA-OECD, (1979)
Greece	67	95	1200	Stoulos *et al.* (2003)
Hong Kong	202	140	1030	Yu *et al.* (1992)
India	82	112	1908	Sonkawade *et al.* (2008)
K.S.A	23±1.6	30.0±0.4	340±6.7	El-Taher (2012)
Palestine	35.1	20.5	639.5	Dabayneh, (2008)
Taiwan	42	73	1055	Chen and Lin, (1996)

4.2. Evaluation and Analysis of Radiological Hazards.

The radium equivalent activity, the calculated radiation dose in granite samples collected from Abu Diab area, Radium Equivalent Activity (Ra_{eq}), External Absorbed Dose Rate Outdoor (D_{out}), Internal Absorbed Dose Rate Indoor (D_{in}), Annual Effective Dose Equivalent Outdoors ($AEDE_{out}$) and Indoors ($AEDE_{in}$) are listed in table (3). Each parameter will be discussed individual.

Table 3: Radium Equivalent Activity (Raeq), External Absorbed Dose Rate Outdoor (Dout), Internal Absorbed Dose Rate Indoor (Din), Annual Effective Dose Equivalent Outdoors (AEDEout) and Indoors (AEDEin) for Abu Diab Area.

Sample Number	Raeq (Bq/kg)	Din (nGy/h)	D_{out} (nGy/h)	AEDEout (mSv/y)	$AEDE_{in}$ (mSv/y)
1	252.72	232.26	120.48	0.148	1.140
2	290.00	263.38	136.64	0.168	1.293
3	261.91	238.69	124.08	0.152	1.172
4	268.48	244.04	126.66	0.155	1.198
5	205.24	185.60	97.62	0.120	0.911
6	295.81	271.07	140.18	0.172	1.331
7	277.60	251.88	131.21	0.161	1.236
8	198.69	178.70	94.36	0.116	0.877
9	189.74	172.52	90.89	0.112	0.847
10	193.58	173.31	91.89	0.113	0.851
11	181.53	165.55	87.14	0.107	0.813
12	245.44	221.39	115.75	0.142	1.087
13	307.91	278.95	144.67	0.178	1.369
14	431.65	392.83	201.86	0.248	1.928
15	281.02	255.52	132.76	0.163	1.254
16	303.54	277.53	143.68	0.176	1.362
Minimum	181.53	165.55	87.14	0.107	0.813
Maximum	431.65	392.83	201.86	0.248	1.928
Average	261.55	237.70	123.74	0.152	1.167
Acceptable value	370	84	55	0.07	0.41

4.2.1 Radium Equivalent Activity (Ra_{eq})

The Ra_{eq} is the weighted sum of activities of ^{226}Ra, ^{232}Th and ^{40}K in a material. It assumes that 370 (Bq/kg) of ^{226} Ra, 259 (Bq/kg) of ^{232}Th and 4810 (Bq/kg) of ^{40}K produces the same gamma ray dose

rate (UNCEAR, 1988 and NEA-OECD, 1979). Ra_{eq} is calculated using the following equation which has also been applied by other researchers (e.g. Beretka and Mathew, 1985).

$$Ra_{eq}\,(Bq/kg) = 370[(A_{Ra}/370) + (A_{Th}/259) + (A_K/4810)] \quad (2)$$

$$Ra_{eq}\,(Bq/kg) = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3)$$

where A_{Ra}, A_{Th} and A_K are the specific activity of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg respectively. According to column (2) in table (3) the calculated values of radium equivalent activity, Ra_{eq}, for Abu Diab granite are ranged from (181.529 Bq/Kg) for sample number (11) to (431.653 Bq/Kg) for sample number (14), with an average value of (261.554 Bq/Kg). The average value is visibly lower than the recommended maximum limit for the safe use of materials in the construction of buildings (370 Bq/kg, UNSCEAR 2000) except for sample number (14). The results of Radium equivalent activity, Ra_{eq}, are presented in figure (4).

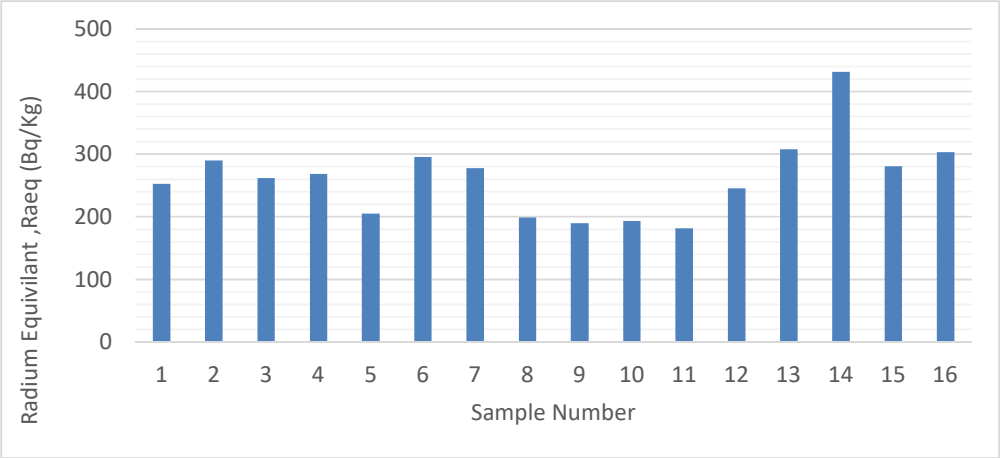

Fig. 4: Radium equivalent activities , Ra_{eq} of granite samples from Abu Diab area.

4.2.2 Absorbed Dose Rate (D)

If naturally occurring radioactive nuclides are uniformly distributed, dose rates, D, in units of nGy/h can be calculated by the following formula (Kohshi *et al.,* 2001: UNSCEAR, 1988; Beck *et al*., 1972):

$$D\,(nGy/h) = A_{i,E} \times C.F \quad (4)$$

where $A_{i,E}$ is the activity concentration (Bq/kg) and C.F is the conversion factor (absorbed dose rate in air per unit activity per unit mass ,nGy/h per Bq/kg).

I. Absorbed Dose Rate Indoor Air (D_{in})

The following equation was used to calculate the dose rate indoor (D_{in}) (Beretka and Mathew, 1985):

$$D_{in}\,(nGy/h) = 0.92\,A_{Ra} + 1.1\,A_{Th} + 0.081\,A_k \quad (5)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226} Ra, ^{232}Th and ^{40}K (in Bq/kg), respectively.

II. Absorbed Dose Rate Outdoor Air (D_{out})

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 (UNSCEAR, 2000). The external absorbed dose rate (outdoor or external, D_{out}) delivered by these radionuclides to the general public in the outdoor air can be calculated by using the following equation (Kleinschmidt and Akber, 2008):

D_{out} (nGy/h) = 0.462 A_{Ra} + 0.604 A_{Th}+ 0.0417 A_k ……..…….(6)

where A_{Ra}, A_{Th} & A_K are the activity concentration (in Bq/kg) for uranium, thorium and potassium, respectively. The results of absorbed dose rate in outdoor air (D_{out}) and internal absorbed dose rate in indoor air (D_{in}) for Egyptian granite samples are listed in table (3) in columns (3) &(4) and D_{out} & D_{in} displayed in figure (5).

The absorbed dose rate values are found to vary from (87.136 & 165.55) in (nGy/h) to (201.85 &392.82) in (nGy/h) for D_{out} & D_{in} respectively. The sample number (11) shows a lowest value (87.136 &, 165.55) nGy/h while sample number (14) has the maximum value of (201.85 &, 392.82) nGy/h for both (D_{out}) and (D_{in}). The mean values of the absorbed dose rate D_{out} & D_{in} are (123.742 &237.7) nGy/h, respectively ,which higher than the permissible level (55 &84) nGy/h (UNSCEAR, 2000).

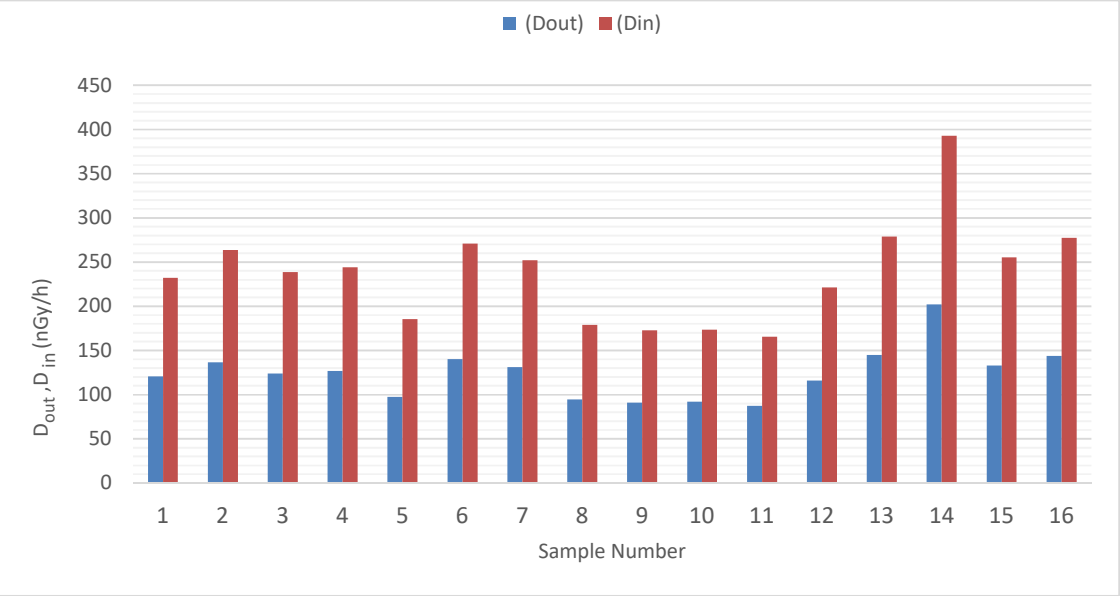

Fig. 5: External absorbed dose rate in outdoor air (D_{out}) and internal absorbed dose rate in indoor air (D_{in}) of granite samples from Abu Diab area.

4.2.3 Annual Effective Dose (AED)

Annual effective dose (AED) received by an individual is two types.The annual indoor effective dose $(AED)_{in}$ and annual outdoor effective dose $(AED)_{out}$ .Therefore, the (AED) is calculated by the following formula (Saito *et al.,* 1990):

AED = D T F ……(7)

where D is the calculate dose rate (nGy/h), T is the occupancy time and F is the conversion factor (Sv/Gy). In the report (UNSCEAR, 2000) a value of 0.7 (Sv/Gy) was used for the conversion coefficient (F), (Billa *et al.,* 2015 and UNCEAR, 1993).

a) Annual Indoor Effective Dose $(AED)_{in}$

Buildings are the main places for daily activities of human beings, so the $(AED)_{in}$ is the dose which a person receives in the indoor environment. Therefore, the (AED) is calculated by the following formula (Saito *et al.,* 1990):

$(AED)_{in}$ = D_{in} (nGy/h) x 80% x 8760 (h) x0.7 (Sv/Gy)…… (8)

where D_{in} is the indoor absorbed dose rate (nGy/h), (d 365.25 d x 24 h = 7012.8 h/y) the fraction of time spent indoors on average, around the world and 0.7 (Sv/Gy) the conversion coefficient (F).

b) Annual Outdoor Effective Dose (AED) $_{out}$

The next formula to estimate the (AED) $_{out}$ (UNCEAR, 2000):

(AED) $_{out}$ = D $_{out}$ (nGy/h) x 20% x 8760 (h) x0.7 (Sv/Gy)……..(9)

where D $_{out}$ is the outdoor external dose rate (nGy/h), (0.2 x 365.25 d x 24 h = 1753 h/y) the fraction of time spent outdoors and 0.7 (Sv/Gy) conversion coefficients (F). The experimental results of annual effective dose rate outdoors and indoors are presented in table (3) columns (5&6) and figure (6).

It can be seen from the table that annual effective dose values are found to vary from (0.106 & 0.812) mSv in sample number (11) to (0.247& 1.928) mSv in sample number (14) for $AEDE_{out}$ and $AEDE_{in}$, respectively. From the table we can notice that the average values (0.151 & 1.166) mSv for $AEDE_{out}$ and $AEDE_{in}$ for Abu Diab granite samples. The results obtained for $AEDE_{out}$ and $AEDE_{in}$ implied that all values of the outdoor and the indoor annual effective dose equivalent for all studied samples from Abu Diab area are much higher than the world values (0.07 & 0.41) mSv respectively, (UNSCEAR, 2000).

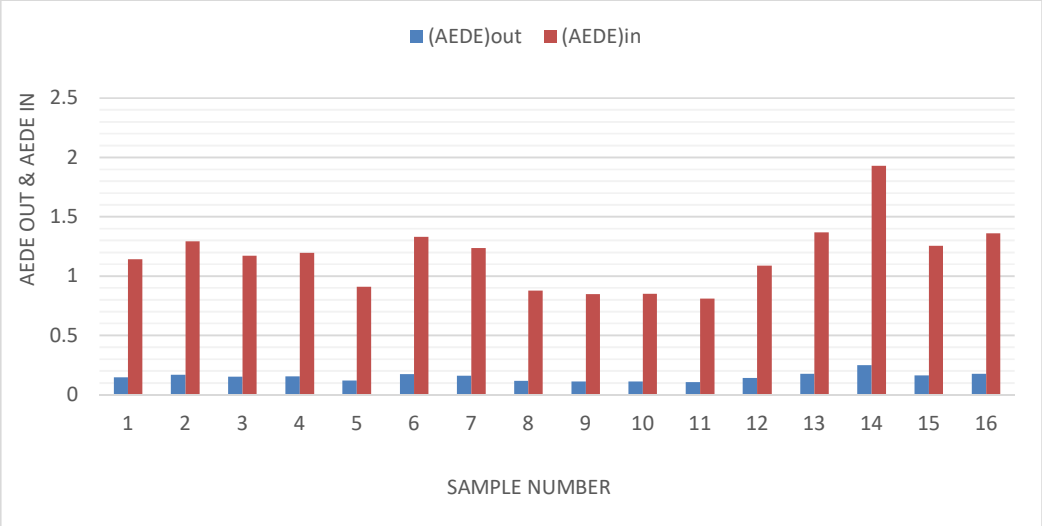

Fig. 6: Annual effective dose equivalent(AEDE) outdoor $AEDE_{out}$ and indoor $AEDE_{in}$, of granite samples from Abu Diab area.

4.3 Hazard Indices

Hazard Indices as Alpha Index (Iα), Gamma Index (Iγ) , External Hazard Index (H_{ex}) , Internal Hazard Index (H_{in}) , Annual Gonadal Dose Equivalent (AGDE) & Excess Lifetime Cancer Risk (ELCR) for Abu Diab Area are listed in table (4) and each parameter will be discussed .

Table 4: Hazard Indices**:** Alpha Index (Iα), Gamma Index (Iγ), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}) , Annual Gonadal Dose Equivalent (AGDE) & Excess Lifetime Cancer Risk (ELCR) for Abu Diab Area.

Sample number	I_γ	I_α	H_{ex}	H_{in}	(AGDE) (mSv/y)	(ELCR)		
						$(ELCR)_{in}$	$(ELCR)_{out}$	(ELCR)total
1	0.931	0.556	0.683	0.983	0.848	3.99 x10^{-3}	0.517x10^{-3}	4.508 x10^{-3}
2	1.053	0.679	0.784	1.151	0.955	4.53 x10^{-3}	0.586x10^{-3}	5.112 x10^{-3}
3	0.961	0.556	0.708	1.008	0.872	4.10 x10^{-3}	0.53 x10^{-3}	4.634 x10^{-3}
4	0.977	0.618	0.726	1.059	0.886	4.19 x10^{-3}	0.54 x10^{-3}	4.737 x10^{-3}
5	0.772	0.247	0.555	0.688	0.695	3.19 x10^{-3}	0.41 x10^{-3}	3.608 x10^{-3}
6	1.076	0.741	0.799	1.200	0.980	4.66 x10^{-3}	0.60 x10^{-3}	5.259 x10^{-3}
7	1.019	0.556	0.750	1.051	0.922	4.33 x10^{-3}	0.563x10^{-3}	4.891 x10^{-3}
8	0.751	0.185	0.537	0.637	0.674	3.07 x10^{-3}	0.40 x10^{-3}	3.476 x10^{-3}
9	0.722	0.185	0.513	0.613	0.651	2.96 x10^{-3}	0.39 x10^{-3}	3.355 x10^{-3}
10	0.737	0.124	0.523	0.590	0.658	2.98 x10^{-3}	0.39 x10^{-3}	3.372 x10^{-3}
11	0.692	0.185	0.491	0.591	0.624	2.84 x10^{-3}	0.37 x10^{-3}	3.219 x10^{-3}
12	0.905	0.432	0.663	0.897	0.816	3.80 x10^{-3}	0.49 x10^{-3}	4.301 x10^{-3}
13	1.114	0.741	0.832	1.233	1.009	4.79 x10^{-3}	0.62 x10^{-3}	5.414 x10^{-3}
14	1.526	1.359	1.167	1.901	1.392	6.75 x10^{-3}	0.86 x10^{-3}	7.616 x10^{-3}
15	1.027	0.618	0.760	1.093	0.931	4.39 x10^{-3}	0.57 x10^{-3}	4.960 x10^{-3}
16	1.104	0.741	0.820	1.221	1.005	4.77 x10^{-3}	0.61 x10^{-3}	5.386 x10^{-3}
Minimum	0.692	0.124	0.491	0.590	0.624	2.84 x10^{-3}	0.53 x10^{-3}	3.219 x10^{-3}
Maximum	1.526	1.359	1.167	1.901	1.392	6.75 x10^{-3}	0.86 x10^{-3}	7.616 x10^{-3}
Average	0.960	0.533	0.707	0.995	0.870	4.08 x10^{-3}	0.37 x10^{-3}	4.616 x10^{-3}
Acceptable value	≤1	≤1	≤1	≤1	*0.3*	—	0.29×10^{-3}	1.45 x10^{-3}

4.3.1 Alpha Index (I_α)

The excess alpha radiation due to radon inhalation originating from building materials is estimated through the alpha index (I_α). I_α is calculated using the following equation (GB6566 – 2010):

$$I_\alpha = A_{Ra}/200 \quad (10)$$

where A_{Ra} is the activity concentration of the alpha emitter ^{226}Ra (Bq/kg). The recommended maximum specific activity limit of ^{226}Ra in building materials specified in (GB6566 – 2010) is 200 (Bq/kg) i.e. I_α =1. The obtained corresponding values of the radioactivity level index (alpha index Iα) see columns (3) in table (4) and figure (7), shows the lowest value of (0.1235) was found in sample number (10) while the maximum value of (1.3585) was found in sample number (14) with mean value of (0.5325). All samples have Iα below the world's limit except sample number (14) is higher than unity.

4.3.2 Activity Indices (I_γ)

Activity Indices (I) is defined as gamma index (I_γ) which refers to the sum of the specific activity ratio of ^{226}Ra, ^{232}Th and ^{40}K in granite sample to their respective standards limits. The following activity concentration index (I) is derived for identifying whether a dose criterion is met (European Commission, 1999):

$$I_\gamma = (A_{Ra}/300) + (A_{Th}/200) + (A_K/3000) \quad (11)$$

where A_{Ra}, A_{Th}, A_K are the radium, thorium and potassium activity concentrations (Bq /kg) in granite samples. Iγ values are in columns (2) of table (4) and figure (7) which shows a lowest value of (0.691) for the sample number (11), while the maximum value of (1.526) is found in sample number (14) with average value (0.9604) which below the permissible level unity (UNSCEAR, 2000) for gamma index (Iγ). .

From the calculated values and figure (7), it can be seen that some of the granite samples have level index above the proposed acceptable level of 1 in area under study.

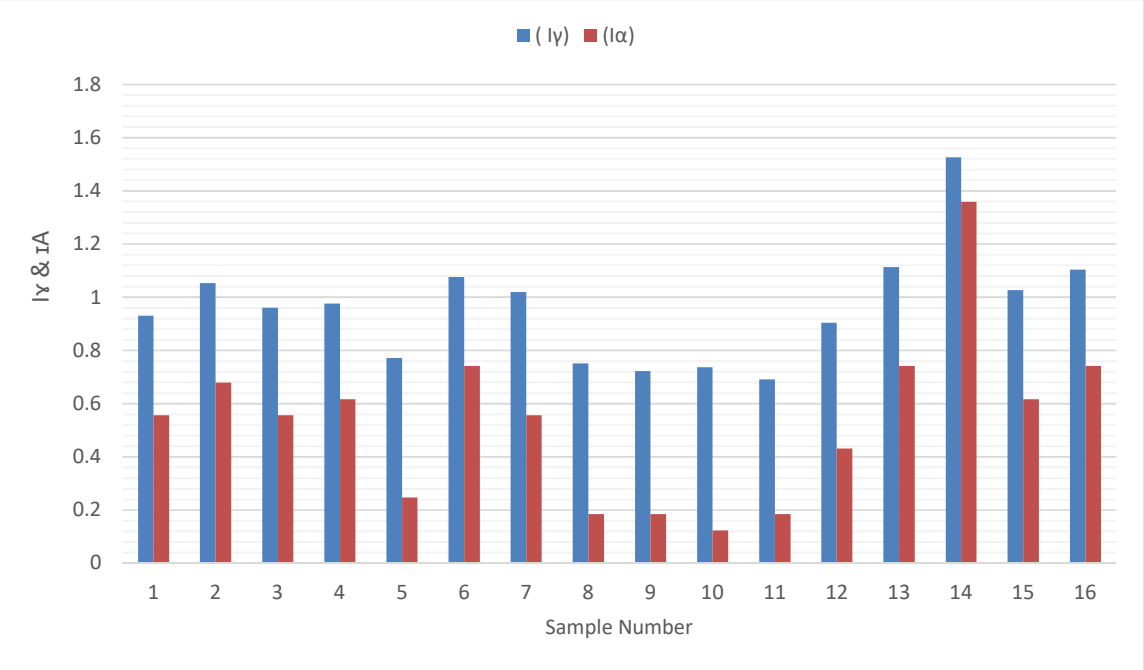

Fig. 7: Gamma index (Iγ) & alpha index (Iα) values of granite samples from Abu Diab area.

4.3.3 Internal (H_{in}) and External (H_{ex}) Hazard Indices

I. Internal Hazard Index (H_{in})

Internal exposure to radon and its progeny can be quantified and controlled using the internal hazard index (H_{in}) which is estimated using equation (12) as follows (Beretka and Mathew, 1985):

$$H_{in} = (A_{Ra}/185)+(A_{Th}/259)+(A_K/4810) \quad (12)$$

where A_{Ra}, A_{Th} and A_K represent the measured activity concentrations (in Bq/kg) for ^{226}Ra, ^{232}Th and ^{40}K, respectively. H_{in} has been found from table (4) in columns (5), the minimum value is (0.5899) in sample number (10); which is under permissible limits while the maximum value of (1.9009) is found in sample number (14). The average value of (0.995) is below the permissible limits (unity) (UNSCEAR, 1993).

II. External Hazard Index (H_{ex})

The external hazard index (H_{ex}) used to measure the external hazard due to the emitted gamma-radiation. H_{ex} can be calculated using the following equation (Hayumbu *et al.,* 1995):

$$H_{ex} = (A_{Ra}/370)+(A_{Th}/259)+(A_K/4810) \quad (13)$$

where A_{Ra}, A_{Th} and A_K represent the measured activity concentrations (in Bq/kg) for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

In table (4) & column (4) the values of (H_{ex}) have been found to be low value of (0.4906) in sample number (11) and the highest value of (1.1666) found in sample number (14). The external hazard gamma index (H_{ex}) for studied granite samples considered in this work with mean value of (0.7069) less than unity except sample number (14). For the utilization of a building material to be considered safe, H_{in} must be less than one (<1) (UNSCEAR, 1993).

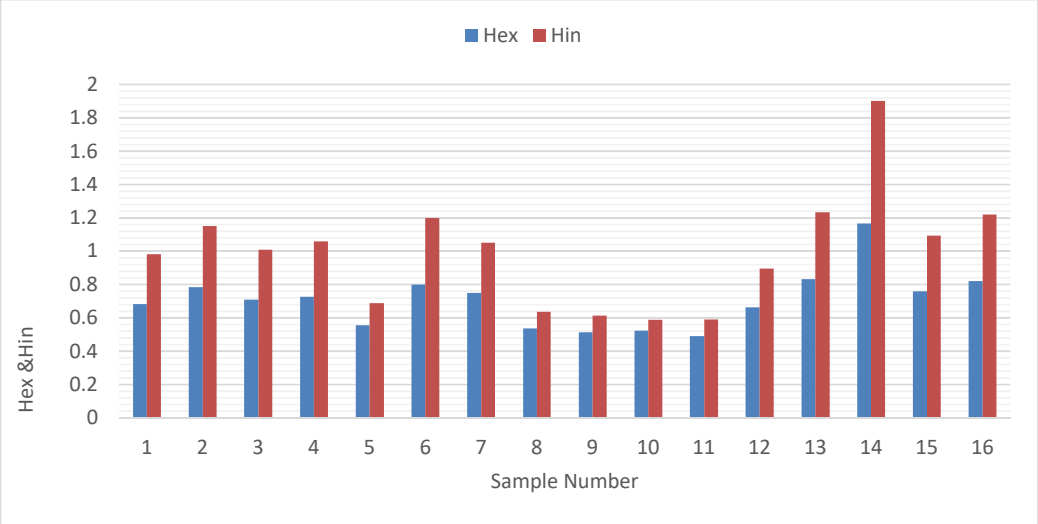

Fig. 8: External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in}) of Granite Samples from Abu Diab Area.

4.3.4 Annual Gonadal Dose Equivalent (AGDE)

The gonads, the active bone marrow, and the bone surface cells are considered as organs of interest (UNCEAR ,2000). The annual gonadal dose equivalent (AGDE) due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K is evaluated using the following formula (Zaidi *et al.,*1999):

$$AGDE\ (\mu Sv/y) = 3.09\ A_{Ra} + 4.18\ A_{Th} + 0.314\ A_{k} \quad \text{.....(14)}$$

where A_{Ra}, A_{Th}, A_K are the radium, thorium and potassium activity concentrations (Bq/kg) in granite samples . The obtained values of AGDE for the studied samples are summarized in table (4) . From the table we can notice that the values of AGDE varied from (0.62) mSv/y to (1.39) mSv/y for Abu Diab granite. The calculated values of AGDE showed that the highest value is in sample number (14), while the lowest value is in sample number (11). The average of AGDE values is (0.86) mSv/y which is approximately three times that world average (0.3 mSv/y) for granitic rocks. The AGDE variation values in mSv/y for the granitic rocks under investigations is shown in figure (9).

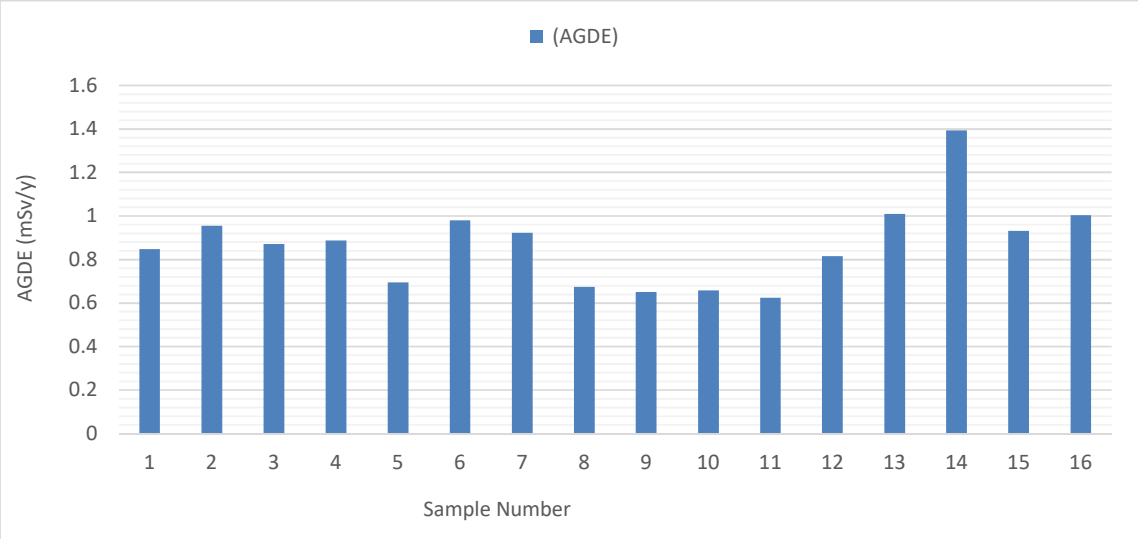

Fig. 9: The annual gonadal dose equivalent (AGDE) of granite samples from Abu Diab area.

4.3.5 Excess Lifetime Cancer Risk (ELCR)

This deals with the probability of developing over a lifetime at a given exposure level. Based upon calculated values of annual effective dose, excess lifetime cancer risk (ELCR) can calculated as follows (Ramasamy *et al.,* 2009):

$(ELCR)_{in} = (AED)_{in} \times L.E \times RF$ ……..….(15)
$(ELCR)_{out} = (AED)_{out} \times L.E \times RF$ ……....(16)
$(ELCR)_{total} = (ELCR)_{in} + (ELCR)_{out}$ ……(17)

Where $(AED)_{in}$, $(AED)_{out}$ are indoor and outdoor annual effective doses , L.E is life expectancy or duration life (66 – 70 years) and R.F is the risk factor (Sv^{-1}) i.e. fatal cancer risk per Sv ,which is 0.05 (Sv^{-1}) for the public (ICRP – 60) . ELCR values are performed in last column of table (4). The ELCR variation values for the granitic rocks under investigations is shown in figure (10). The excess lifetime cancer risk (ELCR) for outdoor exposure ranged from (0.53×10^{-3}) in sample number (3) to (0.86×10^{-3}) in sample number (14), with average value of (0.37×10^{-3}) for Abu Diab granite while the world permissible value of ELCR is (0.29×10^{-3}) (UNSCEAR, 2000).

The indoor ELCR varied from (2.84×10^{-3}) in sample number (11) to (6.75×10^{-3}) in sample number (14) with an average of 4.08×10^{-3} which higher than acceptable value (1.16×10^{-3}) (Taskin, 2009). While the total ELCR varied from (3.219×10^{-3}) to (7.616×10^{-3}) with an average of (4.616×10^{-3}). Finally, the ELCR total values for our study area is greater than the average world's value (1.45×10^{-3}) (Qureshi *et al.,* 2014). According to these results the cancer risk increases with increasing the exposure time to these materials.

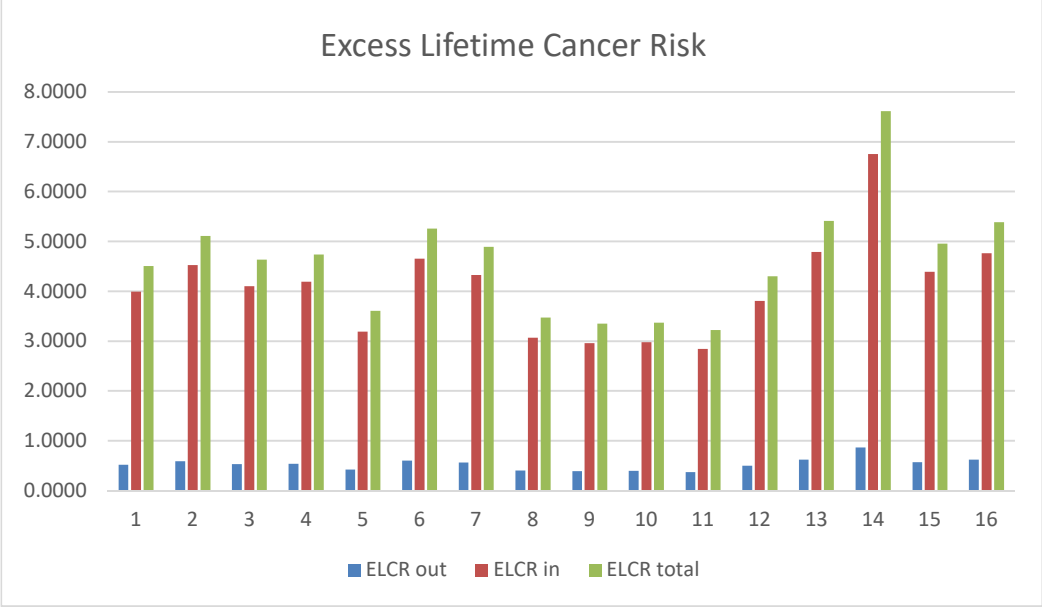

Fig. 10: Excess lifetime cancer risk (ELCR) of granite samples from Abu Diab area.

5. Conclusion

Undoubtedly that the mean activity concentration of ^{238}U ,^{232}Th , and ^{40}K for sixteen granite samples under investigation are ranged from (24.7±5.113) to (271.7±10.323) Bq/kg, (44.66±0.698) to (64.96±0.571) Bq/kg and (904.57±4.634) to (1039.16±3.778) Bq/kg , respectively, which are higher than that the worldwide average (50, 50, and 500) Bq/kg, respectively. The radium equivalent activity, Ra_{eq} ,for Abu Diab granite are ranged from (181.529) Bq/Kg to (431.653) Bq/Kg. The absorbed dose rate values are found to vary from (87.136 & 165.55) in (nGy/h) to (201.85 &392.82) in (nGy/h) for D_{out} and D_{in} ,respectively. It can be seen that the annual effective dose values are found to vary from (0.106 & 0.812) mSv to (0.247& 1.928) mSv for $AEDE_{out}$ and $AEDE_{in}$,respectively. Obviously, values

of alpha index, Iα, ranged from (0.1235) to (1.3585), while gamma index, Iγ, values ranged from (0.691) to (1.526). Whereas internal hazard index, H_{in}, has minimum value of (0.5899) and maximum value of (1.9009), the values of external hazard index, H_{ex} , ranged from (0.4906) to (1.1666). The values of annual gonadal dose equivalent, AGDE, varied from (0.62) mSv/y to (1.39) mSv/y. While the total excess lifetime cancer risk $(ELCR)_{total}$ varied from (3.219×10^{-3}) to (7.616×10^{-3}) with an average of (4.616×10^{-3}). All of these parameters deduced from our granitic samples from Abu Diab area.

Clearly, the radiological hazard indices have been found higher than the world permissible levels . It can be concluded from the analysis of the results that radionuclide activity concentrations differ from one location to another even from one sample to another and are found to be significantly higher than the acceptable values. Therefore, the granite rocks in Abu Diab area, Central Eastern Desert, Egypt may be hazardous to human health and are unsuitable for using in various infrastructures, particularly as construction.

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