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Evaluation of Natural Radioactivity and Risk Assessment of Radon in Surface Soils from Gold Mining Areas

E. S. Abd El-Halim

Nuclear Physics Laboratory, Women Faculty for Art, Science and Education, Ain Shams University, Cairo, Egypt

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ABSTRACT

Measurements of natural radioactivity in surface soils from a gold mining area were performed using aHPGe detector with a specially designed shield. Soil samples were collected from Um Garaiate mine in Southeastern area of Egypt and Mahd Ad-Dahab mine in Western of Al-Madina Al- Munawara area in Saudi Arabia. The obtained results of uranium and thorium series as well as potassium (^{40}K), were discussed. Radiological hazard indices in the gold mining area were found not to exceed the permissible limits. The Pearson correlation has shown a strong correlation between all radiological hazard indices with ^{226}Ra and ^{238}U , while a quite good correlation was obtained with ^{232}Th due to the fact that ^{238}U and ^{232}Th series are associated together in the natural and a negative correlation is with ^{40}K , as this isotope not decayed from ^{238}U and ^{232}Th series. The solid state nuclear track detector SSNTD (CR-39) was also used to measure the radon concentration, as well as the annual absorbed dose D_{Rn} , equivalent dose and effective dose to lungs. The results obtained in this study demonstrate that the mining activity at both um-Garaiate in Egypt and Mahd Ad-Dahab in Saudi Arabia, poses no significant radionuclide hazard to the miners and the public.

1. INTRODUCTION

Soils are considered as the main sources of radioactive nuclides in other environments such as water, air, sediments and biological systems. Hence surface soils are considered as the essential sources to the radiological exposure and are used to evaluate the environment radiological contamination [1].

Radioactivity in the mining areas is usually higher than its value in the surrounding regions because mining activities expose the naturally occurring radioactive materials (NORMs) to the earth's surface, and therefore causing an increase in the background gamma radiation levels [2]. NORMs account for up to 85% of the annual dose exposure received by the world's population [3]. The NORMs that are involved in the mining activities are non-decay potassium-40 and decay series radionuclides of uranium (U) and thorium (Th).

The long-term exposure to radiation can cause harmful health effects, such as chronic lung diseases, anemia and different cancers [4]. Emanation of radon (^{222}Rn), and α - radioactive gas, is associated with the

presences of radium. The inhalation of radon and the short- lived daughter products arising from its decays exposes the subjects. If the radon dose in gold mining is sufficiently high, it may cause lung cancer.

Several publications deal with measuring the low levels of naturally occurring radioactive isotopes in the gold mining areas [5-8]. The gold mining affects the surrounding areas. So it is an important to assess the radioactive exposure on the workers inside the mines. In the present work, the assessment radioactive in um-Garaiate mines of gold, located in Southern Egypt, and Mahd Ad Dahab Western region of Al-Madina Al-Munawara province, in Saudi Arabia are calculated.

^{238}U is present in traces in most soils and rocks and it decays to ^{226}Ra which is the parent of ^{222}Rn . The radium content of soil and rocks is responsible for the radon concentration in the ground. Radon gas and its daughters ^{218}Po and ^{214}Po have been identified as a major contributor to human health risk [9, 10], as when inhaled they emit alpha particles, which can cause damages to human tissues and organs.

Emanation, migration and exhalation are the three basic phases that radon goes through when it is created. When unsaturated rock and soils escape to interstitial space, they migrate through diffusion and follow a concentration gradient until reaching up to the surface. The movement of radon is caused by a transport mechanism, which is dependent on geological conditions such as number fracturing or disturbance, transport is that radon dissolved in water and move with it, the process being called migration [11, 12]. The radon exhalation rate is known by the rate at which radon escapes from the soil into the surrounding air [13, 14]. The inhalation of radon and the short-lived daughter products to which it decays, is a major contributor to the total radiation dose to exposed subjects that may cause lung cancer.

2. MATERIALS AND METHODS

2.1 Geology of the Study Area

Um- Garaiaat gold mine is located at the intersection of latitude $22^{\circ} 30' N$ and longitude $33^{\circ} 30' E$ in the Southeastern area of Egypt, as shown in Figure (1). The sample were collected along a straight line along 1Km. Ten ore rock samples were collected from mine locations, at about 100 m interval from each other.

The Mahd Ad Dahab mine area is located $23^{\circ} 30' N$, $40^{\circ} 52' W$ in the Western of Al-Madina Al-Munawara in Saudi Arabia, covering an area of about 270Km² as shown in Figure (2)[15,16]. Ten ore rock samples were collected from the mine along a straight line with an interval of 5 km from each other.

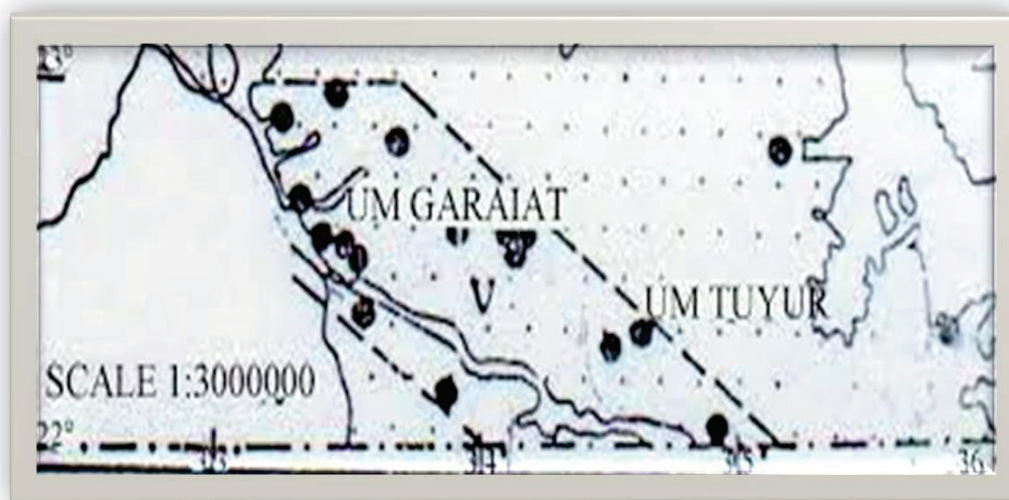


Fig. (1): Map of Um-Garaiaat mine in Southeastern area of Egypt

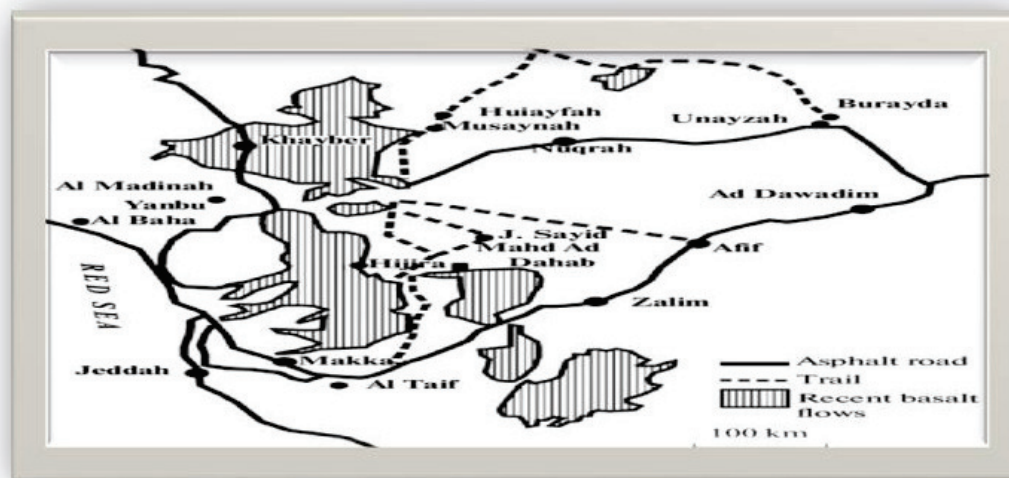


Fig. (2): Map of the study area shows the geology of the Mahd Ad Dahab mine

2.2 Sample Collection and Preparation

The samples collected from the aforementioned areas, each about 1 kg in weight, were ground, homogenized and sieved to about 200 mesh. The samples were then dried at 110°C for 12 h to ensure that moisture is completely removed. After the drying process, the samples were placed in cylindrical polyethylene bottles with a volume of 250 cm³. The bottles were completely sealed for more than one month to ensure reaching secular equilibrium.

3. MEASUREMENT EQUIPMENT

3.1 For Gamma-Ray Spectroscopic Analysis

The studied samples were measured using a high purity vertical germanium detector (HPG) that contains a preamplifier, an amplifier, a power supply and a multi-channel analyzer. The detector has been calibrated by using point sources of ⁶⁰Co, ¹³⁷Cs and ²⁴¹Am.

The detector has a resolution (FWHM) of 1.85 KeV for the 1332.5 KeV γ -ray line of ⁶⁰Co. The absolute efficiency calibration was performed using three well-known reference materials obtained from the International Atomic Energy Agency for U, Th and K activity measurements RGU1, RGTh1 and RGK-1 [17].

Each of these standard sources was placed in the identical polyethylene bottles mentioned before. The detector was surrounded by special heavy lead shield to reduce the background radiation. An empty bottle of the same geometry was used for measuring the background. The accumulation time for each sample was about 70000s.

The γ -ray transitions were used to measure the concentrations of the assigned nuclides in the series as presented in the following.

For ²³⁸U series, the specific activity of ²²⁶Ra was measured using the 186 keV from its own gamma-ray (after the subtraction of the 185.7 keV of ²³⁵U). The specific activity of ²¹⁴Pb was measured using the 241.9, 295.2 keV and 351.9 keV while the specific activities of ²¹⁴Bi and ²¹⁰Pb were measured using 609.3 and 46.5 keV respectively.

The ²³⁵U activity was determined directly by its gamma ray peaks (143.8, 163.4, 185.7 and 205 keV) [17, 18].

The specific activity of ²³²Th was measured using the 338.4 keV and 911.2 keV from ²²⁸Ac and 583 keV and 2614.4 keV from ²⁰⁸Tl. The specific activity of ⁴⁰K was measured directly by its own gamma-ray at 1460.8 keV.

3.1.1 Evaluation of Activity Concentration

The net count rates under the most prominent photo peaks of all radionuclides are calculated from the respective count rate after subtracting the background counts of the spectrum obtained for the same counting time. Then the activity of the radionuclide is calculated from the background subtracted area of prominent gamma ray energies. The activity of radium, thorium and potassium is calculated using the following equation [19]:

$$C \text{ (Bq/Kg)} = \frac{C_a}{\epsilon P M_S} \quad (1)$$

Where C_a is the count rate under each photopeak due to each radionuclide, ϵ is the detector efficiency for the specific γ -ray, P is the absolute transition probability of the specific γ -ray and M_S is the mass of the sample (kg).

3.1.2 Radiological Hazard Indices

Radium Equivalent Activity (Ra_{eq})

Radium equivalent activity (Ra_{eq}) is the weighted sum of the ²²⁶Ra, ²³²Th and ⁴⁰K activities according to the hypothesis that 370 Bq kg⁻¹ of ²²⁶Ra, 259 Bq/kg of ²³²Th and 4810 Bq/kg of ⁴⁰K attain the same dose rates of gamma-ray. Equation [2] can be used to obtain the Radium equivalent activity [20].

$$Ra_{eq} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \right) \times 370 \quad (2)$$

Where, the A_{Ra} , A_{Th} and A_K are the activity concentrations (Bq/Kg) of radium, thorium and potassium, respectively.

Assessment of Outdoor External Dose (D_{out}) and Indoor External Dose (D_{in}):

The absorbed dose rate, D (nGy/h) is a radioactive factor used to assess the effect of gamma radiation at 1 m distance from the radiation sources in the air due to the concentrations of ²²⁶Ra, ²³²Th and ⁴⁰K, and is given by [21].

$$D_{out} = 0.436 A_{Ra} + 0.599 A_{Th} + 0.0417 A_K \quad (3)$$

Where A_{Ra} , A_{Th} and A_K are the activity of ²²⁶Ra, ²³²Th and ⁴⁰K in Bq/kg respectively. The γ -ray dose (D_{in}) imparted by ²²⁶Ra, ²³²Th and ⁴⁰K present in the indoor is calculated by converting the absorbed dose rate into effective dose using the three conversion factors; 0.92 nGy h⁻¹ per Bq kg⁻¹ for ²²⁶Ra, 1.1 nGy h⁻¹ per Bq kg⁻¹ for ²³²Th and 0.081 nGy h⁻¹ per Bq kg⁻¹ for ⁴⁰K. By utilizing

the above mentioned conversion factors, the following equation was used to calculate the (D_{in}) [21].

$$D_{in} = 0.92 C_{Ra} + 1.1 C_{Th} + 0.081 C_K \quad (4)$$

Assessment of Outdoor and Indoor Annual Effective Dose

The annual effective dose (AED) is a radioactive factor utilized to detect the exposure level for radiation during a stationary duration (1 year). The AED can be detected using the following equations [22]:

$$\begin{aligned} \text{AED}_{out}(\text{mSv/y}) &= D_{air} (\text{nGyh}^{-1}) * 0.2 * 8760(\text{h/y}) \\ &* 0.7 (\text{Sv Gy}^{-1}) * 10^{-6} (\text{mSv nGy}^{-1}) \end{aligned} \quad (5)$$

$$\begin{aligned} \text{AED}_{out}(\text{mSv/y}) &= D_{air} (\text{nGyh}^{-1}) * 0.8 * 8760(\text{h/y}) \\ &* 0.7 (\text{Sv Gy}^{-1}) * 10^{-6} (\text{mSv nGy}^{-1}) \end{aligned} \quad (6)$$

Where, the occupancy factors represent 0.2 and 0.8 for outdoor and indoor exposure through 8760 h in one year and 0.7 is the conversion factor from the absorbed dose rate to the effective dose [2].

Assessment of Excess Lifetime Cancer Risk (ELCR)

According to the estimated values of the annual effective dose, the excess lifetime cancer risk (ELCR) detected can be obtained using the following equations [23];

$$\text{ELCR}_{outdoor} = E_{out} \times DL \times RF \quad (7)$$

$$\text{ELCR}_{indoor} = E_{in} \times DL \times RF \quad (8)$$

$$\text{ELCR}_{total} = \text{ELCR}_{indoor} + \text{ELCR}_{outdoor} \quad (9)$$

Where, DL is the duration lifetime (66 y) and RF is a cancer risk factor that uses a value of 0.05 Sv^{-1} for the general public [24].

Assessment of Radiation Level Index (I_γ)

A group of experts suggested that this index could be used to determine the amount of γ – radiation hazard associated with the natural radionuclides [25]. The represented level index radiation is defined by the European commission [26] and is given by the following equation:

$$I_\gamma = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \quad (10)$$

Assessment of External and Internal Hazard Indices

The external hazard index (H_{ex}) is used in order to estimate the biological hazard of the natural gamma radiation and it is given by the following equation [27]:

$$H_{ex} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \right) \leq 1 \quad (11)$$

Where, the A_{Ra} ; A_{Th} and A_K are the activity concentrations (Bq/Kg) of radium, thorium and potassium, respectively. If the maximum concentration of radium is half that of the normal acceptable limit, the internal exposure to ^{222}Rn and its daughter products is controlled by an internal hazard index H_{in} [27] which is equal to:

$$H_{in} = \left(\frac{A_{Ra}}{185} + \frac{CA_{Th}}{259} + \frac{A_K}{4810} \right) \leq 1 \quad (12)$$

Annual Gonadal Dose Equivalent (AGDE)

The organs of interest by UNSCEAR [28] include the thyroid, the lungs, bone marrow; bone surface cell, the gonads and the female breast. Using the formula below, the annual gonadal dose equivalent (AGDE) attributable to the individual activities of ^{226}Ra , ^{232}Th , and ^{40}K can be determined.

$$\text{AGDE} (\text{mSv/y}) = 3.09A_{Ra} + 4.14A_{Th} + 0.314A_K \quad (13)$$

3.2 For Radon- Gas Concentrations Using Solid State Nuclear Track Detectors (SSNTDs)

Ten samples from um-Garaite mining area and also ten samples from Mahd Ad Dahab mining area were collected, weighted and packed in stainless steel containers, having a volume of $V = 0.0005137 \text{ m}^3$, an area of $A = 0.004778 \text{ m}^2$ and being 0.103 m in height.

The samples were well-sealed and stored for 30 days, the CR-39 detector being placed on the top of the container. At the end of the exposure time, the radon detectors were collected. The detectors were etched using 6.25 N NaOH under controlled conditions of temperature (8 hour). The detectors were then washed many times by distilled water several times and dried with tissue papers. The tracks were counted by an optical microscope of 400 X, 50 fields being scanned for each detector to determine the track density per m^2 .

Radon Gas Concentration Using SSNTDs

Track Density

This is defined as the average number of counts per unit area of the electrode, being obtained with the help of the following relation: [29]

$$\text{Track density } (\rho) = \frac{\text{Average number of counts}}{\text{Area of electrode}} \quad (14)$$

The average number of counts used to determine the track density refers to a value obtained from 3 consecutive counts on each detector. The area of field of view was determined from the

diameter (d) of the circular shape of the electrode using the expression in Eqn: $\text{Area} = \frac{\pi d^2}{4}$ where $d = 0.8\text{cm}$

Thus the area of the electrode = 0.5027cm^2

Radon Concentration in (Bq.m⁻³)

After the track density (ρ), the radon gas concentration was delivered from the detector exposed in closed cups. The value of radon concentration at a secular equilibrium is given by the following equation [29, 30].

$$C_{Rn} = \frac{\rho}{KT_{eff}} \quad (15)$$

Where, C_{Rn} is the radon concentration (Bq.m⁻³), ρ is the track density (track.cm²), T_{eff} is the effective exposure time (day) and K is the calibration coefficient of CR-39 nuclear track detectors from the calibration $0.22 \text{ tracks.cm}^{-2} \text{ day}^{-1} / \text{Bq.m}^{-3}$ of radon.

$$T_{eff} = t - 1/\lambda (1 - e^{-\lambda t}) \quad (16)$$

Where, t is the actual exposure time (31 d) and λ is the decay constant for ²²²Rn ($2.1 \times 10^{-6} \text{ S}^{-1}$)

Annual Absorbed Dose

The annual absorbed dose rate equivalent due to the activity of radionuclide was calculated using the following equation [29, 32]:

$$\text{Annual absorbed Dose } (D_T \text{ mSv/y}) = C_{Rn} \cdot D \cdot H \cdot F \cdot T \quad (17)$$

Where: D = Dose conversion factor ($9 \times 10^{-6} \text{ mSv/hr per Bq/m}^3$)

H= Indoor occupancy factor (0.4), outdoor occupancy factor (0.6)

F= Indoor radon equilibrium factor (0.4), Indoor radon equilibrium factor (0.6)

T= Number of hours in a year (24 h x 365 days = 8760 hr/yr)

Annual equivalent dose

The annual equivalent dose is obtained by multiplying the annual absorbed dose by the radiation weighting factor (W_R). The radiation weighting factor recommended by the ICRP for alpha particles is 20. The Annual equivalent dose (H_T) to a whole body is evaluated by this equation [29, 33]:

$$H_T = \sum W_R \times D_T \quad (18)$$

Annual effective dose (to lungs)

This is obtained by multiplying the annual equivalent dose by the tissue weighting factor (W_T) for lungs using Eqn. (18) [29]. The tissue weighting factor recommended by the ICRP for the lungs is 0.12 [33]. Annual Effective dose (E_T) to lungs is given by:

$$E_T = \sum W_T \times H_T \quad (19)$$

W_T = tissue weighting factor (0.12 for lung)

4. RESULTS AND DISCUSSION

4.1 For Gamma-Ray Spectroscopic Analysis

Table (1) displays the mean values of ²²⁶Ra, ²³⁸U, ²³²Th, and ⁴⁰K from Um- Garaiaat, Egypt and Mahad Ad-Dahab, Saudi Arabia, mining areas, and the following values have been obtained: (13.76 ± 0.68 and 19.93 ± 0.99) for ²²⁶Ra, (15.27 ± 0.76 and 20.31 ± 1.01) for ²³⁸U, (10.08 ± 0.50 and 11.51 ± 0.57) for ²³²Th and (513.02 ± 25.65 and 188.16 ± 9.40) ⁴⁰K respectively. The values of the mean activity concentration are lower than the recommended world-wide limits which are 33, 35, 45 and 412 for ²²⁶Ra, ²³⁸U, ²³²Th, and ⁴⁰K respectively except the mean value of ⁴⁰K from Um-Garaiaat mine [28].

Ra_{eq} for both mining areas in Fig. 3 a) - gold mine in Egypt, b)-gold mine in Saudi Arabia. The mean values of Ra_{eq} were (62.38 and 36.31) in Um- Garaiaat area and Mahd Ad Dahab area respectively which are lower than the world's average value of 370 Bq/kg [28].

The outdoor and indoor external dose for both mining areas are given in Fig.4 a), b) – for gold mine in Egypt, c), d) - for gold mine in Saudi Arabia. The mean values of (D_{out}) and (D_{in}) were (35.369 and 66.46) and (21.95 and 41.65) in Um- Garaiaat area and Mahd Ad Dahab area respectively which are lower than the recommended

limit for outdoor and the indoor external the world's average of 59 nGy h^{-1} and 84 nGy h^{-1} , respectively [28].

The outdoor and indoor annual effective dose for both mining areas are given in Fig. 5 a), b) - for gold mine in Egypt, c), d) – for gold mine in Saudi Arabia. The mean

values of AED_{out} and AED_{in} were (0.043 and 0.325) for Um-Garaia area and (0.075 and 0.205) for Mahd Ad Dahab area, respectively which are lower than the recommended limit for the world's average which of 0.07 mSv y^{-1} and 0.41 mSv y^{-1} , respectively [28].

Table (1): The mean activity concentrate on of ^{226}Ra , ^{238}U , ^{234}U , ^{232}Th and ^{40}K for the studied mining areas

Sample No.	um-Garaite gold mining area				Mahd Ad Dahab gold mining area			
	^{226}Ra	^{238}U	^{232}Th	^{40}K	^{226}Ra	^{238}U	^{232}Th	^{40}K
1	5.70 ± 0.285	6.50 ± 0.32	4.90 ± 0.24	295.50 ± 14.7	5.62 ± 0.28	5.48 ± 0.27	3.91 ± 0.19	92.21 ± 4.61
2	9.45 ± 0.47	11.65 ± 0.58	10.35 ± 0.51	428.65 ± 65	6.91 ± 0.34	7.59 ± 0.37	4.71 ± 0.23	90.51 ± 4.52
3	26.98 ± 1.34	25.92 ± 1.29	7.15 ± 0.35	662.55 ± 33.12	8.52 ± 0.42	10.98 ± 0.54	5.82 ± 0.29	280.92 ± 14.04
4	8.91 ± 0.44	9.62 ± 0.48	6.98 ± 0.34	450.30 ± 22.51	11.95 ± 0.59	12.55 ± 0.62	6.29 ± 0.31	285.81 ± 14.29
5	14.82 ± 0.74	15.35 ± 0.76	12.52 ± 0.62	475.95 ± 23.79	7.85 ± 0.39	8.95 ± 0.44	3.82 ± 0.19	110.81 ± 5.54
6	18.20 ± 0.91	20.92 ± 1.04	15.21 ± 0.76	332.57 ± 16.62	10.11 ± 0.50	10.81 ± 0.54	5.11 ± 0.25	112.21 ± 5.61
7	7.97 ± 0.39	10.25 ± 0.51	5.95 ± 0.29	330.98 ± 16.54	28.32 ± 1.41	30.81 ± 1.54	15.21 ± 0.76	160.91 ± 8.04
8	33.14 ± 1.65	35.98 ± 1.79	7.91 ± 0.39	730.55 ± 36.52	18.85 ± 0.94	20.11 ± 1.01	10.85 ± 0.54	150.11 ± 7.50
9	21.82 ± 1.09	20.19 ± 1.01	13.96 ± 0.69	500.92 ± 25.04	15.11 ± 0.75	15.82 ± 0.79	6.99 ± 0.34	130.81 ± 6.54
10	11.95 ± 0.59	15.85 ± 0.85	4.95 ± 0.24	610.22 ± 30.51	34.25 ± 1.71	35.15 ± 1.75	19.12 ± 0.95	170.82 ± 8.54
Min	5.70 ± 0.28	9.62 ± 0.046	4.95 ± 0.24	295.5 ± 14.77	5.62 ± 0.28	5.48 ± 0.27	3.82 ± 0.19	90.51 ± 4.52
Max	21.82 ± 1.09	20.92 ± 1.046	15.21 ± 0.76	730.55 ± 36.52	34.25 ± 1.71	35.15 ± 1.75	19.12 ± 0.95	285.81 ± 14.29
mean	13.76 ± 0.68	15.27 ± 0.76	10.08 ± 0.50	513.025 ± 25.65	19.93 ± 0.99	20.31 ± 1.01	11.51 ± 0.57	188.16 ± 9.40
P.L.	33	35	45	412	33	35	45	412

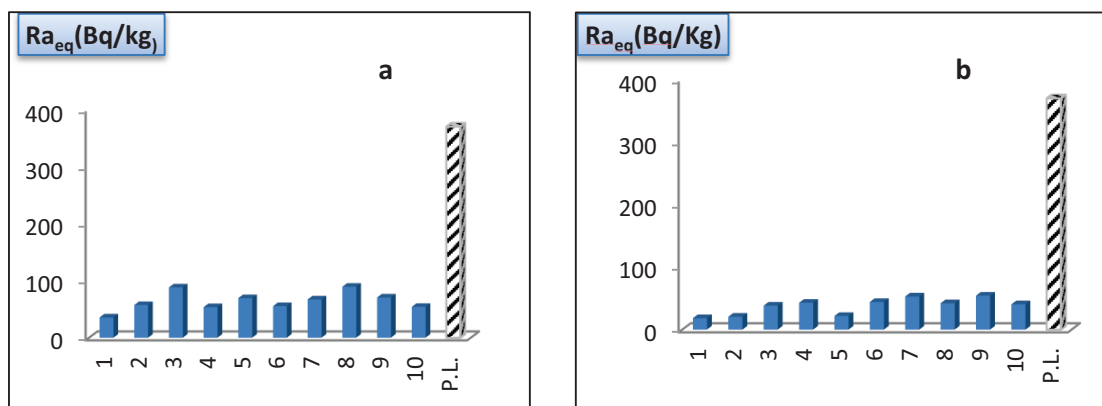


Fig. (3): Radium equivalent activity for the studied mining areas

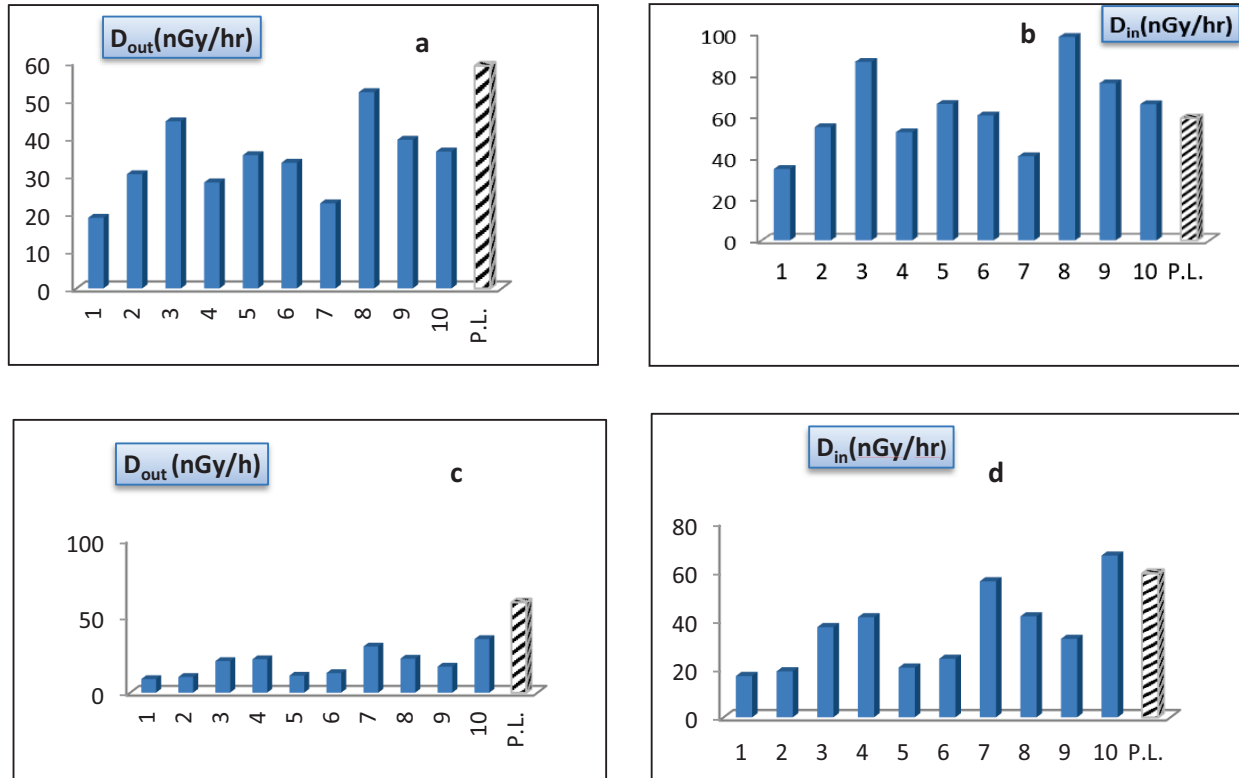


Fig. (4): External and internal dose for the studied mining areas

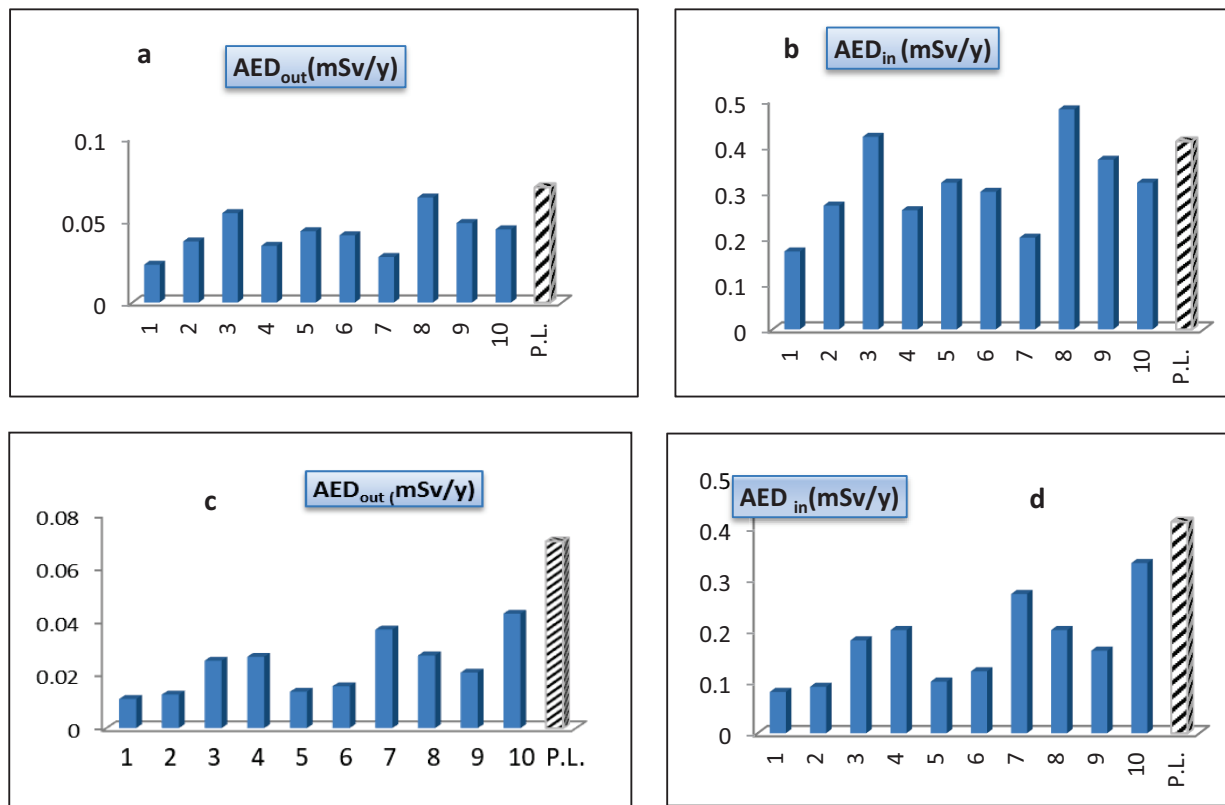


Fig. (5): Annual effective dose for the studied mining areas

The excess lifetime cancer risk for both mining areas are given in Fig. 6 a), b) – for gold mine in Egypt, and c), d) – for gold mine in Saudi Arabia. The mean values of $ELCR_{outdoor}$ and $ELCR_{indoor}$ were (0.143 and 1.0755) for Um- Garaiaat gold mine area (0.088 and 0.674), and Mahd Ad Dahab area, respectively, which are lower than the recommended limit for the world's average value of 0.29

and 1.16 for the $ELCR_{outdoor}$ and $ELCR_{indoor}$, respectively [20].

Radiation level index for both mining areas in fig. 7 a) – for gold mine in Egypt, b)- for gold mine in Saudi Arabia. The calculated mean values of I_{γ} were (0.49 and 0.26) respectively, for Um- Garaiaat gold mine area and Mahd Ad Dahab gold mine, both being lower than unity which represents the world's average value [28].

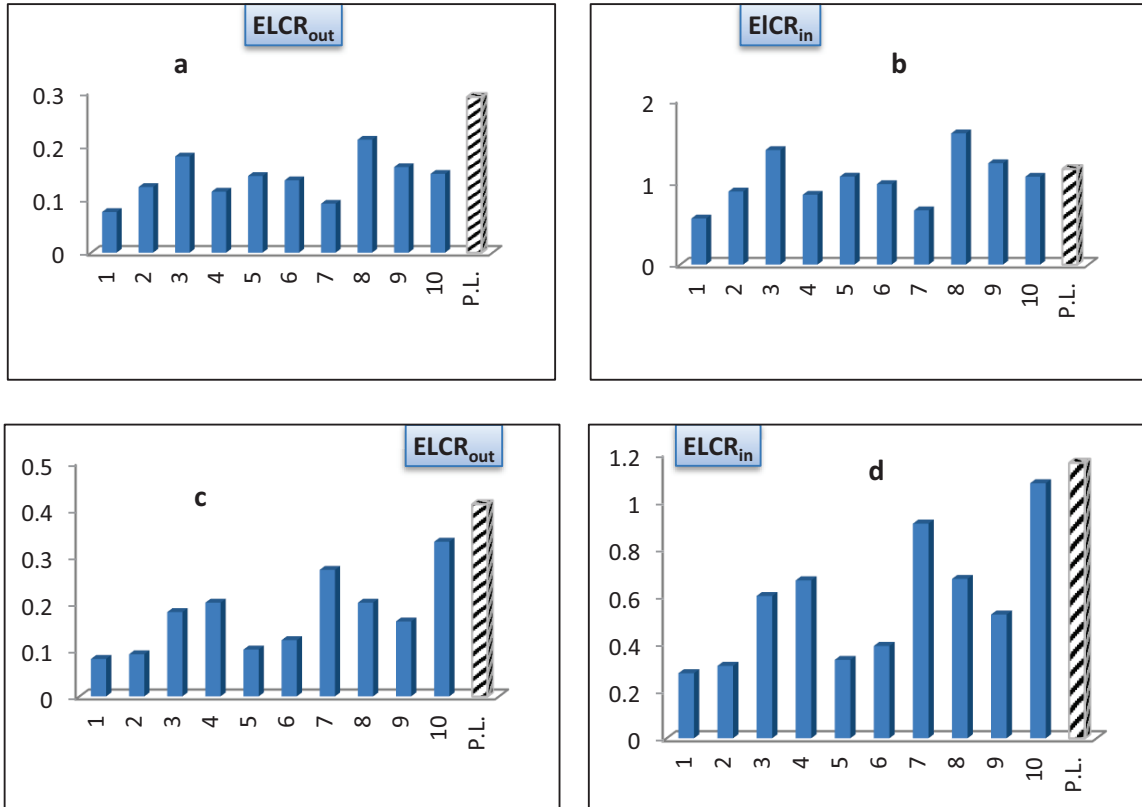


Fig. (6): Excess lifetime cancer risk for the study

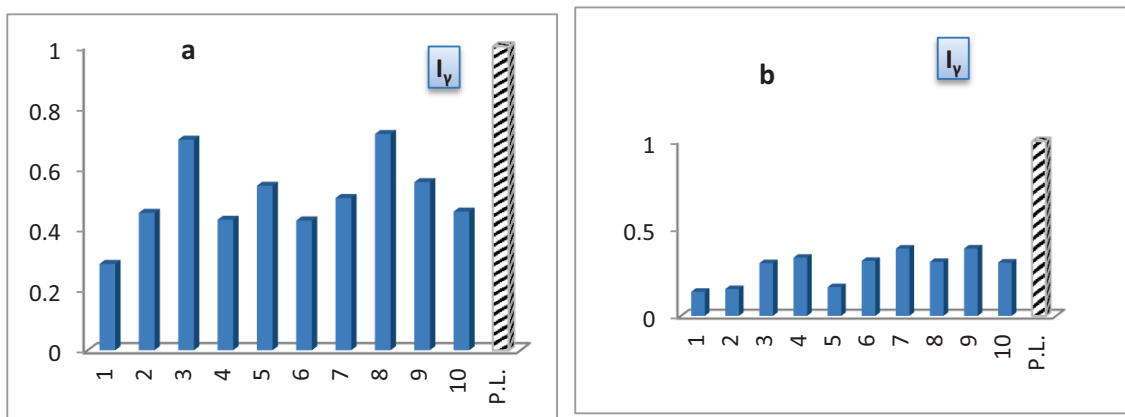


Fig. (7): Radiation level index for the studied mining areas

The external and internal hazard index (H_{ex} and H_{in}) for both mining areas are given in fig. 8 a), b) – for gold mine in Egypt, and c), d) – for gold mine in Saudi Arabia. For safe limitation H_{ex} and H_{in} must be less than unity [20]. In this study, the mean values for H_{ex} and H_{in} were (0.1685 and 0.265) for Um- Garaiaf gold mine area and (0.0977 and 0.199) Mahd Ad Dahab gold mine area, respectively.

In the present study, annual gonadal dose equivalent (AGDE) for both mining areas are given in Fig. 9 a) -for gold mine in Egypt, and b)- for gold mine in Saudi Arabia. the mean average values of (AGDE) for

Um- Garaiaf and Mahd Ad Dahab gold mines areas were (0.247 and 0.150), values being lower than the world average value (AGDE) of 0.3 mSv/y[28, 34].

Figures (3-9) illustrate the radiological hazard indices obtained for the two mining areas of interest for this study.

Correlation coefficients between activity concentrations of naturally occurring radioactive materials and radiological hazard indices measured in selected locations from the two considered mining areas were calculated in the form of the correlation matrix as shown in Table (2).

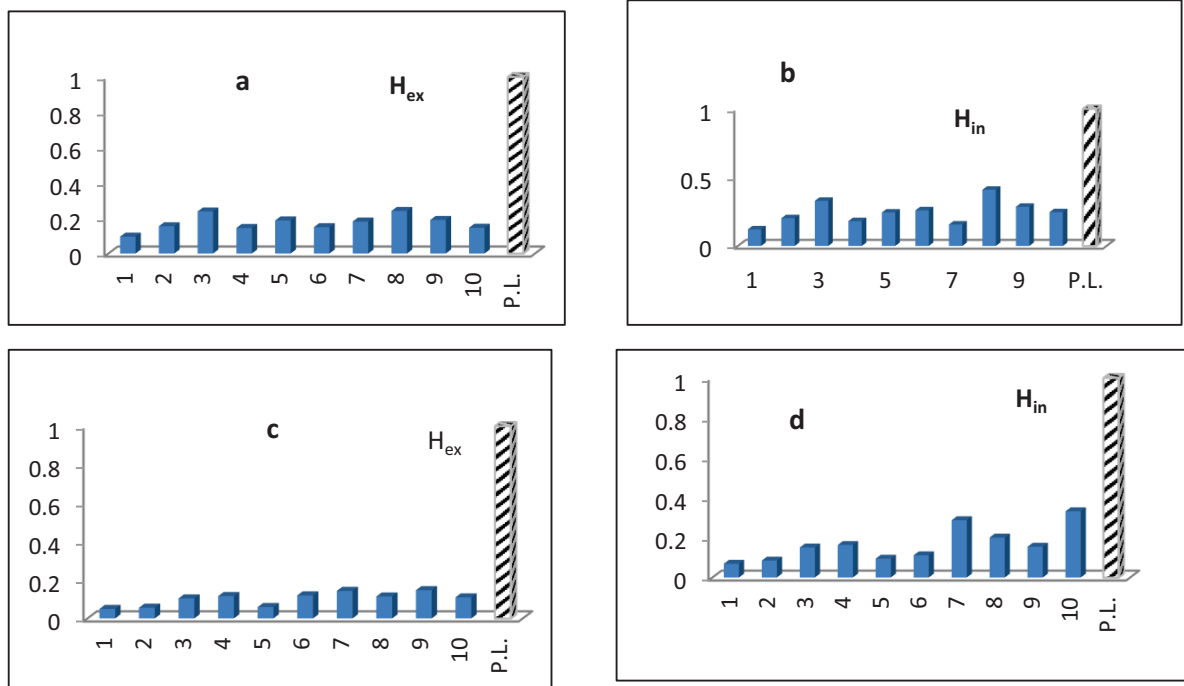


Fig. (8): External and internal hazard indices for the studied mining areas

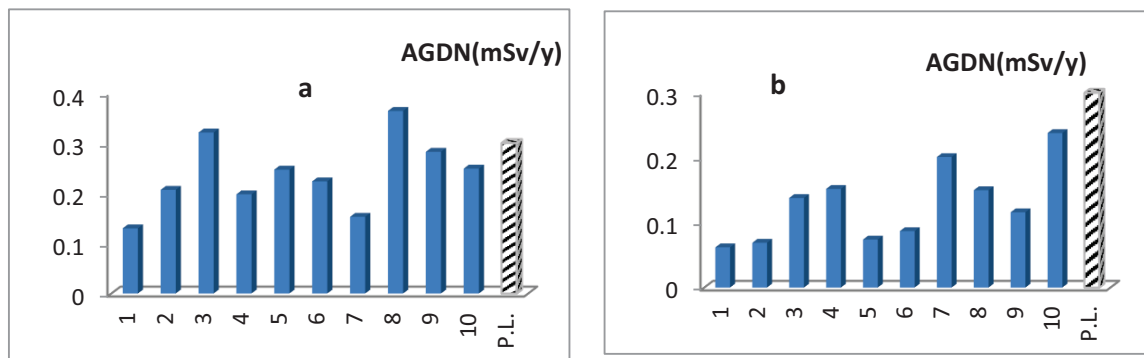


Fig. (9): annual gonadal dose equivalent (AGDE) for the studied mining areas

Table (2): Pearson correlation between natural radionuclides and the radiological hazards parameters the studied mining areas. (*) Um- Garaiaat gold mine area, Egypt and, () Mahd Ad Dahab gold mines area, Saudi Arabia**

	^{226}Ra	^{238}U	^{232}Th	^{40}K	Ra_{eq}	H_{in}	H_{ex}	D_{out}	E_{out}	E_{in}	ELC_{out}	AGDE
^{226}Ra	1*											
	1**											
^{238}U	0.996	1*										
	0.996	1**										
^{232}Th	0.989	0.988	1*									
	0.989	0.988	1**									
^{40}K	-0.127	-0.161	-0.149	1*								
	-0.127	-0.161	-0.149	1**								
Ra_{eq}	0.849	0.818	0.150	-0.746	1*							
	0.578	0.596	0.505	-0.387	1**							
H_{in}	0.972	0.981	0.276	-0.847	0.834	1*						
	0.977	0.985	0.977	-0.323	0.617	1**						
H_{ex}	0.849	0.818	0.150	-0.746	0.999	0.833	1*					
	0.578	0.596	0.504	-0.387	0.999	0.617	1**					
D_{out}	0.940	0.943	0.248	-0.900	0.829	0.988	0.828	1*				
	0.924	0.937	0.932	-0.489	0.628	0.982	0.627	1**				
E_{out}	0.940	0.943	0.248	-0.900	0.829	0.988	0.828	1*				
	0.924	0.937	0.932	-0.489	0.628	0.982	0.627	1**				
E_{in}	0.953	0.942	0.247	-0.896	0.842	0.986	0.841	0.997	0.997	1*		
	0.937	0.945	0.938	-0.464	0.734	0.985	0.734	0.998	0.998	1**		
ELC_{out}	0.940	0.943	0.248	-0.900	0.829	0.862	0.988	0.828	1	1	1*	
	0.924	0.937	0.932	-0.489	0.628	0.982	0.627	1	1	1	1**	
AGDE	0.945	0.934	0.230	-0.908	0.841	0.982	0.841	0.982	0.841	0.997	0.999	1*
	0.921	0.932	0.928	-0.499	0.627	0.980	0.627	0.999	0.999	0.999	1	1**

It can be observed that ^{238}U activity concentration has very strong correlation with ^{226}Ra and ^{232}Th and in contrast, ^{40}K has negative correlation with other radionuclides. The Pearson correlation shows the strong correlation between all radiological hazard indices with ^{226}Ra and ^{238}U , while just a good correlation with ^{232}Th due to the fact that ^{238}U and ^{232}Th series are associated together in the natural, and a negative correlation with ^{40}K is present, as this isotope not decayed from ^{238}U and ^{232}Th series.

4.2 For Solid State Nuclear Track Detectors (SSNTDs)

Table (3) shows the results of the computed track density, radon concentration, absorbed dose, equivalent dose and effective dose to lungs of the measured indoor radon for Um- Garaiaat, Egypt and Mahd Ad Dahab,

Saudi Arabia, gold mines areas. The mean values for indoor radon concentration were (34.045 ± 20.42) for Um- Garaiaat gold mine area, Egypt and (34.595 ± 20.75) for Mahd Ad Dahab gold mine area, Saudi Arabia, respectively. These mean values are slightly lower than the global mean value of 40 Bq/m^3 [2].

The mean effective dose to lungs was ($1.91 \pm 1.14 \text{ mSv/yr}$) and ($0.99 \pm 0.59 \text{ mSv/yr}$) for Um- Garaiaat gold mine area and Mahd Ad Dahab gold mine area, respectively, these mean values being slightly lower than the global mean value of 1.15 mSv/yr [2]. The calculated effective doses was ($19 \pm 11.4 \text{ mSv/yr}$) for Um- Garaiaat gold mine area, and ($8.3 \pm 4.98 \text{ mSv/yr}$) for Mahd Ad Dahab gold mine area, respectively. Both mean values are slightly lower than the international recommended reference levels of 3-10 mSv/yr [35].

Table (3): The values of track density (T/cm²), outdoor radon concentration (Bq/m³), absorbed dose (mSvy⁻¹), equivalent dose and effective dose to lungs for the studied mining areas

Sample No.	um-Garaite mining area					Mahd Ad Dahab mining area				
	Track density (T/cm ²)	Radon con. (Bq/m ³)	Dose (mSvy ⁻¹)	H _T (mSvy ⁻¹)	E _T (mSvy-1)	Track density (T/cm ²)	Radon con. (Bq/m ³)	Dose (mSvy ⁻¹)	H _T (mSvy ⁻¹)	E _T (mSvy ⁻¹)
1	62.26	9.75	0.27	5.4	0.64	61.38	9.62	0.12	2.4	0.28
2	106.17	16.64	0.46	9.2	1.10	75.48	11.83	0.14	2.8	0.33
3	303.08	47.50	1.33	26.6	3.19	95.72	15.00	0.18	3.6	0.43
4	100	15.67	0.43	8.6	1.03	134.24	21.04	0.25	5	0.60
5	166.4	26.08	0.73	14.6	1.75	88.18	13.82	0.17	3.4	0.40
6	204.45	32.04	0.89	17.8	2.13	113.58	17.80	0.21	4.2	0.50
7	89.48	13.94	0.39	7.8	0.93	318.18	49.87	0.59	11.8	1.41
8	372.22	58.34	1.63	32.61	3.91	211.78	33.19	0.39	7.8	0.93
9	245.02	38.40	1.07	21.4	2.56	168.88	26.47	0.31	6.2	0.74
10	134.47	21.02	0.50	11.6	1.39	380.08	59.57	0.71	14.2	1.70
Min	62.26	9.75	0.27	5.4	0.64	61.38	9.62	0.12	2.4	0.28
Max	372.22	58.34	1.63	32.16	2.56	380.08	59.57	0.71	14.2	1.70
Mean	217.24	34.045	0.95	19	1.91	251.42	34.595	0.415	8.3	0.99
	±130.34	±20.42	±0.57	±11.4	±1.14	±150.8	±20.75	±0.249	±4.98	±0.59

CONCLUSION

Natural Radioactivity measurement and radiological hazard evaluation in surface soils for some gold mining areas have been performed to establish the baseline data. Soil samples were collected from Um Garaite mine, in Southeastern area of Egypt and Mahd Ad-Dahab mine, in Western area of Al-Madina Al- Munawara, Saudi Arabia. The activity concentration levels of ²³⁸U, ²³²Th and ⁴⁰K in soil mine samples have been studied using a high purity germanium detector (HPGe). All the samples presented an average activity concentration lower than the permissible levels. Associated radiological hazard indices such as Ra_{eq}, I_γ, D_{out}, D_{in}, H_{ex}, H_{in}, E_{out}, E_{in}, ELCR_{out}, ELCR_{in} and AGDE were calculated, and their values for the areas of interest were still less than the safety limits. The conclusion is that the people living in these locations will not be adversely affected. Radon is a radioactive gas that is found all over the world and is recognized for its effect to cause lung cancer, as its major health implication. A solid state

nuclear track detector SSNTD (CR-39) was used to measure the radon concentration, as well as the following doses: annual absorbed dose, equivalent dose and effective dose to lungs. In comparison to the global average values, the studied parameters presented lower values. In conclusion, the areas under investigation are safe regarding the risk effect of radon presence, but caution should be taken against long term cumulative effects. For the workers, the working hours should be set in such a way to avoid the exposure to a high dose of radon.

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