IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 16, Issue 8 Ser. I (August 2022), PP 32-45
www.iosrjournals.org

Radioactive Risk Assessment of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt

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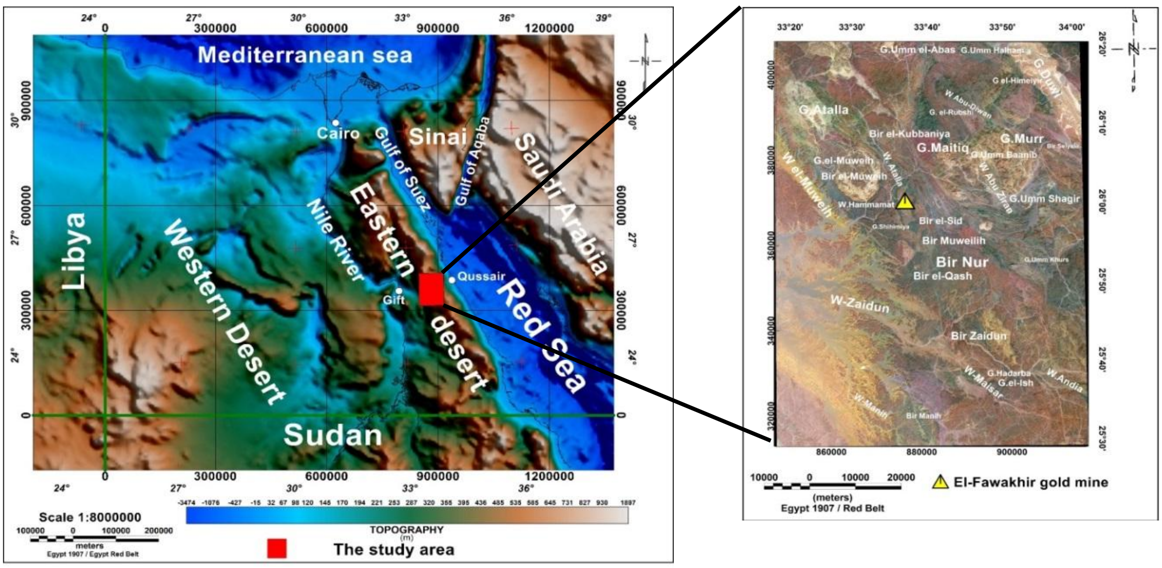
Abstract
Radioactive environmental hazard assessment was done for the location of the gold mine in El-Fawakhir area, eastern desert of Egypt by using the airborne gamma ray spectrometric data in order to evaluate the radioactive pollution and recommend certain precautions to safe life of the people who are working in the gold mine and living in the nearby sites. The obtained results of theabsorbed dose rate, effective dose rate, excess lifetime cancer risk, annual gonadal equivalent dose, internal and external hazard indices at El-Fawakhir gold mine and some other surrounding sites indicate that the values of these radioactive factorsexceed the recommendedinternational levels of radiation. Radioactive risk map is prepared for the study area, where the site of the gold mine lies in a risky zone. Accordingly, the study area should besubjected to further follow up investigations to assess the land uses and a dose monitoring program is necessary. It is also recommended for the workers in the El-Fawakhir gold mineto live and build their homes far away from the younger granites and metamorphic rocks and away from the drainage and structural linesto keep the exposure duration as short as possible. The water wells must be drilled, as possible, in basic or ultrabasic rocks to avoid high radioactive dose rate found in the younger granites and metamorphic rocks. Finally, special health precautions should be applied for the peoples who are working and living in the area of El-Fawakhir gold mine.
Key words: *Airborne gamma ray spectrometry, radioactive hazards, El-Fawakhir gold mine, Eastern desert, radioactive risk factors.*

Date of Submission: 20-08-2022 Date of Acceptance: 04-09-2022

I. Introduction

El-Fawakhir area is one of the most promising areas for mining activity in Egypt.It is located in the Eastern desert, about 88 km to the west of the Qusier city and almost 85 km to the east of the Qift city on the asphaltic road connecting the Red Sea to the Nile River (Fig.1).EL-Fawakhir gold mine is located in the center of this area and represents one of the largest mesothermal vein-type gold deposits in the Eastern Desert of Egypt (Zoheir et al., 2015).



(Fig.1): Landsat image of El-Fawakhir gold mineand surroundings, central part of Eastern Desert, Egypt

Since the creation of the earth, all humans have been exposed to natural radiation which comes from natural sources like cosmic rays and naturally occurring radioactive materialsassociated with human activities such as mining, nuclear industries, and the use of ores containing naturally radioactive materials. Radon gas, which comes from the soil and may accumulate in houses, contributes significantly to human exposure to radiation hazards. In order to determine the effects of radiation exposure, it is necessary to know the levels of radiation and the distribution of radionuclides in our environment, as some areas have higher levels of natural radiation exposure than the global average.Living cells can be damaged by this radiation, resulting in cell death or cell alteration depending on the dose of radiation received.Radiation has been related to most types of leukemia as well as malignancies of the lungs, breast, and thyroid (UNSCEAR 2000).Cancer caused by radiation may appear after periods of exposure, which does not differ in symptoms and effects from cancers that produced by other factors.

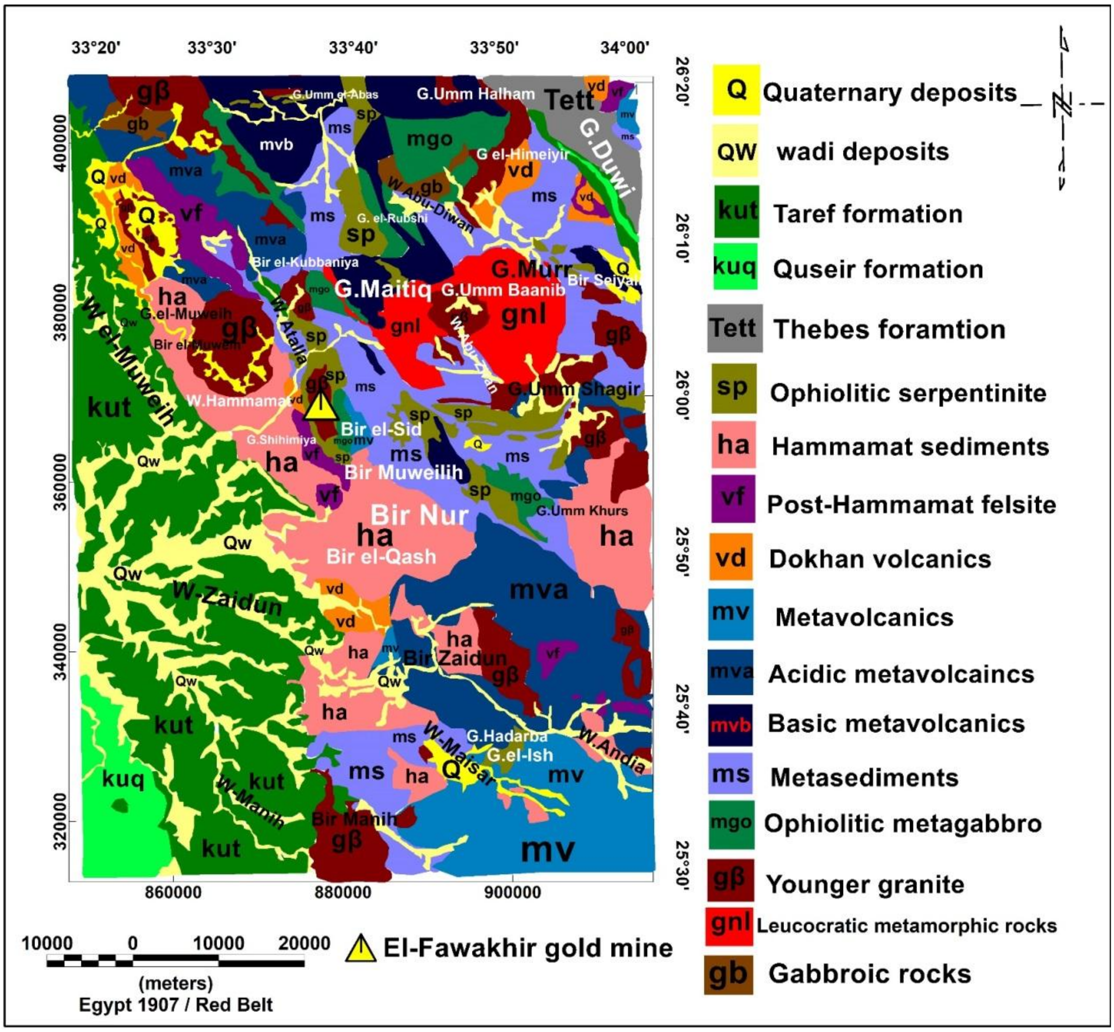
The present study uses airborne gamma-ray spectrometric data to assess the radiation hazards in El-Fawakhir gold mine and surroundings. The exposure rate, effective dose rate (EDR), excess lifetime cancer risk (ELCR), annual gonadal equivalent dose (AGED), Internal and External Hazard Indices (H_{in}, H_{ex}) were calculated and analyzed in order to delineate the possible hazards caused by anomalous natural radioelement distribution.

II. GEOLOGY OF EL-FAWAKHIR AREA AND SURROUNDINGS

El-Fawakhir area contains a variety of rock types including sedimentary, metamorphic and igneous rocks. The main Precambrian basement rock units in the study area (Fig.2) arranged from the oldest to the youngest as serpentinite, metagabbro-diorite complex, ophiolitic metagabbro, metavolcanics, metasediments, hammamat sediments, gabbroic rocks, older granites, younger granites, dokhan volcanic and post hammamat felsite. The Pre-Cambrian basement rocks are overlain by Phanerozoic sediments (Nubian sandstones and Qusier clastic formation(Hume,1937; Akaadand Noweir,1969& 1980;Hamdy and Khedr,2021; Rieset. al.,1983;Abdel-Karim and El-Shafei,2018;Abd El- Rahman et. al.,2009; El-Ramly and Akaad,1960; Hickey and Frey,1982; Hart et. al.,1974; Mohy et. al.,2016; Zoheir and Moritz,2014; Meneisy and Lenz, 1982; Gehad,2020; El-Bahariya,2019;Moghazi, 2003; Ressetar and Monrad,1983; Neumayr et. al.,1996; El-Qassas,2018; Youssef et. al.,2016; Strougo and Abul-Nasr,1981 and Osman and Taman,1996)

The gold, in El-Fawakhir area, appears in the form of structurally controlled hydrothermal quartz veins and veinlets, surrounded by wall rock alteration envelopes hosted in the Nubian Shield's igneous and metamorphic rocks.Sulfide gold mineralization occurs in rocks with varying composition, ranging from acidic to mafic or even ultramafic rock types. Quartz veins and veinletsare the main targets of gold mineralization in the Eastern Desert of Egypt(Khalil et. al.,2015& 2016;Beniamin et. al.,2005; Loizenbauer et. al.,2006;Bordonosov and Sabet,1984; Fakhry,1999; Harraz,2000;Abou El-Magd et. al.,2015;Mohy et. al.,2016;Helmy et. al.,2018;El-Sayed et. al.,2019 andAbd El Monsef,2020.

EL-Fawakhir area has suffered from various tectonic activities.There are three major faults affecting the whole area in the NW-SE, ENE-WSW and NE-SW directions. The ENE-WSW trend is younger than the NNE-SSW trends and it is mainly a strike-slip fault of right-lateral type, while the other trends are mainly of normal type and steeply inclined to near vertical (Harraz and Ashmawy,1994).

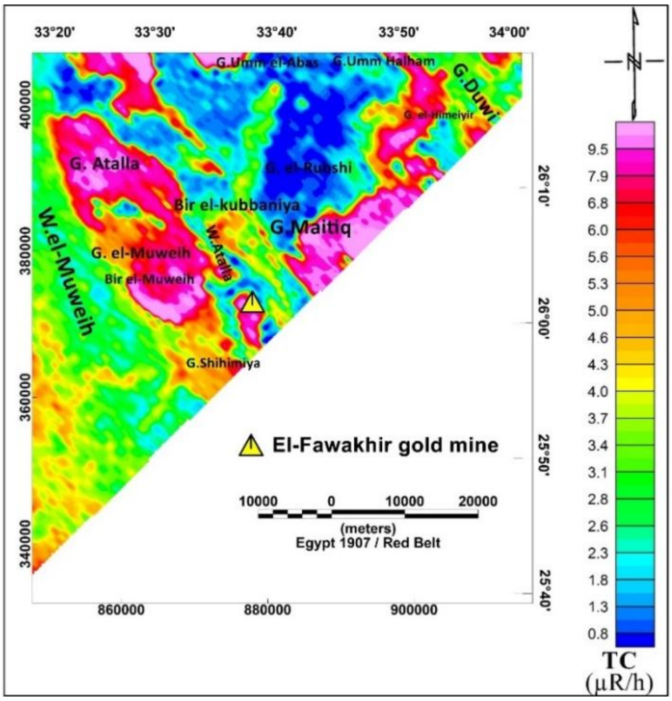


(Fig.2): Geological map of El-Fawakhir area and surroundings, central part of Eastern Desert, Egypt

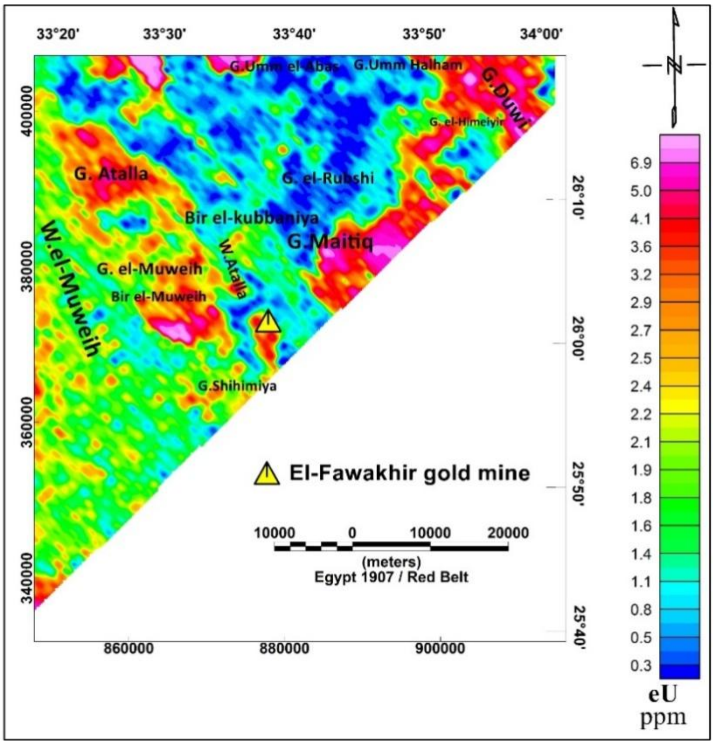
III. AIRBORNE GAMMA RAY SPECTROMETRIC DATA OF EL-FAWAKHIR AREA AND SURROUNDINGS

The gamma-ray spectrometry is a technique for determining uranium, thorium, and potassium contents in materials near the earth's surface. The concentrations of the radio elements are variable in the different types of rocks. Thus, gamma-ray spectrometric data could be used to detect areas of consistent lithology and contact between different lithologies (Atef et. al., 2000). The surface concentrations of the radioelement (i.e., potassium, uranium and thorium) can be quantified by measuring the intensities of the gamma radiation emitted by K^{40}, Bi^{214} and Tl^{208} radioisotopes respectively. These measurements are frequently made using airborne gamma-ray spectrometry, which can then be correlated to surface concentrations using suitable calibration processes (Grasty et. al., 1985). The information gathered is then utilized to create maps illustrating the distribution of the three radioelements which is of great help in determining the radioactive levels in the study area and their relation with the safe radioactive levels.

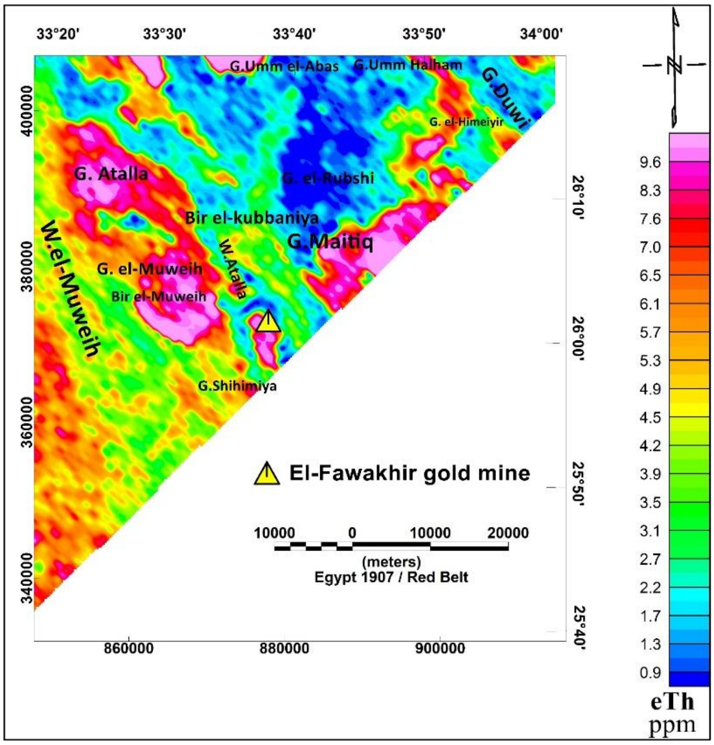
The airborne gamma ray radiometric survey of El-Fawakhir area and surroundings was carried out by Aero-Service Division, Western Geophysical Company of America on 1982 (Aero Service Report,1984) for the Egyptian General Petroleum Corporation (EGPC) and the Egyptian Geological Survey and Mining Authority (EGSMA). This survey covered El-Fawakhir gold mine and surroundings in the form of triangle shape (Fig.2).The radiometric data are gridded to generate total count (TC in μR/h), equivalent uranium (eU in ppm), equivalent thorium (eTh in ppm) and potassium (K in %) maps which display the surface distribution of these elements and clearly delineate surface lineaments (Figs. 3,4,5&6).



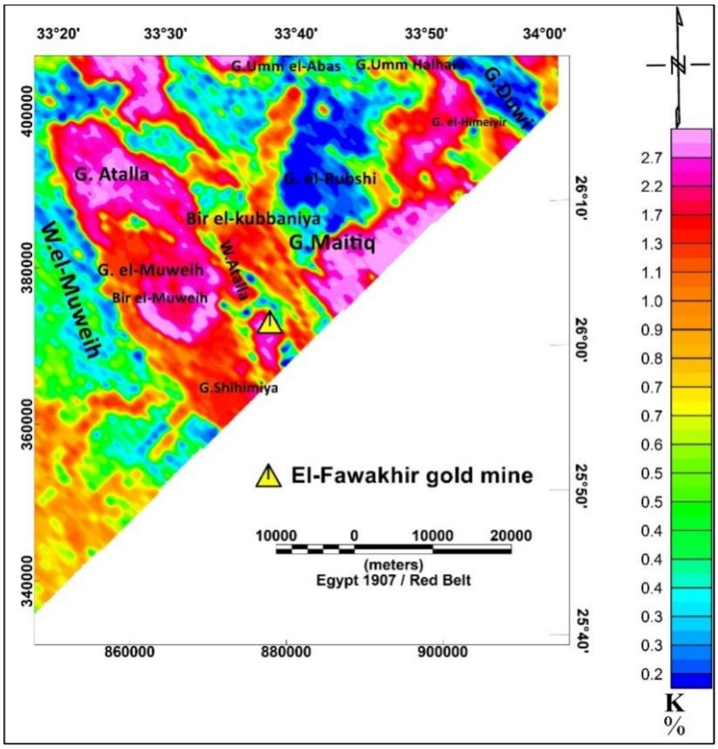
(Fig.3): Total radiation counts map, measured in(μR/h) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



(Fig.4): Equivalent uranium (eU) concentration map of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



(Fig.5): Equivalent thorium (eTh) concentration map of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



(Fig.6): Radioactive potassium abundance map in percentage (K %) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

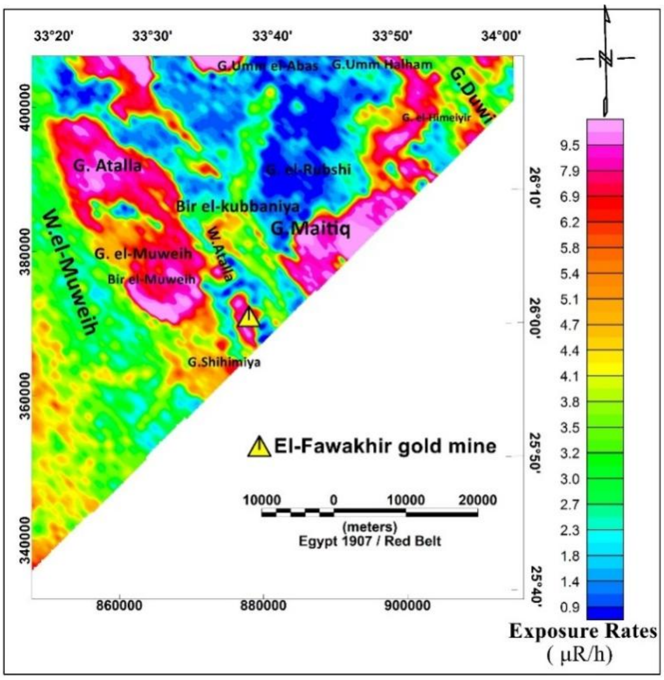
IV. RESULTS AND DISCUSSION

The obtained spectrometric maps of El-Fawakhir area and surroundings have been processed and interpreted in the light of the prevailing geological rock units in order to assess the radioactive risk in the gold mine area as well as to locate the safe and unsafe sites to take the necessary precautions for the people who are working and living in the area. These processing steps can be done through the determination of the exposure rate, the effective dose rate (EDR), the excess lifetime cancer risk (ELCR), the annual gonadal equivalent dose (AGED), the internal and external hazard indices (H_{in}, H_{ex}).Results and discussion of these radioactive risk factors are given in the following paragraphs:

4-a: Radioactive Exposure

The radiation strength at a specific location is termed as "Exposure" (E) and it isdetermined byits ability tocreate ionization atthat place.The exposure rate of radiation, expressed in μR/h, is commonly used as a reference for comparing man-made radiation sources such as nuclear weapons fallout and nuclear power generation. This exposure rate is now considered as one of the powerful tools in environmental mapping. It can be calculated from the apparent abundance of K (%), concentrations of eU (ppm) and eTh (ppm) using the following equation (IAEA, 2003):

It should be highlighted here that this equationexpresses only the gamma-ray exposure rate fromradioactive sources in the ground and excludes the cosmic-ray component and any cesium fallout on the earth.The exposure rate map of El-Fawakhir gold mine and surroundings shows that it ranges between 0.9 and 9.5 μR/h, where the site of the gold mine expresses the highest value which exceeds 9.5 μR/h (Fig.7). This result should be considered to safe the people who are working in the gold mine and living in the surrounding sites.



(Fig.7): Exposure rates map (in μR/h)of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

4-b: Radioactive Dose Rates

The International Atomic Energy Agency (IAEA) has referred to the term absorbed dose (D) as a measure of energy deposition by radiation, whilethe ratio of the doses accumulated by radiation in an object to the exposure period is known as absorbed dose rate, (D′). The unit of the absorbed dose is Gray (Gy)which is derived from the International System of Units (SI), and it is equal to 100 rad. The gamma dose rate in air, which is commonly stated in nGy/h, is used to describe the terrestrial radiation(IAEA, 2003). The absorbed dose rate (D′), expressed in nGy/h, can be calculated from the apparent abundance of K (%), concentrations of eU (ppm) and eTh (ppm) using the following equation (IAEA, 2003):

It can also use the following equation to convert terrestrial exposure rate (E) to terrestrial absorbed dose rate in air (D′):

The normal terrestrial absorbed gamma dose rate in the air ranges from 20 to 100 nGy/h, with a worldwide average of about 59 nGy/h (UNSCEAR,2000).

However, the Effective Dose Rate (EDR) expresses the biological effects of radiation on human organs or tissue.It is measured in millisieverts (mSv) and reported annually (UNSCEAR,2000).The following equations can be used to convert the dose absorbed in the air to the effective dose affecting on human organs and tissues (i.e. in-door and out-door) using a dose conversion factor of 0.7 Sv/Gy and occupancy factors of 0.2and 0.8 for out-door and in-door respectively (IAEA, 2003).

$$EDRout\ (mSv/y) = \mathbf{D'\,(nGy/h) \times T \times 0.7 \times 0.2 \times 10^{-6}}$$

$$EDRin\ (mSv/y) = \mathbf{D'\,(nGy/h) \times T \times 0.7 \times 0.8 \times 10^{-6}}$$

Where D′ is the absorbed dose rate in the air, 0.7 is the conversion factor from Gy to Sv, which converts the absorbed dose rate in the air to human effective dose received and T is the time for one year (i.e. 8760 hrs). Accordingly, the total effective dose rate EDR_{tot} expressed in mSv/y can be calculated from the following relation:

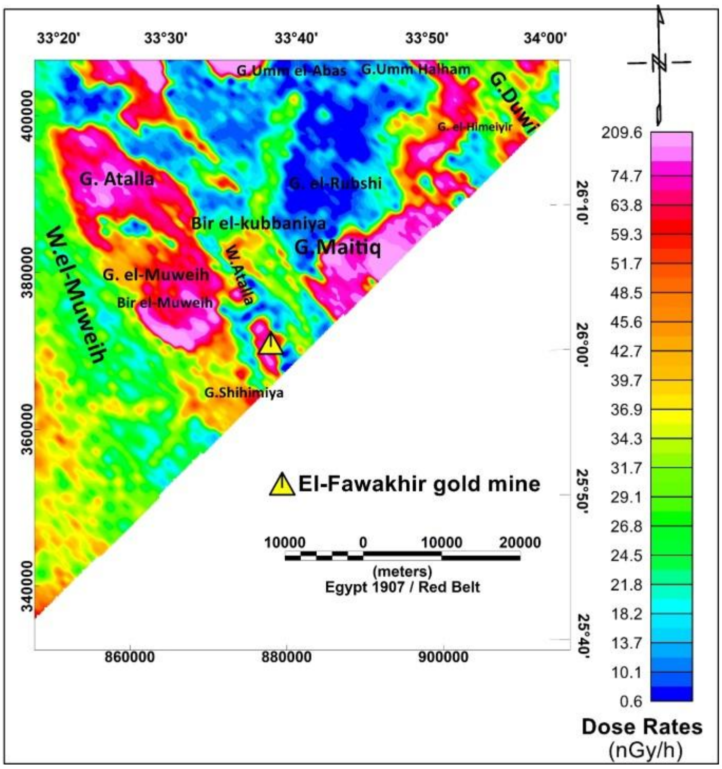
$$EDR_{tot} = \mathbf{EDR_{out} + EDR_{in}}$$

The following table shows worldwide average of EDR_{out}, EDR_{in}, and EDR_{tot}. (UNSCEAR,2000):

Table no 1: worldwide average of EDR_{out}, EDR_{in}, and EDR_{tot}.

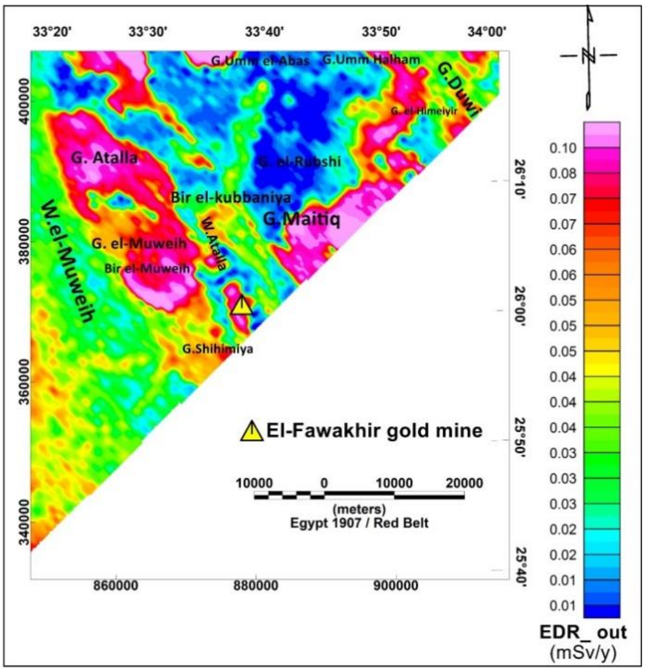
Dose rates	D'_{out}	EDR_{out}	D'_{in}	EDR_{in}	D'_{tot}	EDR_{tot}
Units	nGy/h	mSv/y	nGy/h	mSv/y	nGy/h	mSv/y
worldwide average	59	0.07	84	0.41	143	0.48

In the total effective dose rate map (EDR) of El-Fawakhir gold mine and surroundings, three levels of radiation dose rate could be recognized based on the total amount of terrestrial gammaradiation in the study area (Fig.8). The lowest level has concentration values ranging from 0.6 to 34.3 nGy/h and related to taref formation, serpentinite, metasediments, gabbroic rocks, metavolcanics (acidic, basic) and ophiolitic metagabbro. The concentration values of the intermediate level are ranging from 34.3 to 59.3 nGy/ h and recorded over hammamat sediments and wadi deposits. Whereas, the highest levels of the radiation dose rate range from 59.3 to 209.6 nGy/h and more which are exceeding the world's average values (i.e. 59 nGy/h, UNSCEAR 2000). They are recorded over El-Fawakhir younger granitic pluton, which encloses El-Fawakhir gold mine, leucocratic medium to high grade of metamorphic rocks, dokhan volcanics, and post hammamt felsite.

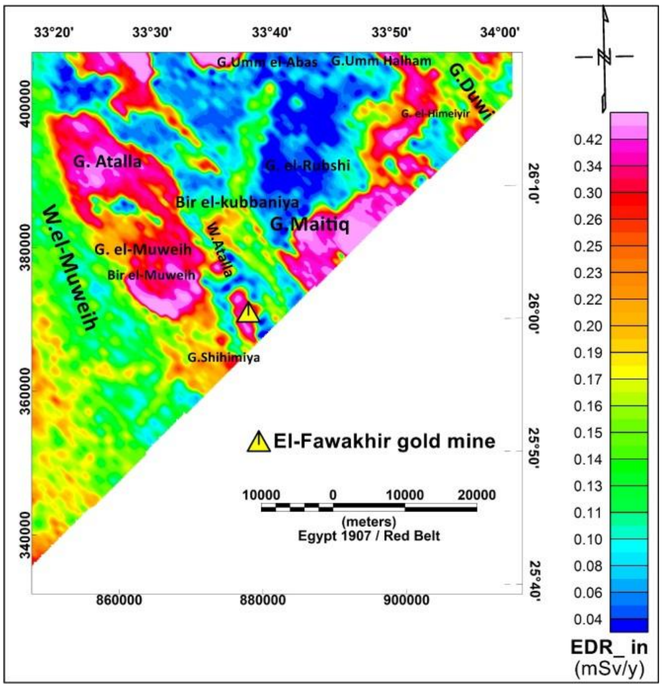


(Fig.8): Total Effective dose rate map (in nGy/h) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

The values of the effective dose rate out-door map (EDR_{out}) of El-Fawakhir gold mine and surroundings vary from 0.01 to 0.10 mSv/y with high values recorded over El-Fawakhir gold mine (Fig.9), which are higher than the world's average effective dose rates out-door (i.e. 0.07 mSv/y, UNSCEAR 2000). Whereas, the effective dose rate in-door map (EDR_{in})shows that the rates range from 0.04 to 0.42 mSv/y (Fig.10) with high values over 0.42 mSv/y, which are higher than the world's average effective dose rate in-door (i.e. 0.41 mSv/y; UNSCEAR 2000) and recorded over El-Fawakhir gold mine and other sites in the study area.



(Fig.9): Effective dose rate out-door map (EDR_{out}) (in mSv/ year) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



(Fig.10): Effective dose rate in-door map (EDR_{in}) (in mSv /year) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

4-c: Excess Lifetime Cancer Risk (ELCR)

Exposure to radiation at a particular level for many periods of human life is a serious factor for cancer. High doses of radiation can cause many diseasesby reducing red blood cell production and damaging the digestive system, blood vessels and cardiovascular system. Radiation injury caused by continuous exposure to high doses of radiation is considered to be a histological reaction (UNSCEAR,2000).Considering 70 years as the average duration of life for human being,the excess lifetime cancer risk (ELCR) can be calculatedusing the following equations(Taskin et. al., 2009):

$$ELCRout = EDRout \times DL\times RF$$
$$ELCRin = EDRin \times DL\times RF$$
$$ELCRtot = ELCRout + ELCR\ in$$

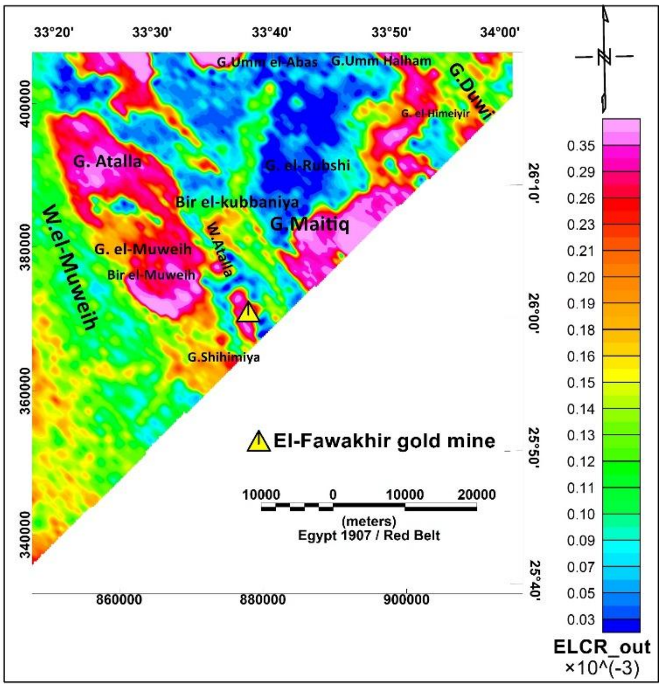
Where DL and RF are duration of life (70 years) and risk factor (0.05 Sv-1) respectively. The following table shows the worldwide average of ELCR $_{out}$, ELCR $_{in}$, and ELCR $_{tot}$. (Taskin et. al. 2009 and Qureshi et. al. 2014)

Tableno 2: worldwide average of ELCR out, ELCR in, and ELCR tot.

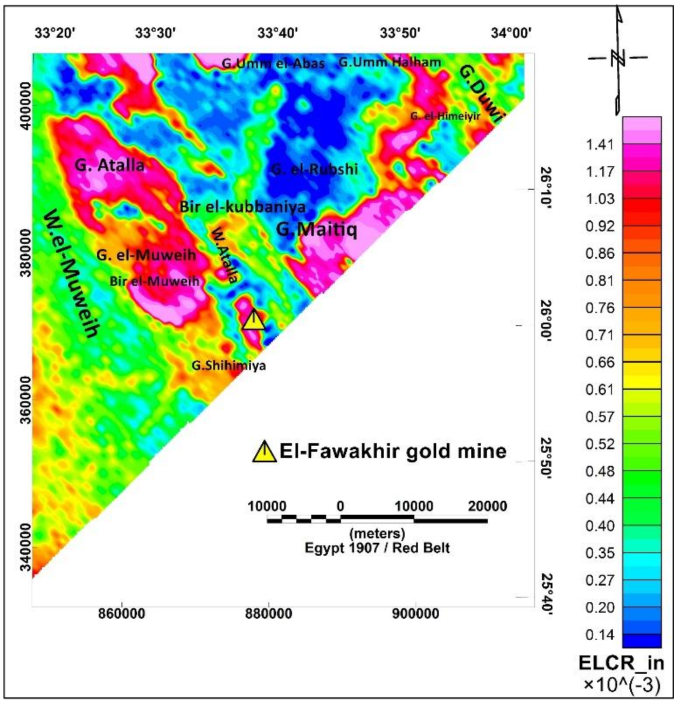
ELCR	ELCR $_{out}\times 10^{-3}$	ELCR $_{in}\times 10^{-3}$	ELCR $_{tot}\times 10^{-3}$
worldwide average	0.29	1.16	1.45

The values of the excess lifetime cancer risk for outdoor exposure ($ELCR_{out}$) in El-Fawakhir gold mine and surroundings (Fig.11) range from 0.03×10^{-3} to 0.42×10^{-3}, where the area of the gold mine recorded the highest values ($\approx 0.40 \times 10^{-3}$) which are higher than the world's average (i.e.,0.29×10^{-3}; Taskin et. al. 2009). Whereas, the values of the in-door ELCR map (Fig.12) range from 0.14×10^{-3} to 1.41×10^{-3}, with high values over 1.17×10^{-3} that exceed the world's average (1.16×10^{-3}; Taskin et al. 2009) and recorded over the area of the gold mine.

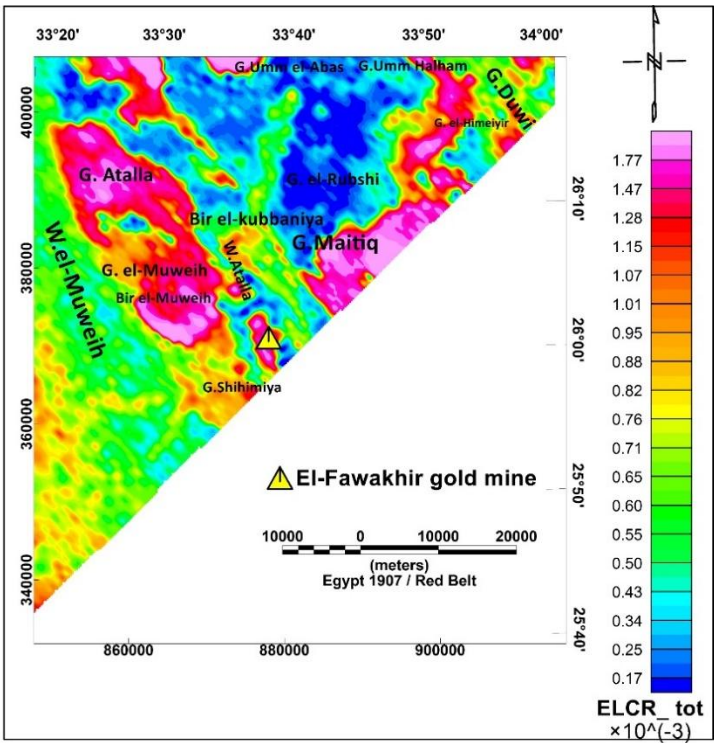
The total ELCR map of El-Fawakhir gold mine and surroundings(Fig.13) showed that the values recorded over the younger granite which encloses the gold mine ($\approx 1.47 \times 10^{-3}$) are greater than the world's average (i.e.,1.46×10^{-3}, Qureshi et. al. 2014).



(Fig.11): Excess lifetime cancer risk map for out-door exposure ($ELCR_{out}$) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



(Fig.12): Excess lifetime cancer risk map for in-door exposure ($ELCR_{in}$)of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.



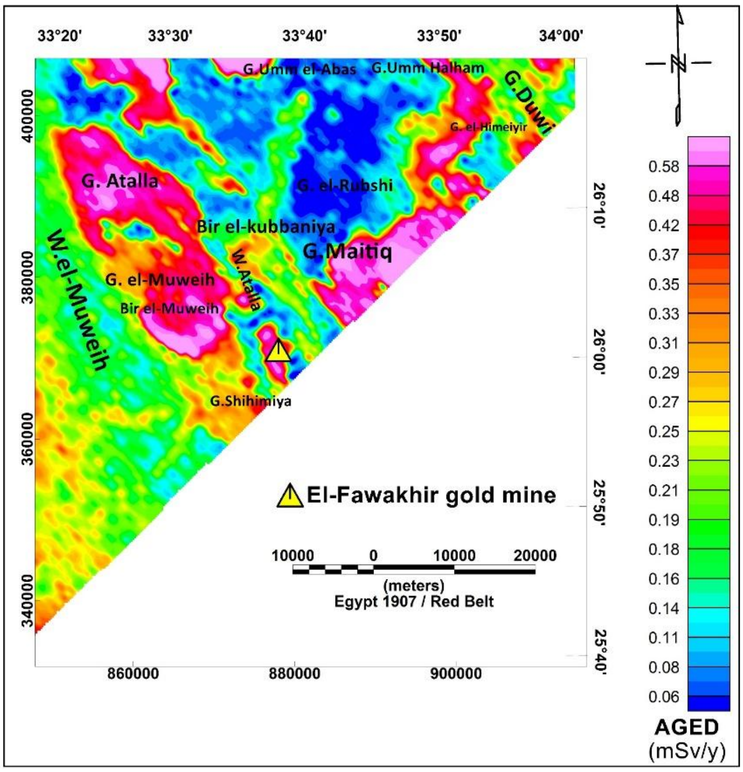
(Fig.13): Excess lifetime cancer risk map for total exposure ($ELCR_{tot}$) ofEl-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

4-d: Annual Gonadal Equivalent Dose (AGED)

It is important to shed light on some vital organs that are highly sensitive to radiation such as gonads, bone surface cells and bone marrow. Increasing the equivalent annual dose of gonads has a direct effect on the bone marrow, leading to the destruction of red blood cells, which arereplaced by white blood cells (Avwiri, et. al., 2012). The AGED world average for soil is 0.30 mSv/y and can be calculated using the following equation (UNSCEAR,2000):

Where, C_u, C_{Th}, and C_K are the activity concentrationof eU, eTh and K respectively. Using the conversion factors recommended by the IAEA technical report No 1363, the activity concentrations of 238U, 232Th, and 40K in Bqkg-1 can be computed from the elemental concentrations of 238U (in ppm), 232Th (in ppm), and 40K (in percent) as follows:

The annual gonadal equivalent dose rate map (Fig.14) of El-Fawakhir gold mine and surroundings has concentration values ranging from 0.33 to 0.58 mSv/ywhich exceed the world's average (i.e. 0.30 mSv/y; UNSCEAR,2000). These high values are recorded over younger granites of the gold mine, leucocratic medium to high grade of metamorphic rocks, dokhan volcanics, and post hammamt felsite.



(Fig.14): Annual gonadal equivalent dose rate map of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

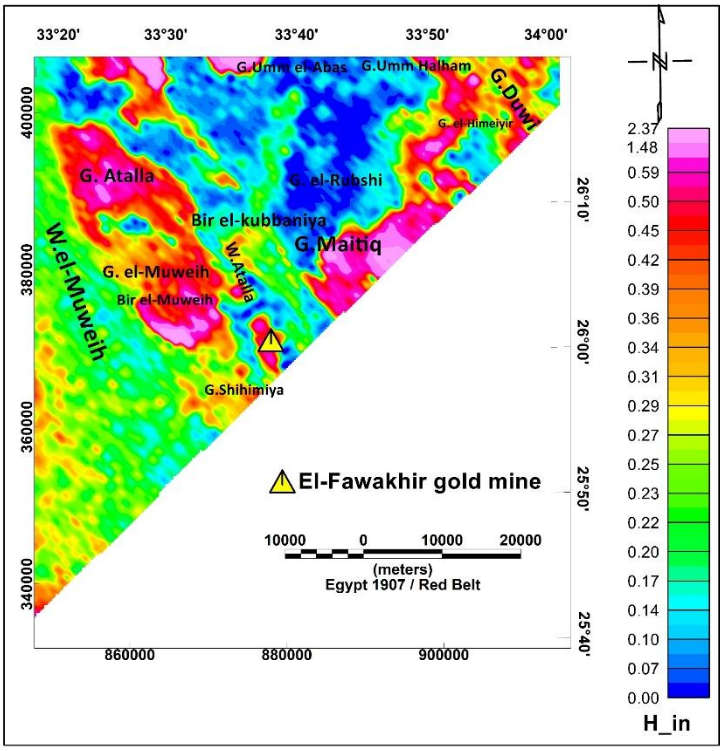
4-e: Internal andExternal Hazard Indices (H_{in}, H_{ex})

Internal and external hazard indices are used to estimate the level of gamma radiation risk resulting from natural radionuclides such as 238U, 232Th, and 40K.The external Hazard Index (H_{ex}) or out-door radiation hazard index and the internal hazard index (H_{in}) or in-door radiation hazard index due to the radon gas and its daughters can be calculated using the following equations (Tufail, et. al. 2007):

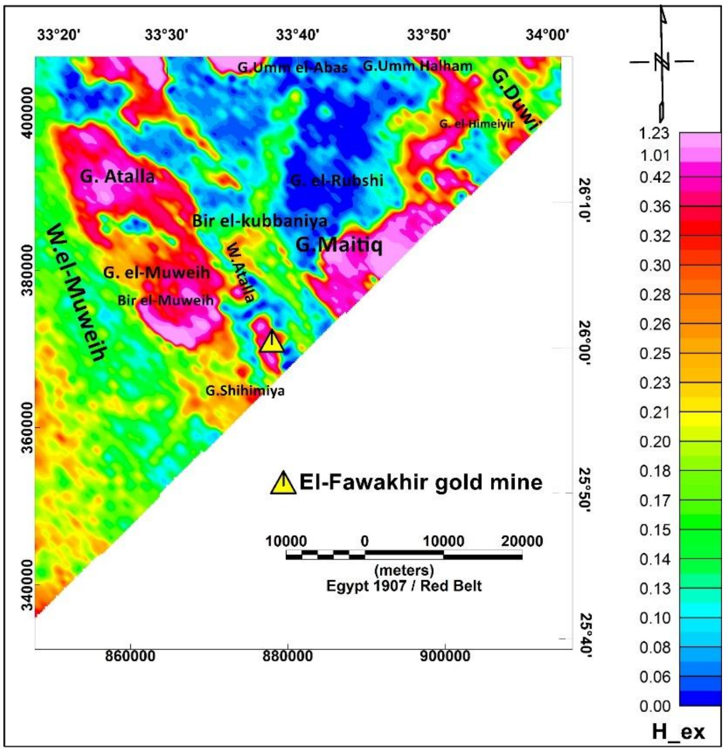
Where, C_u, C_{Th}, and C_K are the activity concentrationof eU, eTh and K respectively.

According to Tufail et. al., 2007, the internal hazard index should be less than one, while the external hazard index should be less than or equal the unity to avoid radiation hazards and chronic diseases such as asthma.

The Internal hazard index map (H_{in}) of the study area reveals that the zones associated with the younger granites of El-Fawakhir gold mine, leucocratic medium to high grade of metamorphic rocks, dokhan volcanics, and post hammamt felsite have high levels of concentration values ranging from 1.48 to 2.37 (Fig.15) which are exceeding the world's average (≈ 1.00; UNSCEAR2000). Also, the same zones have external hazard index values ranging from 1.01 to 1.23 (Fig.16), which also exceed the world's average value.



(Fig.15): Internal hazard index map (H_{in}) of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

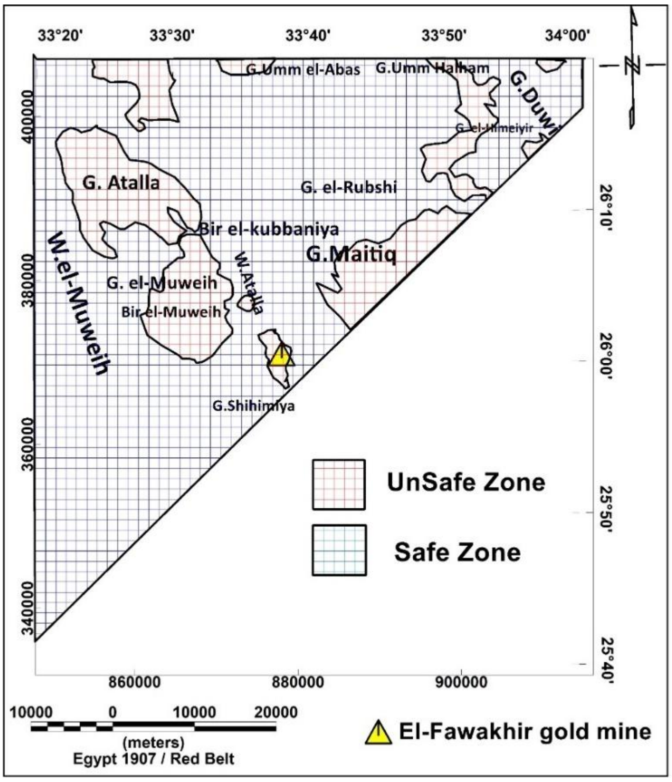


(Fig.16): External hazard index map (H_{ex}) of El Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

V. CONCLUSION

Evaluation of the radioactive health hazards of an area depends on the level of background radiation. The values ofthe absorbed dose rate, the effective dose rate, the excess lifetime cancer risk, the annual gonadal equivalent dose and the internal and external hazard indices are of great help in the environmental radioactive assessment. These factors are calculated for the area of El-Fawakhir gold mine and surroundings in the Eastern desert of Egypt by using the airborne gamma ray spectrometric data (i.e. eU in ppm, eTh in ppm and K in %) in order to evaluate the radioactive risk hazards of that area to safe the people who area working and living there.

Analysis of the gamma ray spectrometric data indicated that the radiation in the studyarea exceeds the recommended international levels and it is considered as a risk location for human activities. It is worth to mention that the gold mine in El-Fawakhir area lies in this risky zone. Accordingly, a map of safe and unsafe zones could be created for the study area and surroundings (Fig. 17). Special health precautions should be applied for the peoples who are working and living in the area of the gold mine and surroundings. This area should besubjected to further follow up investigations to assess the land uses and a dose monitoring program is necessary. It is the recommended for the workers in the El-Fawakhir gold mine to live and build their homes far away from the younger granites and metamorphic rocks and away from the drainage and structural lines to keep the exposure duration as short as possible. The water wells must be drilled, as possible, in basic or ultrabasic rocks to avoid high radioactive dose rate of the younger granites and metamorphic rocks. It is also recommendedthat the miners should take care in dealing with younger granites wastes and use adequate protective clothes to protect themselves against radioactive pollution.



(Fig.17): Safe and unsafe zones of radiation of El-Fawakhir gold mine and surroundings, Eastern Desert, Egypt.

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