



Radiological environmental studies of Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia

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Abstract The Al Aziziah area is built on volcanic and granitic rocks. The igneous rocks always contain a high amount of naturally radioactive elements such as uranium, thorium and potassium, which produce gamma rays causing environmental hazards when exceeding the permissible limit. Radon gas is a result from the decomposition of uranium/thorium leaks into enclosed areas (e.g.

homes or offices). This leakage is controlled by many conditions, and one of them is the underlining rock type. To work on such an environmental study, a gamma ray spectrometer survey was used. The uranium, thorium and potassium contents, as well as their ratios and the total radiation, were determined and mapped. The radiation dose rate was calculated and mapped in mSv/y and nGy/h units. The radiation contamination of groundwater is detected from the contour map of the dose rate over the artificial drainage lines of rains and floods which move this water to the groundwater wells. The main results are as follows: granitic rocks show an average dose rate of about 2.4 mSv/y, while the deposits of these rocks have an average dose rate of 1.2 mSv/y. A low average dose is recorded over the basalt. The average radiation dose recorded in the study area is 1.08 mSv/y, while its range is from 0.001 to 4.41 mSv/y. The estimated effective doses within the Al Aziziah area and vicinity area were higher than 1 mSv/y, which is the public exposure limit, and lower than the occupational exposure limit of 20 mSv/y. We recommend ventilating homes and offices in these places on an ongoing basis and constant radon measuring in closed places.

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Introduction and geologic setting

Al Madinah Al Monawarah is considered one of the most important provinces in Saudi Arabia due to its holy

value among the worlds. The Al Aziziah area and its vicinity are located within Madinah city. The Al Aziziah area includes the University of Taibah, residential areas, activities and government buildings. Thus, the study of this area is crucial in terms of environmental radiation, especially since it is built on rocks, mostly basement rocks (granite or volcanic). Furthermore, it is important to know the number of radioactive elements present in groundwater wells, whether used for drinking or agriculture. The expansion of large cities, such as Al Madinah Al Monawarah, is usually accompanied by the threat of random distribution of pollutants from agricultural, industrial and/or man-made activities. In the study area, pollution may result from the surrounding mountains and the subsurface rocks emitting gamma rays from beneath the buildings or by man-made activities. Many buildings in the Al Aziziah area have been constructed over granitic rocks or granitic deposits. The buildings were constructed from limestone, sandstone, brick, natural stone, granitic country rocks and concrete. Granite rocks are also used in the decoration of walls, floors and kitchens.

Granite and granitoid rocks contain radioactive elements that emit temporal gamma rays, even from building materials and decorations (IAEA 2000; ICRP 2000), wherein protection is considered. Radon gas can affect the health of the residents. Radon gas decays and leaks from the uranium and thorium in these rocks and accumulates in enclosed spaces, such as homes or offices or any buildings, which can cause cancer after time. The amount of radon gas produced can be controlled in many ways; one of them depends on the type of rock under the buildings.

In recent years, many researchers have studied the distribution of these elements in the subsoil in megacities (Dierke et al. 2011; Cook et al. 1996; Pracilio et al. 2006). Alternatively, only gamma ray spectrometry is used to investigate such a threat due to environmental reasons (Spadoni and Voltaggio 2013; Bollhöfer et al. 2008; Drovnikov et al. 1997).

The study area lies between latitudes $24^{\circ} 22' 20.25''$ N– $24^{\circ} 29' 25.25''$ N and longitudes $39^{\circ} 27' 12.52''$ E– $39^{\circ} 32' 37.29''$ E (Figs. 1 and 2), forming a shallow basin. It is bounded by the Jammah Mountain (mountain means Gabel in Arabic) and Gabel (G.) As Salam from the north, G. Al Habash from the east and G. Ayr from the southeast. The western side is bounded by G. Al Jawwah in the north and G. Al Suluk and G. Al Aswad in the south (Fig. 3). The area under study is



Fig. 1 Location map of the Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia

characterised by arid conditions, such as high temperatures and low rainfall, with average temperatures ranging between 27 and 43 °C in July and August and 10–25 °C in December and January. It also receives an average rainfall of about 40.1 mm/year.

During the survey, most of the inhabited areas and the hills which are distributed within the surveyed area were covered. Maps of radioactive elements, uranium, thorium and potassium were created. Calculating the



Al-Aziziah region and vicinity

Fig. 2 Tracks of radiation car-borne surveys and the rocky presence in and around the residential area, Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia

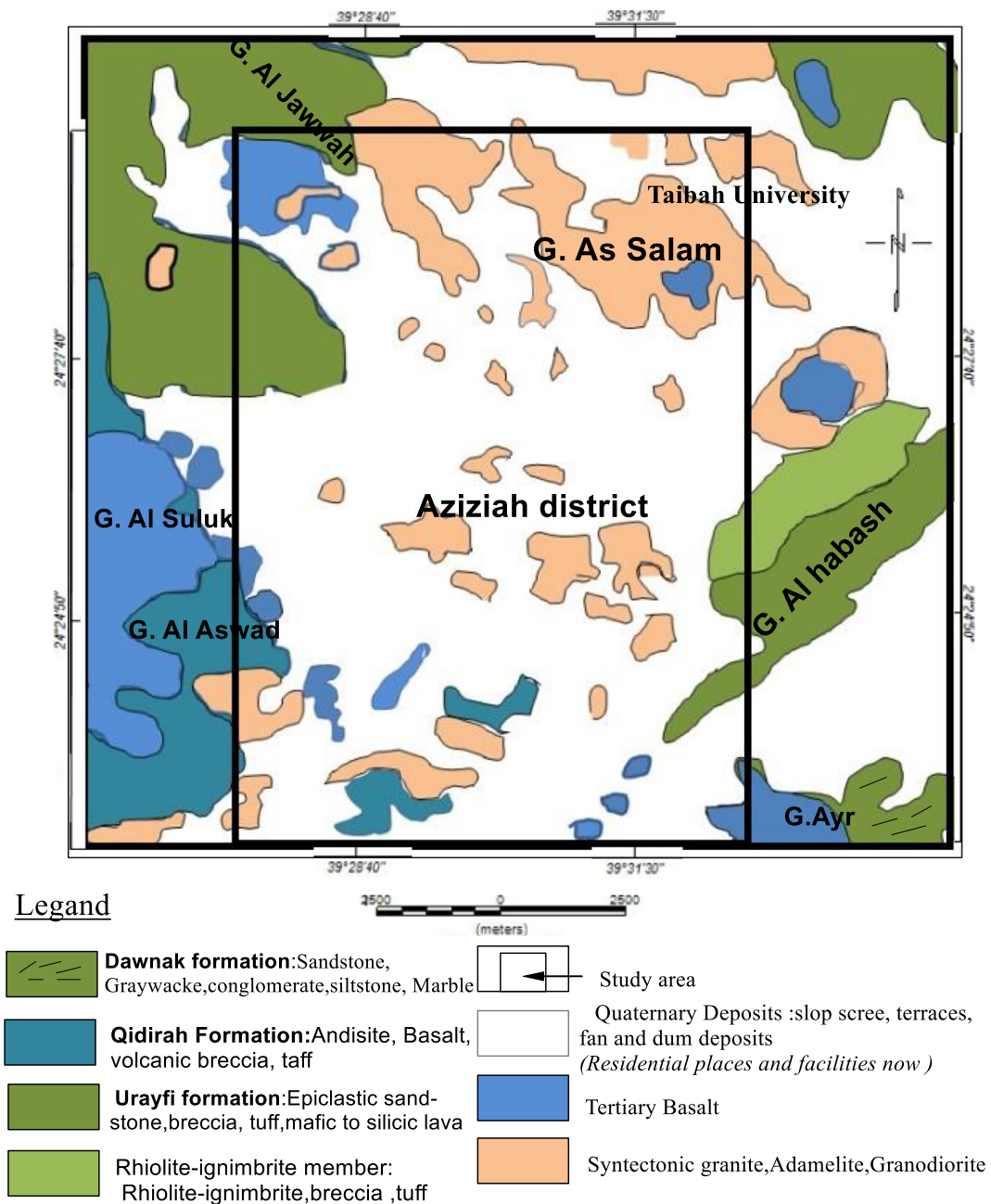


Fig. 3 Geologic map of Al Aziziah area, Al Madinah Al Monawarah, Saudi Arabia (compiled by Pellaton 1981)

rate of radiation exposure and radiation dose by detecting gamma rays is not something new. It is just being used for the first time in the Al Aziziah area and the neighbouring areas. Sanderson et al. (2004) studied background radiation in Belgium using an airborne gamma survey. Mohamed et al. (2016) measured gamma rays in granite samples obtained from building materials in Madinah city, Saudi Arabia, and concluded

that the annual effective doses are relatively lower. Hedley et al. (2016) surveyed the dairy farm at Massey University, Auckland, to map radioactive elements and their impact on the environment. Al-Kawazini et al. (2016) measured the background radiation at the German Jordanian University in Jordan and concluded that the background radiation in the Jordanian dwelling varies from location to location depending on the type

of building, the building materials used, ventilation and the place on which it is built. Osman et al. (2019) surveyed the university campus in Istanbul, Turkey, to estimate the annual radiation dose rate. Aboud et al. (2019) surveyed the campus of King Abdulaziz University using the RS-700 system and concluded that the highest annual dose rate is 3.66 mSv/y in and around the new college building area. They recommended that since this area had high radiation emission, precautions should be taken into account to prevent hazards.

Sets of radioactive element maps and radioactive dose rate maps in the Al Aziziah area were developed to mitigate the damage caused by radioactive pollution and help decision-makers make more efficient future for the city. This information can be useful in raising the awareness regarding radioactive pollution and its effects on exposed human beings, animals and plants. It can be vital for designing future strategies in terms of national security. This will be done according to the rules recommended by UNSCEAR (2000). The importance of estimating the level of natural gamma radiation in the environment is to not only determine its environmental usefulness but also assess the degree of radiation contamination or pollution in the environment in the future.

The Precambrian igneous and metamorphic basement, which is known as the Arabian shield, and the other sedimentary rocks known as the Arabian shelf are the two main rock units in the Kingdom of Saudi Arabia. One-third of the total country's area lies in the Arabian shield which covers most of the western part of the Kingdom (Al-Shanti 2009). The surveyed area was covered by rock units that are sedimentary, volcanic, plutonic and metamorphic that can be distinguished from the geologic map (Figs. 3 and 4) (Pellaton 1981). These rock units are varied, and their age ranges from the lower Proterozoic to the Cenozoic era. The sedimentary volcanic and metamorphic rocks belong to the lower Proterozoic Eon and are represented by Al Ays Group which is found in the Urayfi Formation (e.g. epiclastic sandstone, breccia, tuff, mafic to silicic lava). This group is represented by the rhyolite-ignimbrite member (rhyolite-ignimbrite, breccia, tuff) and followed by a major unconformity.

The Furayh Group followed the unconformity and is represented in the study area by two formations: Qidirah Formation (andesite, basalt, volcanic breccia, tuff), followed by the Dawnak Formation (sandstone, graywacke, conglomerate, siltstone, marble).



Fig. 4 Landsat image showing the study area and the rock units in and around the residential area, Al Aziziah, Al Madinah Al Monawarah, Saudi Arabia

In the lower Proterozoic, the intrusive igneous rocks of Cambrian to Ordovician are represented in the study area by syntectonic granite, adamellite and granodiorite followed by an unconformity.

The Cenozoic is represented also by Tertiary basalt and Quaternary deposits (slope scree, terraces, fan and dump deposits). The Quaternary deposits have been converted into residential places and facilities (Figs. 3 and 4).

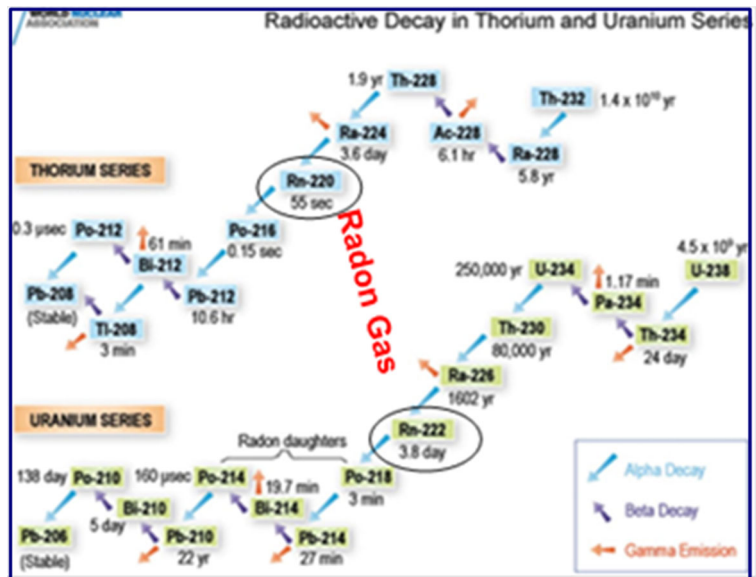
The earth's crust contains granite, which has naturally radioactive elements. Gamma rays come from radionuclides belonging to the ²³⁸U, ²³²Th and ⁴⁰K series, which are the basic radioactive elements of granite (UNSCEAR 2017). The radioactivity of these granite rocks varies according to the content of the radioactive elements. Some granite rocks sometimes contain more radioactive elements than others of the same type, and these radioactive elements decay into radon which may be released from these rocks over time (Fig. 5).

The main result of this research is that the estimated effective doses within the Al Aziziah area and vicinity are higher than 1 mSv/y, which is the public exposure limit and lower than the occupational exposure limit of 20 mSv/y (as per the recommendation of IAEA 2000).

Data source

Gamma radiation has been measured in Al Aziziah and adjacent areas to assess the radiation risk and rate of

Fig. 5 Thorium and uranium decay series and their relation to radon gas



emission by Geohazards Research Center (GRC) at the King Abdulaziz University. The gamma ray RS-700 spectrometer system was used in the survey in March 2018. It is a self-contained spectrometer designed for mobile gamma ray detection. This system was configured to detect gamma ray radiation during the survey. The RS-700 system consists of two 4-l sodium iodide nobbled with thallium (NaI) detectors, a Trimble GPS global positioning system (GPS), power sources, a vehicle with a trailer, RS-700 console multi-channel analyser and a laptop computer for real-time gamma ray and GPS position monitoring as well as data collection. The detectors were installed on the underside of the trailer, about 27.5 cm from the ground and parallel to each other, with a separation of 29 cm between the detectors. During the survey, the RS-700 was installed at the top of a car (Fig. 2) and the recording was monitored continuously while moving.

Distribution of radioactive elements and their ratios in the Al Aziziah area and its vicinity

Total count radiometric distribution in cps

The total count (TC) radiometric contour map along with the car-borne survey of the study area (Fig. 6) shows that the eastern part has high levels of radiation reaching up to 534.86 cps, especially east G. Al Jawwah lying north of the study area and east G. Al Suluk lying

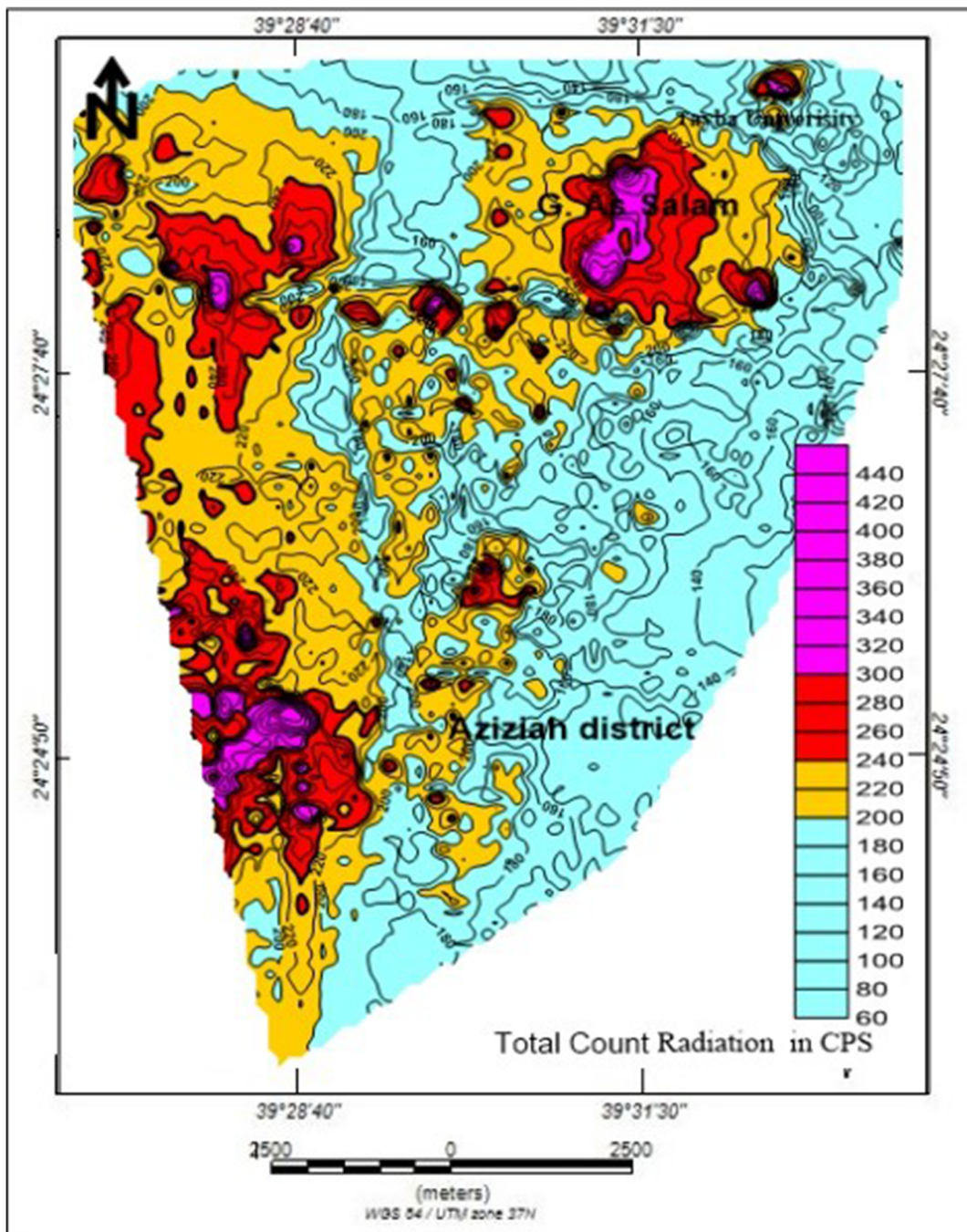


Fig. 6 TC radiometric contour map in cps, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

southwest of the study area. We think that these abnormal readings are due to the intrusions of granite rocks in these areas, but they were not tracked correctly in the original geological map, as such high levels are considered anomalies. Also, two large anomalies were recorded in the north of the study area over G. As Salam and

north of the Taibah University. The isolated granitic intrusion hills distributed in the residential area and surrounding show a high level of anomalies emitting radiation up to 300 cps. The TC radiation decreases to moderate levels of 200 cps as one moves away from the granitic rocks reflecting the distribution of granitic

deposits in these parts. A low total count radiation was recorded in the eastern side of the study area reflecting the readings of Tertiary basalt and its Quaternary sediments (Figs. 3 and 6). The statistical treatment of the total count radiation in the Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia, is shown in Table 1. It shows that the study area has higher radioactive elements (⁴⁰K, eU and eTh) than the average crustal rocks as shown in the correlation between Tables 1 and 2.

K (%) distribution

The potassium contour map (Fig. 7) shows that the area is rich in potassium content ⁴⁰K, especially the western and northern sides, which indicates that these areas reflect the intrusions of granite rocks in these locations. Since the average global ⁴⁰K in these rocks is 4% (Clarke et al. 1966), we believe that the area is rich in ⁴⁰K where it has 21 K% over the parts of granitic rocks, exhibiting anomalies with an average of 7.3 K% in the study area. In radioactive potassium, three levels of radiation can be distinguished: the first level is greater than 9 K%, which was recorded over pink granite in east G. Al Jawwah lying to the north of the study area and in east G. Al Suluk lying to the southwest of the study area. This level was also recorded in the north of the study area over G. As Salam and north of the Taibah University (Figs. 3 and 7). The second level is also relatively high and reflects the readings over places that have granite deposits in ancient valleys and around granite mountains. The percentage of potassium decreases as we head east in the study area. This reflects the presence of basalt rocks and its recent deposits. The statistical treatment of K% in the study area is shown in Table 1.

Equivalent uranium (in ppm) distribution

The equivalent uranium (eU) in ppm contour map (Fig. 8) shows that the area is rich in eU content, especially in the intrusions of granite rocks in the western and northern sides of the study area by an average 17 ppm and ranges between 12 and 48. The average global eU in these rocks is 4.5 and ranges 1–12 ppm (Clarke et al. 1966). The study area recorded relatively high readings of eU, where it reached 46 ppm with an average of 8.6 ppm. Four levels of radiation can be distinguished from the eU contour map; *the first level* is greater than 20 ppm and considered an anomaly, which was recorded over pink granite in east G. Al Suluk lying southwest of the study area and inside the drainage lines of flood south of this part (Figs. 3 and 8). *The second level* is relatively moderate (12–20 ppm) and reflects the readings over most of the granitic exposure in the study area. *The third level* is low (8–12 ppm) and was recorded over granite deposits in ancient valleys and around granite mountains. *The fourth level* records very low readings (0–8 ppm), and it is restricted to the northern and western sides of the study area over the basaltic rocks and its recent deposits. The percentage of potassium decreases as we head east in the study area. This reflects the presence of basalt rocks and its recent sediments. The statistical treatment of eU in ppm in the study area is shown in Table 1.

Equivalent thorium distribution

The eTh (ppm) contour map is displayed in Fig. 9 showing that the area contains normal levels of thorium except the parts especially in granite rocks containing anomalies, where the reading reached 29.6 ppm. The

Table 1 The statistical treatments of radioactive element distribution in the Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia

Statistical treatments	Total count	Exposure rate	Dose rate (nGy/h)	Dose rate (mSv/h)	K%	eU	eTh	eU/eTh	eU/K	eTh/K
No.	71,261	71,261	71,261	71,261	71,261	71,261	71,261	71,261	71,261	71,261
Min.	83.54	5.24	25.11	0.001	0.45	0.02	0.05	0.01	0.003	0.005
Max.	534.86	58.18	136.38	4.41	21.88	46.35	29.60	301	18.126	6.46
X	197.12	18.18	47.81	1.08	7.33	8.64	5.23	3.74	1.27	0.74
SD	44.43	5.79	8.30	0.48	2.37	5.544	3.01	13.30	0.89	0.43
CV	0.23	0.32	0.17	0.45	0.32	0.64	0.58	3.56	0.70	0.5729

No., number of readings; Min, minimum; Max, maximum; X, mean; SD, standard deviation; CV, coefficient of variability

Table 2 Radioelement concentrations in crustal rocks (Clarke et al. 1966)

Rock types	K% average	U (ppm)		Th (ppm)		Th/U	
		Average	Range	Average	Range	Average	Range
Crustal average	2.1	3		12		4	
Mafic igneous	0.5	1	0.2–3	3	0.5–10	3	3–5
Intermediate igneous	1–2.5	2.3	0.5–7	9	2–20	4	2–6
Acid igneous	4	4.5	1–12	18	5–20	4	2–10
Arenaceous sediments	1.4	1	0.5–2	3	2–6	3	
Argillaceous sediments	2.7	4	1–13	16	2–47	4	1–12
Limestones	0.3	2	1–10	2	-	1	-
Black shales	2.7	8	3–250	16	-	2	Wide
Laterites	Low	10	3–40	50	8–132	5	Wide
Metamorphics	Depends on parent rock						

average global eTh in these rocks is 18, and the range is 5–20 ppm (Clarke et al. 1966), and most of the granitic eTh readings are found in this range. The readings reach a maximum over granitic rocks and decrease as one moves away from over the recent deposits of these rocks. The low readings recorded in most of the study area except the granitic exposure areas reflect basaltic rocks and its recent deposits. The average readings of these rocks, seen in this area, fall within the globally accepted range (Tables 1 and 2). The statistical treatment of eTh in ppm in the study area is shown in Table 1.

eU/eTh ratio distribution

The eU/eTh ratio contour map in the study area reflects the increase in eU than eTh in some parts of the granitic areas and the location of artificial drainage canals for flood (elongated features), where the leached uranium follows these lines that appear as an elongated line in its contour map (Fig. 10). The normal ratio of eU/eTh may not exceed 1 or 1.5 in igneous rocks normally. In the study area, this ratio shows anomalies as readings reached 100 times that of eU to eTh (Fig. 10) as a result of high leaching of uranium and its precipitate in the anomalies parts. The statistical treatment of eU/eTh distribution in the study area is shown in Table 1.

eU/K ratio distribution

The eU/eTh ratio contour map in the study area (Fig. 11) reflects the increase in eU than K% in some parts of the granitic areas as in G. Al Suluk and G. As Salam and the

location of artificial drainage canals, in south G. Al Suluk, in the southwestern part of the area. In these parts, the eU contents are two or three times of the K% contents. The other parts of the study area have a eU/K ratio of less than 2 and lesser than 1 in the areas of basic contents, such as basalt and its recent deposits. The statistical treatments of eU/K ratio in the study area are shown in Table 1.

eTh/K ratio distribution

The eTh/K ratio contour map in the Al Aziziah area and vicinity (Fig. 12) reflects the increase in K% over most of the study area. The anomaly parts, where the thorium level is more than potassium, are found in the location of granitic rock and its recent deposits as in G. Al Suluk, G. As Salam and north of the Taibah University as well as the location of a granitic hill exposed and distributed in the study area. The statistical treatment of the eTh/K ratio in the Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia, is shown in Table 1.

Methods for estimating radiation exposure rate

The specialised committee used two methods of evaluating external exposures from naturally occurring radionuclides. The first method is to directly measure the external gamma dose rate occurring in the atmosphere and subtracting the dose rate due to cosmic rays.

The dose rate in nGy/y = directly measured external gamma dose rates – cosmic rays.

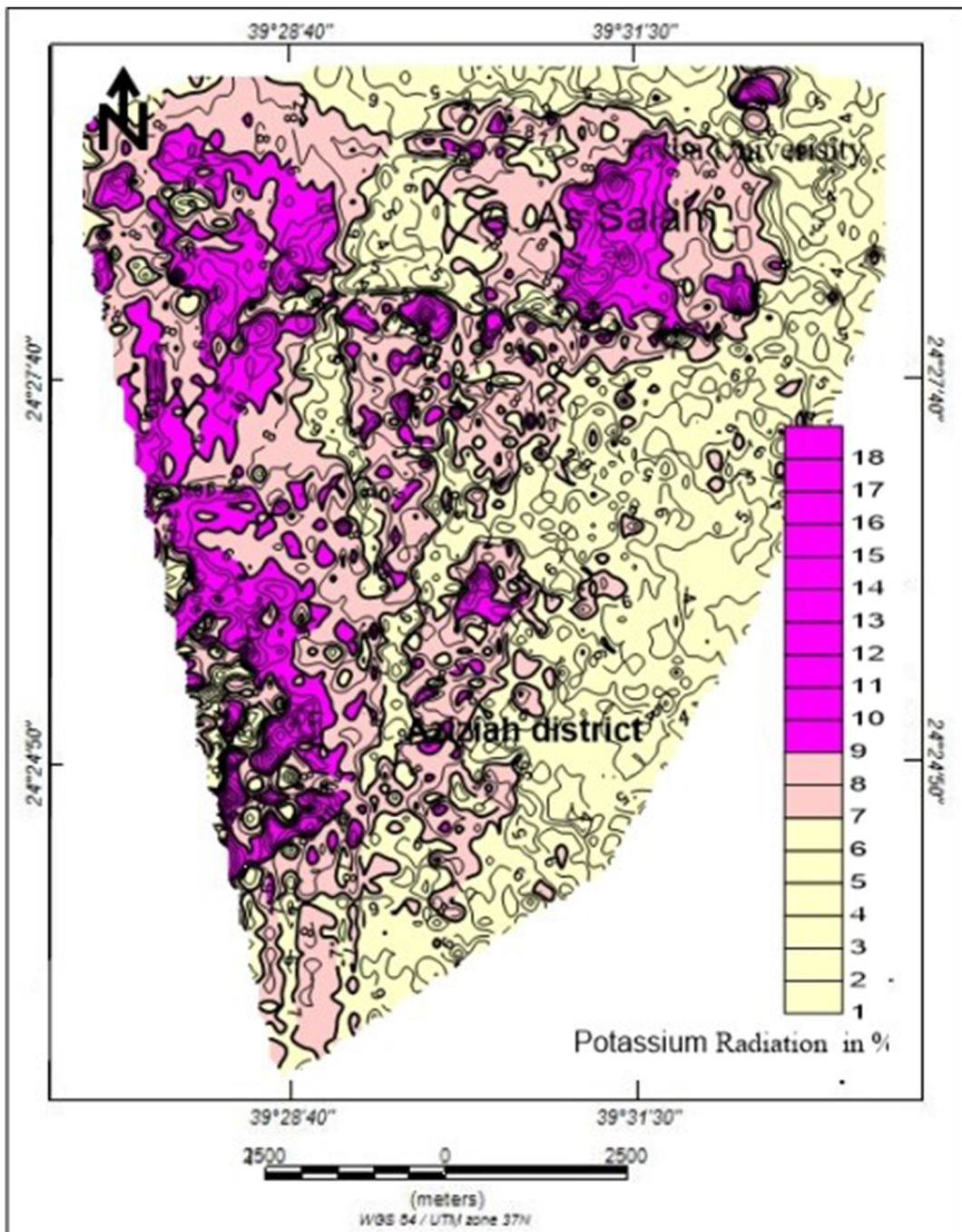


Fig. 7 Potassium contour map (in %), Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

In this study, the dose rate in nGy/h was measured directly after subtracting the cosmic rays.

The dose rate can be calculated according to the formula (IAEA 1989; IAEA 1991; Løvborg 1984):

$$\text{Dose rate (nGy/h)} = 13.078K (\%) + 5.675 \text{ eU (ppm)} + 2.494 \text{ eTh (ppm)}$$

(1)

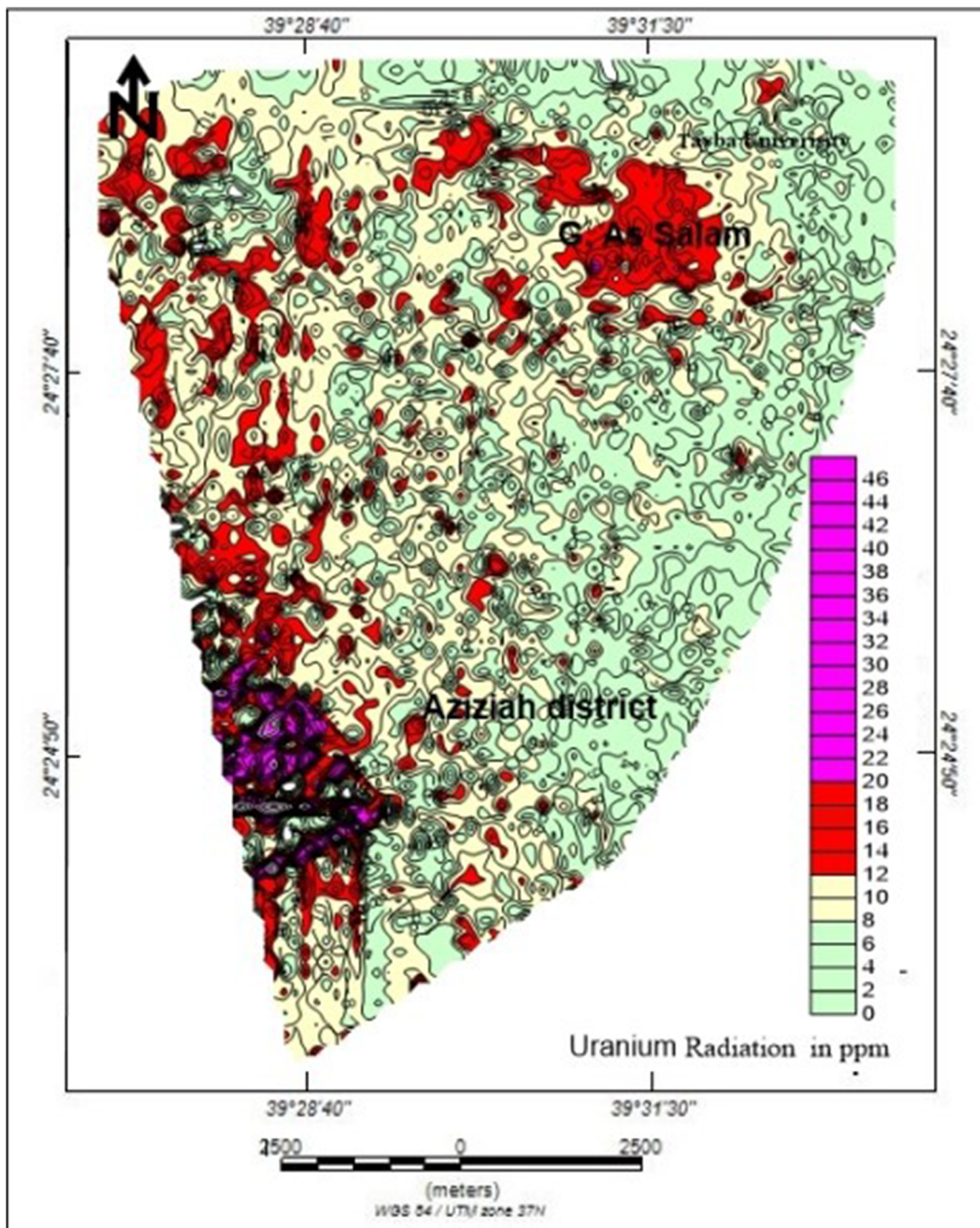


Fig. 8 Equivalent uranium distribution contour map in ppm, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

The second method is to estimate the external gamma dose rates in air from the concentration of the relevant radionuclides available in the soil. The two methods have provided generally consistent estimates of exposure.

The radiation dose rate contour map in mSv/y was calculated from the concentration of the main common three radioactive elements, K%, eU and eTh from these

concentrations, and we estimated the exposure rate in $\mu\text{R/h}$ according to the formula of IAEA (1991). These exposure radioactivity values are converted to the dose rate in mSv/y according to the formula of IAEA (1979).

The exposure rate (E) can be estimated from the apparent concentrations of K (%), eU (ppm) and eTh (ppm) using the formula given by IAEA (1991):

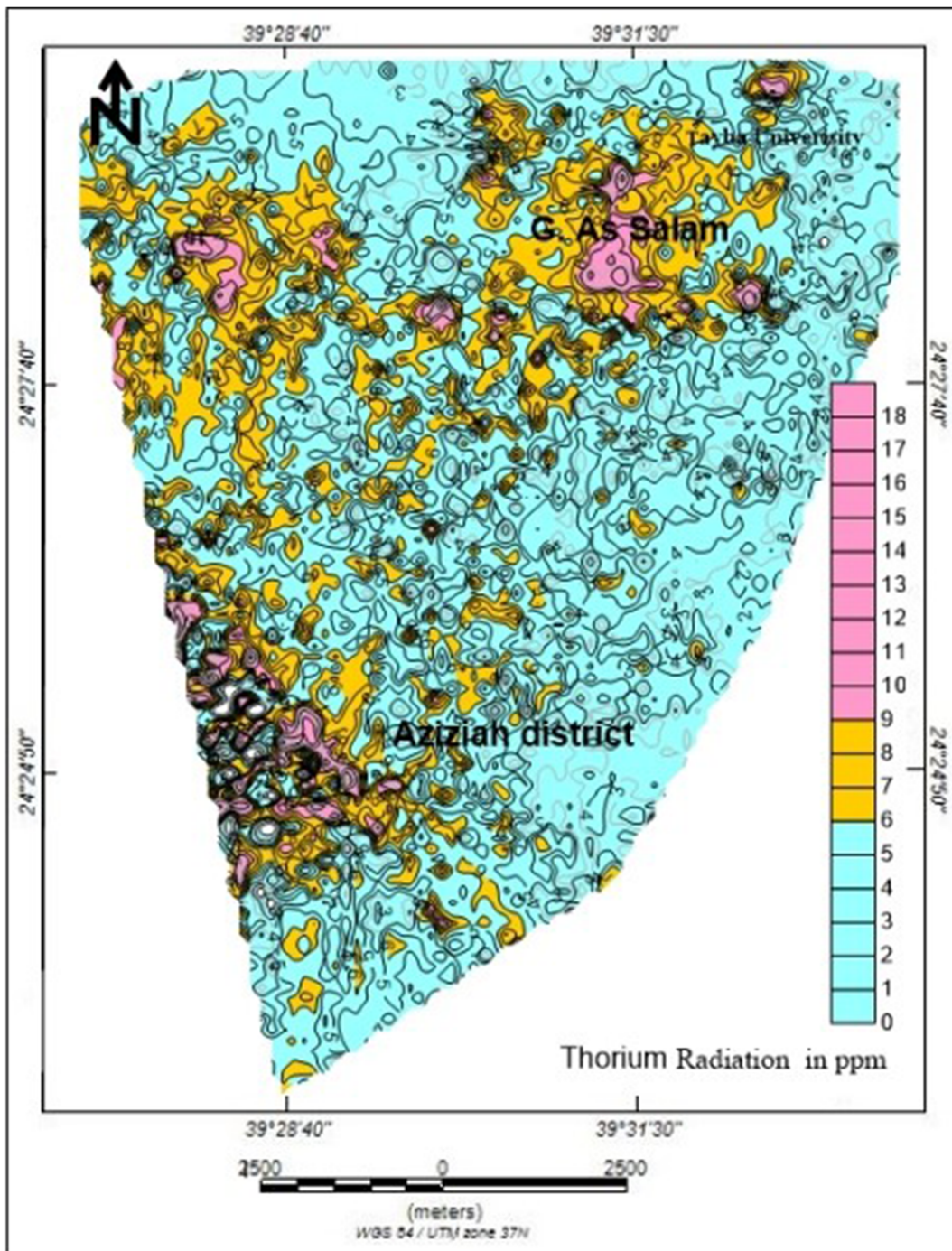


Fig. 9 Equivalent thorium distribution contour map in ppm, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

$$\begin{aligned} \text{Exposure rate } (\mu\text{R/h}) &= 1.505 \text{ K } (\%) + 0.653 \text{ eU } (\text{ppm}) \\ &+ 0.287 \text{ eTh } (\text{ppm}) \end{aligned} \tag{2}$$

The equivalent radiation dose can be estimated from the radiation exposure rate by using a simple conversion factor (IAEA 1979), as follows:

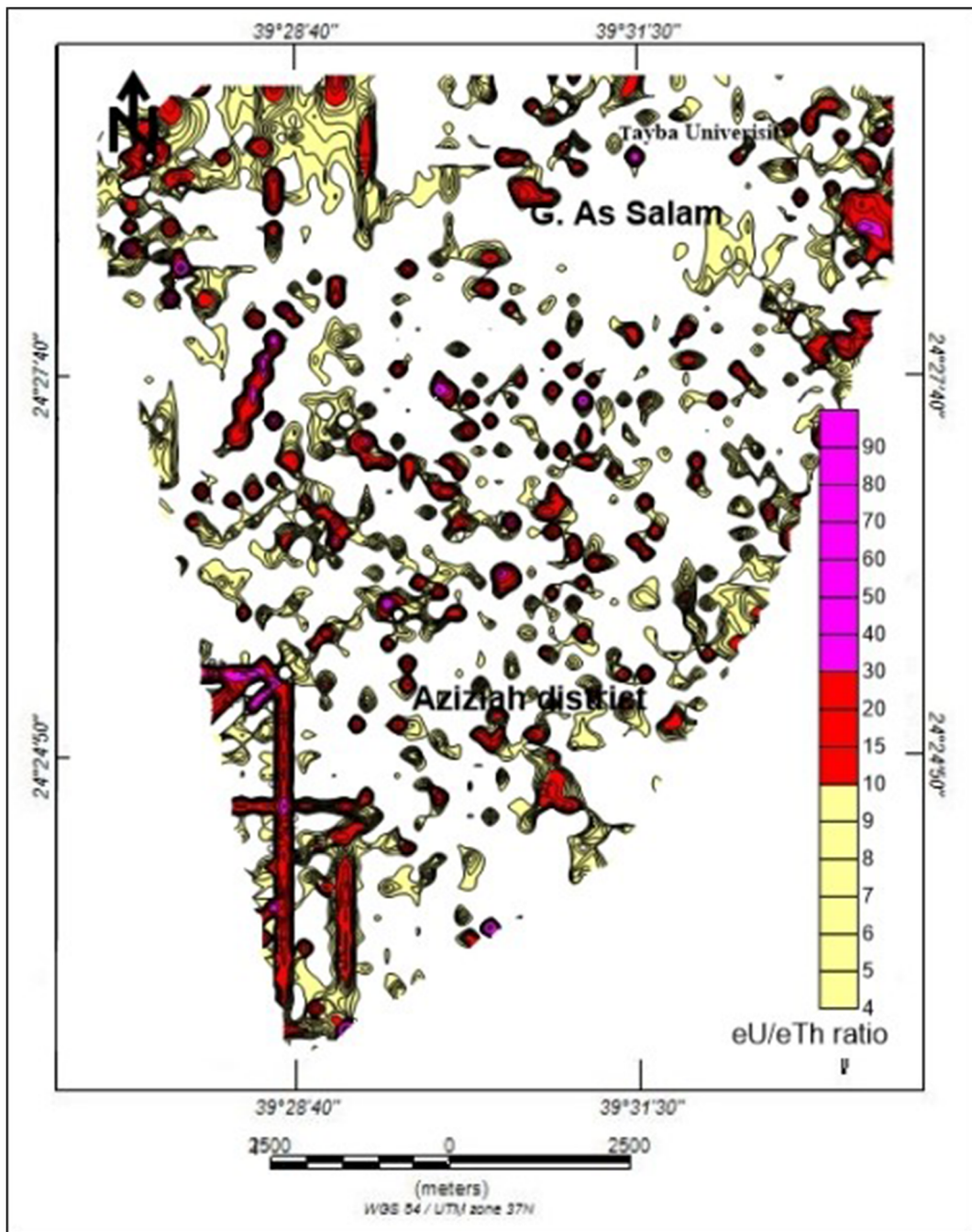


Fig. 10 The eU/eTh ratio contour map, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

$$\text{Dose rate (mSv/y)} = 0.0833 * \text{Exposure rate } (\mu\text{R/h}) \quad (3)$$

There are wide distributions of exposures from many sources and the consequent effective doses combine in various ways at each location. The average global

exposure does not pertain to any one individual: this average depends on the specific concentration of radionuclides in the environment and in the body, the latitude and altitude of the location and many other factors (UNSCEAR 2000).

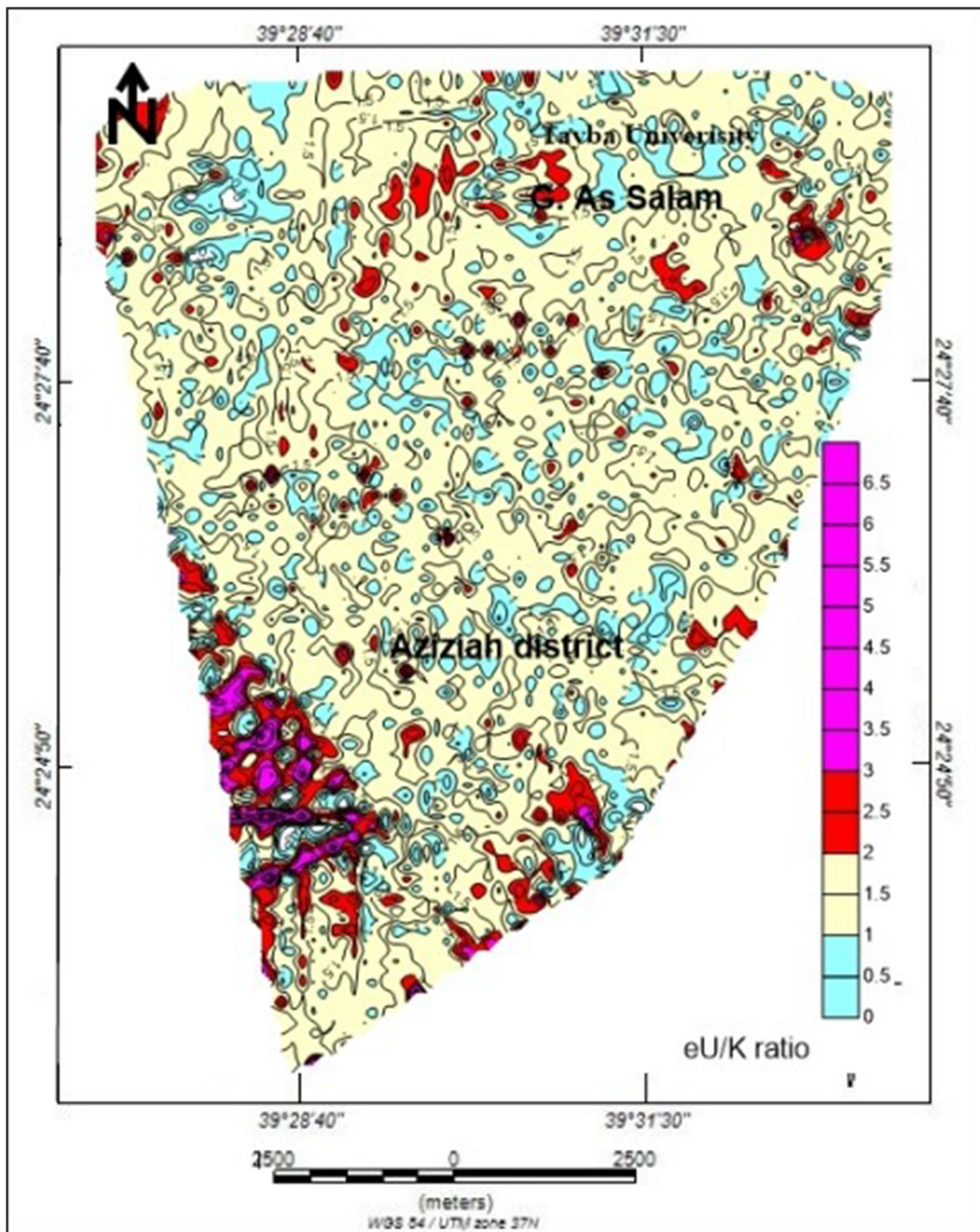


Fig. 11 eU/K ratio contour map, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

Distribution of radioactive elements and their dose rate

Radiation dose rate contour map in nGy/h

The radiation dose rate contour map in nGy/h (Fig. 13) shows that the study area has some high anomalies of

dose rate radiation in nGy/h. The dose rate radiation reached 136 nGy/h with an average value of about 47.81 nGy/h. This anomaly was restricted mainly to G. As Salam, situated north of the study area, and eastern part of G. Al Suluk (Figs. 3 and 13) beside some minor anomalies distributed over the granitic exposure hills in the study area. The dose rate in nGy/h decreased as one

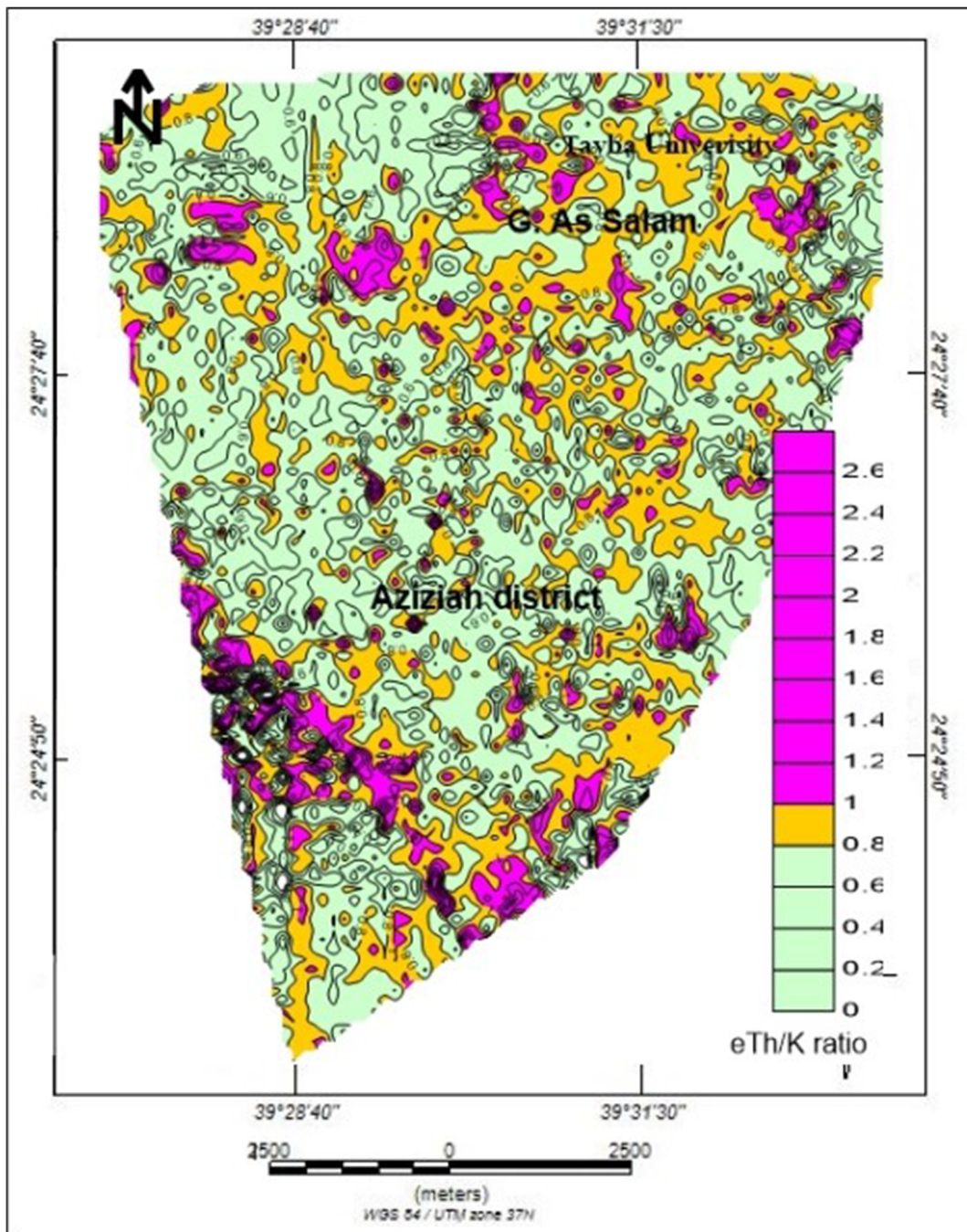


Fig. 12 The eTh/K ratio contour map, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

moved away from the granitic rocks to minor traces in the location of old wadis which have granitic deposits. The other parts of the study area reflect a low dose rate, especially over the basaltic rock and its deposits. The statistical treatment of the dose rate in nGy/h distribution in the study area is shown in

Table 1. In the UNSCEAR report (1993), it was reported that direct measurements of the air dose rate of natural terrestrial radionuclides were performed in most populated areas of the world, and it concluded for countries or regions where three-fifths of the world's population lives.

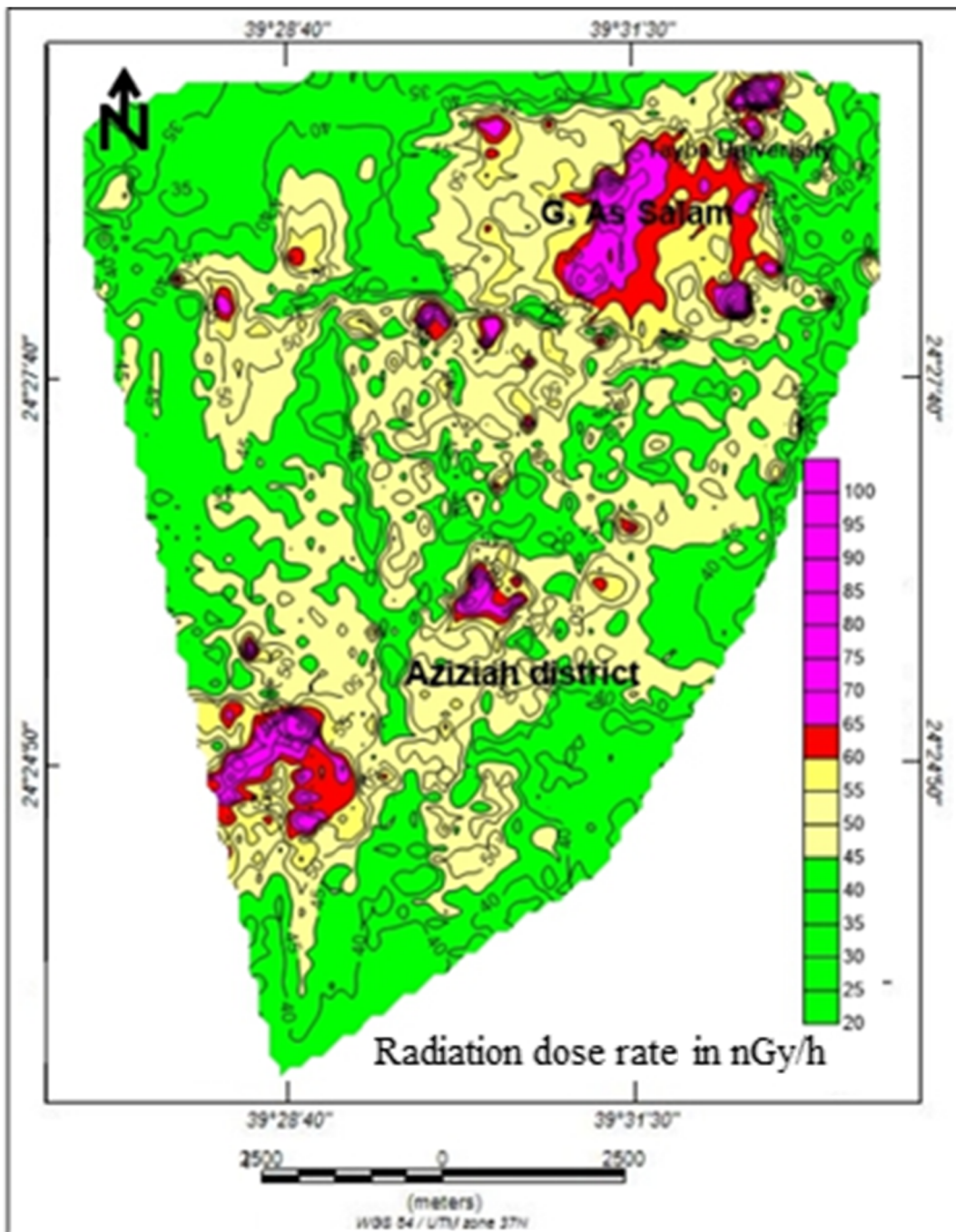


Fig. 13 Radiation dose rate contour map in nGy/h, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia (without cosmic rays)

The international dose rate which is in between 24 and 85 nGy h⁻¹ with an arithmetic mean of 55 nGy h⁻¹ (UNSCEAR 1988). Accordingly, the granitic places in

the study area are considered higher than the average world reading, where they have a range from 60 to 105 nGy/h⁻¹ with an average of about 82 nGy h⁻¹.

Radiation dose rate contour map in mSv/y

The dose rate contour map radiation in mSv/y of the study area has relatively higher anomalies reaching up to 4.48 with an average value of about 1.08 mSv/y. This anomaly (pink colour) is restricted mainly to G. As Salam, situated north of the study area, the eastern part

of G. Al Suluk and inside the artificial drainage canals in south G. Al Suluk (Figs. 3 and 14). The relatively higher reading anomalies are related to the granite exposures (red colour) and decreased as one moves away over to the granitic deposits (yellow colour), besides some minor anomalies are seen in areas, distributed over the granitic exposure hills, in the study area (red colour).

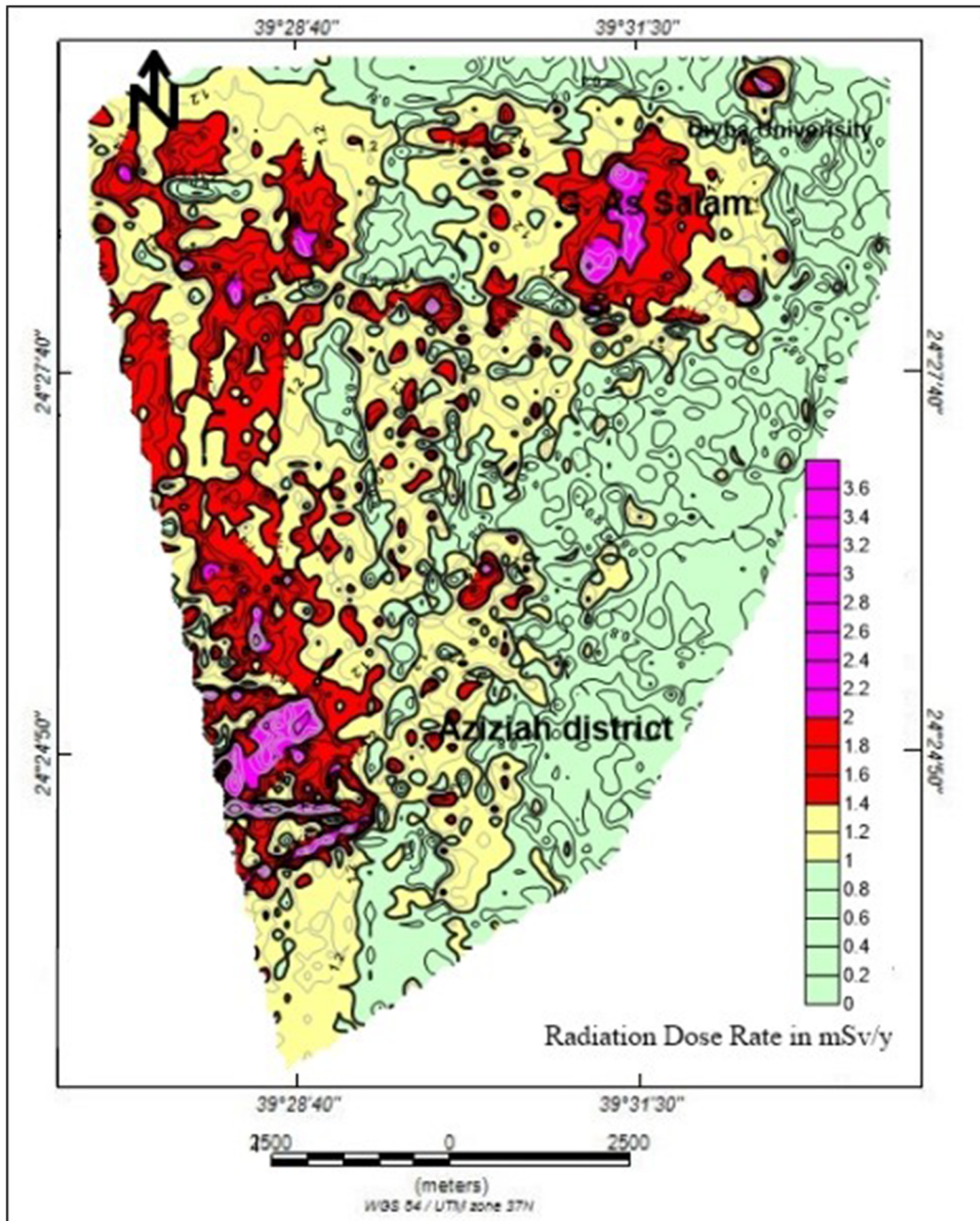


Fig. 14 Radiation dose rate contour map in mSv/y, Al Aziziah area and its vicinity, Al Madinah Al Monawarah, Saudi Arabia

These coloured areas (pink, red and yellow) are over 1 mSv/y and are considered out of the safe limit of ICRP (2000) as in Fig. 15. The other parts of the study area, especially the northern and eastern parts, are considered safe for population, where they reflect the basaltic rocks and their recent deposits (green colour).

The statistical treatments of the dose rate in mSv/y distribution in Al Aziziah area and vicinity are shown in Table 2. The estimated effect of radiation dose rate within the study area was found to be higher than 1 mSv/year, which is the maximum exposure for the general population, and well below the permissible exposure limit of 20 mSv/y (ICRP 2000). The safe limit has been changed over many years according to the increasing research and results (Fig. 15). However, further research is necessary for the radon gas concentration in the closed space of the study area. More awareness is needed regarding the nature of the place where populations live, especially the granite places where radon can be accumulated in enclosed places and poses a danger to health.

The average annual exposure worldwide to natural radiation sources (both high and low LET) is in the range of 1–10 mSv, with 2.4 mSv being the present estimate of the central value (UNSCEAR 1993, 2000). Of this amount, about one-half (1.2 mSv/y) comes from radon and its decay products. The average annual background exposures in the USA are slightly higher (3.0 mSv) due to higher average radon levels. In the UK, the annual average dose is 2.6 mSv/y. After radon, the next highest percentage of natural ionising radiation exposure comes from cosmic rays, followed by terrestrial sources and “internal” emissions (National

Fig. 15 Changes in dose limit in mSv/y (ICRP 2000) (safe levels)

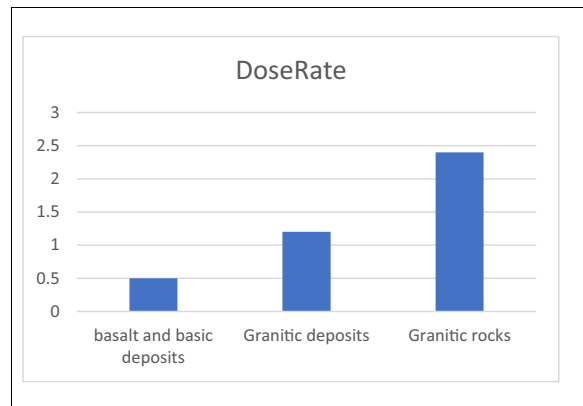
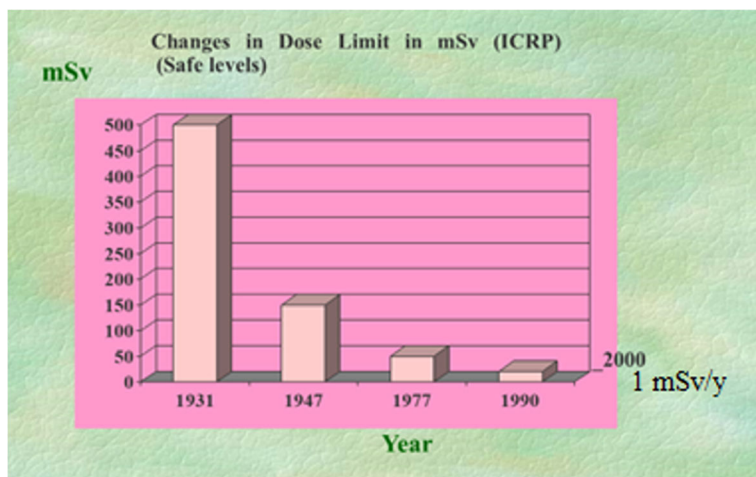


Fig. 16 Histogram showing the average radiation dose in mSv/y from main rock units: granitic rocks, 2.4 mSv/y; granitic deposits, 1.2 mSv/y; and basaltic and basic deposits, 0.5 mSv/y

Academy of Sciences 2006). Most of the study area lies in a range less than the world average value, except the high anomaly area which sits over the granitic intrusions in the northern and western parts of the study area (Fig. 14).

In the study area, the average dose rate from the main rock units is shown in Fig. 16. Granitic rocks and granitic deposits in the western and northern parts have an average over the safe limit (1 mSv/y), while basalt and basaltic and basic deposits in the eastern and northern parts of the study area have an average below the safe limit.

Granite rock is used as a famous building material because of its decorative appearance and attractive colours. Radon gas beneath houses is more dangerous than radon produced from granite building materials since granite is generally not very porous; radon gas is likely

Fig. 17 People remove part of the granite mountain and build on it



to form more in the case of porous stone such as sandstone. In many cases in the study area, people remove part of the granite mountain and build on and over it as shown in Figs. 17 and 18. In addition, it is possible to reduce the risk of radon leakage from granite rocks (e.g. in kitchens or bathrooms) if good ventilation is found. Notably, the half-life of radon is 3.8 days. Radon that accumulated in offices and closed rooms affects populations, increasing the risk of cancer. Inhalation of radon and smoking lead to lung cancer, the chances of which are higher in this regard.

Surface and well water

The high permeability of the Harrat Rahat area in the southeast of Madinah and the alluvial sediments to the west, including the central part of the city, are the two main groundwater resource areas outside the study area. The sediments are Quaternary, and they consist of clay,

sand and gravel that resulted from weathering of pre-Cambrian rocks with fragments of basalt from the late Third and Quaternary periods. The quality of groundwater depends almost on the extent to which it is influenced by weathering, lithology, nature of geochemical reactions, slow suicide or various human activities, such as agriculture, sanitation and industrial waste generation (Singh and Chandel 2006; Nisi et al. 2008; Jiang and Yan 2010).

In the present study, the eU, eU/eTh ratio and radiation dose maps (Figs. 8, 10 and 14) show that they have high readings in drainage canals and rain-drenched places, which reach the nearest groundwater wells. This confirms that uranium is washed away from its source in granite rocks and transported to drains. The readings here reflect a higher radiation dose than the permissible rate, and thus, this accumulated water that reaches the wells is not drinkable. This study supports the evidence in some previous studies about the validity of groundwater. WHO (2011) and Bamoussa and

Fig. 18 People build over granite



Maghraby (2016) studied most of the wells situated near or in the study area. They concluded that the groundwater of El Madinah should be considered unsafe for drinking purposes, whereas it is moderately appropriate for irrigation.

Conclusion

Al Aziziah area and vicinity, Al Madinah Al Monawarah, Saudi Arabia, is surveyed using a radiation car-borne scanner to determine the risk of dose rate radiations. The average radiation dose recorded in the study area is 1.08 mSv/y, while its range is from 0.001 to 4.41 mSv/y. The estimated effective doses within the Al Aziziah area and vicinity area, Al Madinah Al Monawarah, were higher than 1 mSv/y, which is the public exposure limit and lower than the occupational exposure limit of 20 mSv/y (IAEA; 2000; UNSCEAR 2000). In this area, granitic rocks show an average dose rate of about 2.4 mSv/y, while the deposits of these rocks have an average dose rate of 1.2 mSv/y. A low average dose is recorded over the basalt, basaltic and basic deposits. However, further research is necessary to determine the amount of radon in closed places. The uranium contour and radiation dose maps reflect a higher radiation dose than the permissible rate in the sites of artificial drainage canals, and thus, this accumulated water that reaches the wells is not drinkable. More awareness is needed on the nature of the place where populations live, especially the granite places where radon can be accumulated in enclosed places and would pose a danger to health. We recommend ventilating homes and offices in these places on an ongoing basis in the study area and constant radon measuring in closed places.

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