النشاط الاشعاعي الطبيعي لعينات التربة السطحية في المناطق الساحلية بين طرابلس و الزاوية

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الملخص بالعربي

تم قياس تركيزات النشاط للنويدات المشعة الطبيعية لكل من (الراديوم 226) و (الثوريوم 232) و (البوتاسيوم 40) باستخدام كاشف الجرمانيوم عالي النقاوة في عينات التربة السطحية التي تم جمعها من المناطق على طول الساحل بين طرابلس والزاوية ، ومؤشرات المخاطر الاشعاعية مثل : معدل جرعة جاما للهواء الطلق الممتصة وما يقابلها من الجرعة السنوية الفعالة ، وزيادة خطر الإصابة بسرطان مدى الحياة ، ونشاط مكافئ الراديوم ، ومؤشر الخطر الخارجي التي تم حسابها ـ أيضا ـ لتقييم الآثار الإشعاعية التي تسببها النويدات المشعة الأرضية على السكان والعاملين في المناطق المختارة .

وتمت مقارنة مستويات النشاط الإشعاعي الطبيعي ، ومعايير خطر الاشعاع بالقيم الدولية الموصى ، وبعد تجميع تجميع النتائج التي تم الحصول عليها وجد أنها أقل من الحد الموصى به دوليا .

وهذا يدل على أن التربة تعتبر آمنة ، ويمكن استخدامها في بناء المساكن ، ومصادر مواد البناء دون إعطاء أي خطر إشعاعي للسكان المحليين .

natural radioactivity of surface Soil samples in coastal regions between Tripoli and Zawiya

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Abstract:

The activity concentrations of the natural radionuclides ^{226}Ra, ^{232}Th, and ^{40}K were measured using a high-purity germanium detector in surface soil samples collected from the regions along the coast between Tripoli and Zawiya, The radiological hazard indices like the outdoor absorbed gamma dose rate and their corresponding annual effective dose and excess lifetime cancer risk, radium equivalent activity and external hazard index were also calculated to assess the radiological impacts caused by the terrestrial radionuclides on the population working and living in the selected regions. The levels of natural radioactivity and radiation hazard parameters were compared with the international recommended values. All obtained results were found to be below the international recommended limit. This indicates that the soils considered were safe and can be used in the building of dwellings and sources of construction material without giving any radiological hazard to the local population.

Keywords: Natural radioactive nuclides; soil; activity concentration; absorbed gamma dose rate; annual effective dose and excess lifetime cancer risk

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Introduction:

The exposure of human populations to ionizing radiation arises from natural and man-made sources. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the average annual dose received by the human population from ionizing radiation emitted from natural and artificial radiation is 2.8mSv of which 2.4 mSv y^{-1} is due to the natural radiations and 0.4 mSv y^{-1} is due to exposure to artificial radiations (UNSCEAR 2000; UNSCEAR 2008). The natural radiation arises from two main sources, cosmogenic (cosmic radiation or cosmic rays) and terrestrial radionuclides. The natural radiation (also called natural background radiation) arises from two main sources, cosmogenic (cosmic radiation or cosmic rays) and terrestrial radionuclides. Cosmogenic radionuclides are produced from the reaction of high-energy cosmic rays (emitted by the stellar sources) with the nuclei of atoms in the atmosphere. The average annual dose received by people from these radiations is 0.39 mSv y^{-1}, which varies with altitude and latitude.

The terrestrial radionuclides are the long-lived primordial radionuclides and their daughter nuclides, which are present on earth's crust since the creation of the earth. The soil is the most important source of the terrestrial

radionuclides, whose radiation level varies from place to place and it is related to the geological structure and composition of the soils. The presence of terrestrial radionuclides in soil originates from the disintegrating of rocks through the processes of erosion and deposition, and they are carried to the soil by rain and flows and become an integral component of the soil. The terrestrial

component of the natural radiations comes mainly from long-lived primordial radionuclides and their daughter nuclides, which are present on earth's crust since the creation of the earth. The most important primordial radionuclides present in the soil are the radionuclides with half-lives comparable to the age of earth, mainly Uranium-238 ($t_{1/2}$ = 4.47 x 10^9 y), Thorium-232 ($t_{1/2}$ = 1.4 x 10^9 y) and Potassium-40 ($t_{1/2}$ = 1.25x 10^9 y) and their decay series nuclides.

The terrestrial radiations find their way from environment into human body through two main pathways; external and internal exposure. External exposure occurs when the body is exposed to gamma rays emitted by terrestrial radionuclides outside the body. While, the internal exposure occurs when the primordial radionuclides or their decay products are incorporated into the body. A major portion of the internal exposure from natural sources is formed by the inhalation exposure to inert radioactive gas and its progeny. This gas is produced from the disintegration of ^{238}U and ^{232}Th in the soil; it percolates through the soil, and diffuses into the air we breathe. The average effective dose from radon radiation is approximately 1.3 mSv y^{-1} (UNSCEAR 2000; UNSCEAR 2008).

The determination of natural radioactivity concentration in the environment, especially soil is of particular importance for assessing gamma radiation dose and terrestrial gamma dose rate, which plays a vital rule for the health risk estimation due to the terrestrial external radiation exposure and internal exposure from inhalation and ingestion. Also, it is necessary to measure and monitor the activity levels of radionuclides in the soil to establish baseline map and database on environmental radioactivity levels

for ascertaining of any changes in radiation levels with time as a result of the nuclear industries and other human activities. The measurements of radionuclide concentration in soil and assessment of radiological hazard from soil samples have been made by many researchers throughout the world (Baeza et al. 1992; Anagnostakis et al. 1996; Ahmed and Mohamed 2005; Singh et al. 2005; Ajayi 2009; Al-Hamarneh and Awadallah 2009; Belivermis et al. 2010; Jabbar 2010; Al-Trabulsy et al. 2011; Harb et al. 2012; Asgharizadeh et al. 2013; Jallad 2014; Guidotti et al. 2015; Mohammed and Ahmed 2017; El Samad 2018). In Libya, many studies related to determination of distributions of the terrestrial radionuclides and their concentrations in soil and rocks were performed (Shenber 1997; Tereesh et al. 2013; Elnimr et al. 2017).

However, according to thorough literature review, a comprehensive study related to measurement of activity concentrations of the terrestrial radionuclides and assessment of associated radiological hazards in soil samples collected from areas along the coast between Tripoli and Zawiya in northwest Libya has not yet been performed. Hence, the main objective of this study is to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in 11 soil samples collected from the coastal region between Tripoli and Zawiya around the northwest Libya and to evaluate the absorbed gamma dose rate, annual effective dose, excess lifetime cancer risk, radium equivalent activity and the external hazard index.

Material and method

Description of study area

The study area is in the region situated between Tripoli

(the capital of Libya) and Zawiya district. These two cities have a shoreline bordering the Mediterranean Sea, and they are the most populated areas in western Libya. Zawiya district is located on the northwestern side of Tripoli. The investigated region extends along the shore of the Mediterranean Sea at a few kilometres (1-2 km) from the water, between the latitudes 32°46′02.32″N and 32°50′36.39″N and the longitudes 12°41′55.43″E and 13°04′21.54″E and along the coastal highway which links the capital Tripoli with Zawiya district. The land use of these regions is mainly residential and agricultural.

In the present investigation, the soil samples were collected from 11 sites along the coastal highway between Tripoli Zawiya and along a distance of about 40 km. The sampling sites were at a distance 1-3 km from each other. The sampling sites locations in the study area are shown in Fig. 1. Table 1 shows the geographical coordinates (longitude and latitude) of sampling sites. The longitude and latitude of sampling locations were obtained by using the Global Positioning System (GPS).

Table 1: Geographical positions of soil sample locations.

Sample location code	Latitude	Longitude
C01	32°46′02.32″N	12°41′55.43″E
C02	32°46′54.12″N	12°45′7.45″E
C03	32°47′22.24″N	12°46′52.03″E
C04	32°47′47.40″N	12°50′29.26″E
C05	32°47′48.92″N	12°51′54.22″E
C06	32°48′22.97″N	12°54′42.77″E
C07	32°48′49.64″N	12°55′58.91″E
C08	32°49′26.69″N	12°58′59.52″E

C09	32°49′40.04″N	13°00′08.60″E
C10	32°50′14.14″N	13°02′47.70″E
C11	32°50′36.39″N	13°04′21.54″E

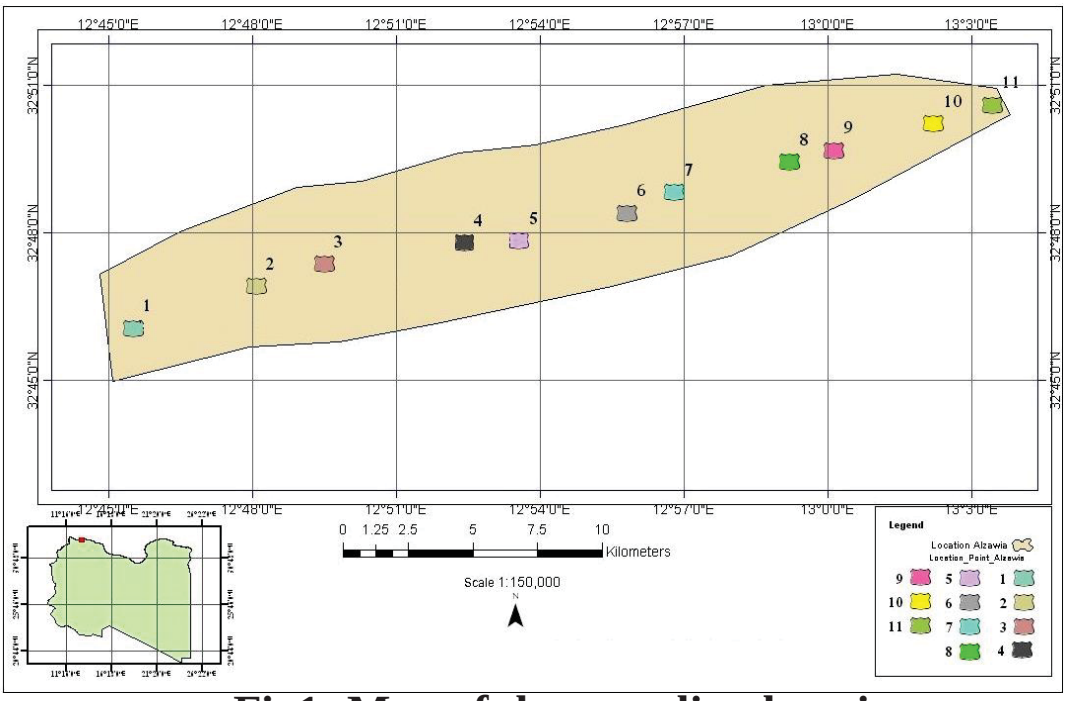

Fig1: Map of the sampling locations.

Sampling and sample preparation

At each selected site an area of 40×40 m was marked and three soil samples were randomly taken and thoroughly mixed together and homogenized to ensure a representative sample of the sampling site. After clearing the ground of selected sampling area from organic material, vegetation, roots, pebbles and stones, 1.5 kg of soils were collected from a depth of about 5–10 cm since topsoil and filled into labeled plastic bags and then transferred safely to the laboratory. The collected samples were ground into a fine powder and sieved through 2 mm mesh to ensure a homogenized uniform size. The samples were then dried in an oven at a temperature slightly above 100 °C to ensure that the moisture content was completely removed. Then each dried

sample was weighed, packed in 350 ml standard plastic Marinelli beakers, sealed, and stored for 1 month to ensure the establishment of secular equilibrium between ^{226}Ra, ^{232}Th and their short-lived progenies. The preparation of samples and radioactivity measurements were made in Tajoura Nuclear Research Centre (TNRC), Libya.

Calculation of activity concentration and estimation of radiological hazards

Activity concentration

In this study, High Purity Germanium detector (HPGe) mounted on 40 liter liquid Nitrogen Dewar is used to detect and measure the natural elements in the earth crust. This detector is connected to Gor Tec ACE multichannel analyzer (MCA) with efficiency of 30%. The ACE is made up of a model 916 card; it monitors the presets, lifetime, real time and other functions. It has an energy resolution of l.8 keV for the l332.5 keV gamma-ray transition of ^{60}Co. The shielding required around the detector or around the whole Dewar is Lead shield contained two inner concentric cylinders copper and cadmium to reduce the background level of the system.

The concentration of natural radionuclide was calculated by the application of Eq. (1), 1460 keV was used to determine ^{40}K and the series of ^{226}Ra daughters, respectively. The gamma ray lines of 295.l – 351.7 keV (Pb-214) and 609.3 - 1120.3 -1764.5 (Bi-214) were used to determine ^{226}Ra. The gamma-ray lines of 238.63 (Pb-214), 338.4 - 911.19 - 968.9 keV (AC-228) and 583.19 keV (Tl-208) were used to determine ^{232}Th.

$$Ac(\mathrm{Bq.kg^{-1}}) = \frac{C_n}{P_\gamma M \varepsilon} \qquad (1)$$

Where Ac is the activity concentration of the radionuclide in the sample, C_n is the net count rate under the corresponding peak, P_γ is the absolute transition probability of the specific gamma ray, M is the mass of the sample (kg) and ε is the detector efficiency at specific gamma ray energy.

Radiological hazards

Absorbed gamma dose rate and annual effective dose

The absorbed gamma dose rate in outdoor air at 1 m above the ground (D_{out} in nGy h^{-1}) and corresponding annual effective dose D_{eff} (mSv y^{-1}) were estimated by using the activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K, and according to the following equations (UNSCEAR 2008):

$$D_{out}(\text{nGy}\,.\,\text{h}^{-1}) = 0.462.A_{Ra} + 0.604.A_{Th} + 0.0417.A_K \quad (2)$$

$$D_{eff}(Sv.y^{-1}) = D(\text{nGy h}^{-1}) \times 8760\ (\text{h y}^{-1}) \times 0.2 \times 0.7\ (\text{Sv Gy}^{-1}) \quad (3)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations in the soil samples (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K, respectively. 8760 is the annual exposure time, 0.7 is the conversion factor from the absorbed dose in air to the effective dose for adults) (UNSCEAR 2008) and 0.2 is the outdoor occupancy factor.

Excess life time cancer

The excess lifetime cancer risk (ELCR) is the probability of development of mortal cancer over a lifetime of an average adult individual caused by exposure to ionizing radiation. For outdoor exposure, ELCR can be calculated from outdoors annual effective dose D_{eff} using the following equation (Taskin et al. 2009):

$$ELCR = D_{eff} . LE . RF \qquad (4)$$

where LE is the average life expectancy (approximately 70 years) and RF (Sv^{-1}) is the risk factor, which reflects the fatal cancer risk per sievert (Taskin et al. 2009). For stochastic effects, RF is determined by the ICRP (1990) at 0.05 for the public (ICRP, 1990).

Radium equivalent activity (Ra_{eq}) and external hazard index H_{ex}

In order to assess if soil which could be used as dwelling areas and sources of building material without giving any significant, the two hazard index: radium equivalent (Ra_{eq}) activity in $Bqkg^{-1}$ and external hazard index (H_{ex}) were calculated at all sampling locations. The Ra_{eq} is defined as a weighted sum of the specific activities of ^{226}Ra, ^{232}Th and ^{40}K on the base assumption that 370 $Bq.Kg^{-1}$ of ^{226}Ra, 259 $Bq.Kg^{-1}$ of ^{232}Th and 4810 $Bq.Kg^{-1}$ of ^{40}K produce the same gamma-ray dose rate. Ra_{eq} is calculated through the following relation as defined by Beretka and Methew (Beretka and Mathew 1985):

$$Ra_{eq} = A_{Ra} + 1.43 . A_{Th} + 0.077 . A_k \qquad (5)$$

Where A_{Ra}, A_{Th}, and A_K are the activity concentrations ($Bq.Kg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}K respectively.

The external hazard index (H_{ex}) was calculated using the following the equation (Beretka and Mathew 1985):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \leq 1 \qquad (6)$$

Results and discussion

Activity concentration results

The activity concentrations of terrestrial radionuclides ^{226}Ra, ^{232}Th and ^{40}K in investigated surface soil samples have

been measured by using the gamma spectrometry. The measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, with their range and their average value, are shown in Table 2. As can be seen from Table 2, the measured activity concentration of ^{226}Ra ranged from 9.46 to 13.08 $Bqkg^{-1}$ with an average value of 11.67 $Bqkg^{-1}$. The highest value of the activity concentration of ^{226}Ra radionuclide has been reported in the soil sample collected from location C08, whereas the lowest value is found at location C01. For ^{232}Th, the range of measured activity concentration varies from 7.37 to 11.50 $Bqkg^{-1}$ with an average value of 8.81 $Bqkg^{-1}$. The lowest value was measured in location C11 while the highest value is found at the location C07. The average value of the activity concentrations of ^{40}K is 277.47 $Bqkg^{-1}$ in a range of 215.88–316.92 $Bqkg^{-1}$. The lowest value was found in location C08 and the highest value was observed in location C11. The differences in the activity concentrations of natural radionuclides in the different soil samples may be due to the different composition of the soil in each region, and to the types of the rock from which the soils originate and also to the formation and geological processes that are involved. The results revealed also that the measured activity concentration of ^{40}K is significantly higher than the measured activity concentration values of both ^{226}Ra and ^{232}Th in all the soil samples. This indicates that ^{40}K is a most abundant terrestrial radionuclide than the other radionuclides in the investigated soils.

It can be observed from Table 3 that average activity concentration of ^{226}Ra measured in the present study is quite close and comparable to those measured in Libya's Tripoli region (Shenber 1997), as well in some Arab countries and Middle

Eastern countries such as Egypt (Qena) (Ahmed and Mohamed 2005), Saudi Arabia (Coastline of the Gulf of Aqaba) (Al-Trabulsy et al. 2011) and Kuwait (Failaka Island) (Jallad 2014), it is lower than that measured at Jabal Eghei (Libya) (Tereesh et al. 2013), Valley Rwagh (Libya) (Elnimr et al. 2017), Algeria (UNSCEAR 2002), Jordan (Amman) (Al-Hamarneh and Awadallah 2009), Lebanon (Mount Lebanon) (El Samad et al. 2018), Yemen (North of Sana'a) (Harb et al. 2012), Iraq (Basrah) (Mohammed and Ahmed 2017), Spain (Caceres) (Baeza et al. 1992), Italy (Lombardia) (Guidotti et al. 2015), Greece Anagnostakis et al. 1996), Nigeria (Southwestern) (Ajayi 2009), Iran (Tehran) (Asgharizadeh et al. 2013), Turkey (Istanbul) (Belivermis et al. 2010), Pakistan (Rechna interfluvial) (LaBrecque 1994), and India (Punjab and Himachal Pradesh) (Singh et al. 2005). This behaviour is almost similar for ^{232}Th, except for Saudi Arabia and Kuwait the average activity concentration of ^{232}Th in this work is also higher than the values reported in these two countries.

The average activity concentration of ^{40}K obtained in the present work is higher than the average values of ^{40}K measured at Tripoli and Valley Rwagh in Libya, Lebanon (Mount Lebanon) and Yemen (North of Sana'a) and lower than that measured at Jabal Eghei in Libya, Algeria, Egypt (Qena), Saudi Arabia (Coastline of the Gulf of Aqaba) and Kuwait (Failaka Island), Jordan (Amman), Iraq (Basrah), Spain (Caceres), Italy (Lombardia), Greece, Nigeria (Southwestern), Iran (Tehran), Istanbul (Turkey), Pakistan (Rechna interfluvial), and India (Punjab and Himachal Pradesh). The variation among the activity concentrations of the radionuclides in soils of different countries

could be due to the different composition of the soil in each region, and to the types of the rock from which the soils originate and also to the formation and geological processes that are involved.

Table 2: Activity concentrations of ^{26}Ra, ^{232}Th and ^{40}K measured in the soil samples

Sampling code	Activity concentration ($Bqkg^{-1}$)		
	^{226}Ra	^{232}Th	^{40}K
C01	9.46 ± 0.64	8.17 ± 0.47	269.19 ± 4.74
C02	11.22 ± 0.69	8.70 ± 0.57	299.84 ± 5.14
C03	12.66 ± 0.71	8.25 ± 0.49	278.00 ± 4.77
C04	11.81 ± 0.73	10.33 ± 0.61	297.81 ± 5.07
C05	12.17 ± 0.63	7.66 ± 0.56	208.33 ± 4.10
C06	10.57 ± 0.70	7.39 ± 0.49	272.95 ± 4.63
C07	11.88 ± 0.77	11.50 ± 0.57	304.55 ± 5.22
C08	13.08 ± 0.75	9.22 ± 0.55	316.92 ± 5.39
C09	12.65 ± 0.69	9.07 ± 0.50	300.46 ± 5.12
C10	11.40 ± 0.70	9.26 ± 0.48	288.21 ± 4.91
C11	11.53 ± 0.62	7.37 ± 0.41	215.88 ± 4.25
Range	(9.46-13.08)	(7.37-11.50)	(215.88-316.92)
Average	11.67	8.81	277.47

World average (UNSCEAR 2008)	32	45	412

Table 3: Comparison of activity concentration (Average value) of ^{226}Ra, ^{232}Th and ^{40}K in soil samples with those reported for other countries and different regions of Libya.

Region and Country	Activity concentration ($Bqkg^{-1}$)			Reference
	^{226}Ra	^{232}Th	^{40}K	
Tripoli/Libya	10.5	9.5	270	Shenber (1997)
Jabal Eghei/Libya	339	73	1224	Tereesh et al. (2013)
Valley Rwagh/Libya	121	202	73	Elnimr et al. (2017)
Coastal regions between Tripoli and Zawiya /Libya	11.67	8.81	277.47	This study
Algeria	50	25	370	UNSCEAR (2002)
Qena/Egypt	11.90	10.50	1636	Ahmed, N.K. and Mohamed El-Arabi (2005)
Amman/Jordan	44.00	20.90	241.6	Al-Hamarneh and Awadallah (2009)
Mount Lebanon/ Lebanon	46	24	206	El Samad et al. (2018)
North of	48.2	41. 7	939.1	Harb et al.

Sana'a/Yemen				(2012)
Coastline of the Gulf of Aqaba/ Saudi Arabia	11.42	22.48	641.08	Al-Trabulsy et al. (2011)
Failaka Island/Kuwait	14.7	9.69	333	Jallad, K. N. (2014)
Basrah/Iraq	58.44	19.38	321.76	Mohammed and Ahmed (2017)
Caceres/Spain	46.00	49.00	650.00	Baeza et al. (1992)
Lombardia/Italy	72.00	48.00	617.00	Guidotti et al. (2015)
Greece	25	–	355	Anagnostakis et al. (1996)
Southwestern/Nigeria	54.50	91.10	286.50	Ajayi (2009)
Tehran/ Iran	38.80	43.40	555.10	Asgharizadeh et al. (2013)
Istanbul/Turkey	27.70	32.50	388.00	Belivermis et al. (2010)
Rechna interfluvial/Pakistan	50.6	62.3	662.2	LaBrecque (1994)
Punjab andHimachal Pradesh/India	56.74	87.42	143.04	Singh et al. (2005)
World average	32	45	412	UNSCEAR (2008)

Radiological hazards

Absorbed gamma dose rate

The terrestrial gamma dose rates in outdoor air at 1m from

the ground surface (D_{out}, nGy h^{-1}) originates from the terrestrial radionuclides in soil were calculated using the Eq. (2). The results of D_{out} are presented in the second column of Table 4. It can be observed that the calculated absorbed dose rate varied in a range of 18.78-25.13 $nGyh^{-1}$ with an average value of 22.29 $nGyh^{-1}$. This average value is lower than the world average absorbed dose rate of 59 $nGyh^{-1}$ as reported by UNSCEAR (UNSCEAR, 2008).

Annual effective dose

The annual external effective dose (D_{eff}) from outdoor terrestrial gamma radiation received by the population living in the study area was calculated by using the Eq. (3). The calculated values of D_{eff} were found lower than the world average annual effective dose received from terrestrial gamma radiation of 70 μSv y^{-1} as reported by (UNSCEAR, 2008). They lie in the range of 23.03–30.83 μSv y^{-1} with an average value of 27.33 μSv y^{-1}.

Excess life time cancer

The excess lifetime cancer risk (ELCR) of the soil in the study area has been estimated using the formula (5) and presented in the 4 column of Table 4. The calculated values of ELCR lie in the range of 8.06×10^{-5}-10.08×10^{-5}, with an average value of 9.57×10^{-5}. This value is less than 24×10^{-5} which corresponds to the world average limit of ELCR for outdoor terrestrial gamma radiation. According to this result, the risk to develop mortal cancer among the local population caused by exposure to terrestrial radiations is about 95.7 out of a million adults, which is lower than the prediction reported by UNSCEAR which is 245 out of a million deaths due to cancer (if the UNSCEAR total natural radiation dose of 0.07 mSv y^{-1} was

used).

Radium equivalent activity and external hazard index H_{ex}

The estimated radium equivalent activities (Ra_{eq}) for the collected samples are shown in the six column of Table 4. The average value of Ra_{eq} in the present study was calculated as 45.61 $Bqkg^{-1}$, which is within the range of 38.66 and 51.74 $Bqkg^{-1}$. All estimated values of Raeq are lower than the suggested limit value of 370 $Bqkg^{-1}$ as recommended by the Organization for Economic Cooperation and Development (OECD 1979). Therefore, soil from these regions is safe and can be used in building of dwellings and sources of construction material without giving any significant radiological threat to the population.

The calculated values of external hazard index ($H_{ex)}$ for the soil samples of the study area are given in the last columns of Table 4. The obtained values of Hex were found to range between 0.104 and 0.14 with an average value of 0.12. All results were found less than the recommended limits 1 as reported in the Radiation Protection 112 report given by the European Commission (EC) (European Commission 1999). Since the regions from which the soil samples were collected are safe and can be used as dwelling areas and sources of the building material without giving any radiological hazard to the local population.

Table 4: Absorbed gamma dose rate, annual effective dose, excess lifetime cancer risk, radium equivalent activity and the external hazard Index.

Sampling code	Radiological Index				
	Absorbed dose rate. D_{out} ($nGyh^{-1}$)	Annual effective dose. D_{eff} ($\mu Sv\ y^{-1}$)	Excess lifetime cancer risk ($\times 10^{-5}$)	Radium equivalent activity R_{eq} (Bqkg-1)	External hazard index. H_{ex}
C01	20.53	25.18	8.81	41.84	0.113
C02	22.94	28.13	9.85	46.71	0.126
C03	22.42	27.50	9.63	45.83	0.124
C04	24.11	29.57	10.04	49.48	0.134
C05	18.94	23.23	8.13	39.14	0.106
C06	20.73	25.42	8.90	42.12	0.114
C07	25.13	30.83	10.08	51.74	0.140
C08	24.83	30.45	10.07	50.64	0.137
C09	23.85	29.25	10.02	48.72	0.132
C10	22.88	28.06	9.82	46.80	0.126
C11	18.78	23.03	8.06	38.66	0.104
Range	(18.78-25.13)	(23.03-30.83)	(8.06-10.08)	(38.66-51.74)	(0.104 - 0.140)
Average	22.29	27.33	9.57	45.61	0.12
World average (UNSCEAR 2008)	58	70	25	370	1

1. Conclusion

In this study, the activity concentrations of the terrestrial radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in the soil samples collected from 11 sites along the coast between Tripoli and Zawiya, northwest Libya, were measured using gamma-ray spectrometry with a high-purity germanium detector. The results obtained showed that the values of the radionuclides concentration for all the selected sampling locations are found to be lower than the world averages. In addition, the results in this study are comparable to those determined in other Libyan regions and other countries.

Moreover, for more conclusive assessment of the radiological hazard due to gamma radiation emitted from the radionuclides present in the soil of the studied areas, the following radiological hazards parameters: absorbed gamma dose rate (D_{out}), total annual effective dose (D_{eff}), excess lifetime cancer risk (ELCR), radium equivalent activity (Ra_{eq}), and the external hazard index (H_{ex}), were calculated for each soil sample. All the calculated radiological parameters were below the international recommended limit values. Therefore, no significant radiological hazards are posed to the human population living in the investigated areas. Hence, these areas are safe and can be used as dwelling areas and sources of the building material without giving any radiological hazard to the local population.

The data obtained in the present study as reference data for monitoring any changes in the radioactive background level in the studied area, caused by nuclear activities in the future. The results may also be useful to establish soil radioactivity mapping in Libya.

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