Measurement of Natural Radioactivity in the Soil of Kufa City-Iraq

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Abstract:

The natural radioactivity in soil has been determined by using gamma-ray spectroscopy technique. The (average) and (range) of specific activity (in Bq/kg units) of the primordial nuclides were (8.73) (1.82 to 24.71), (4.75) (1 to 9.44) and (103.05) (47.27 to 206.67) for ^{238}U, ^{232}Th and ^{40}K respectively. The value of Radium equivalent activity (in Bq/kg units) was found to be varied from 11.54 to 42.61 with an average of 23.47. The absorbed dose calculations (in nGy/h units) showed that the minimum value was 5.57 whereas the maximum value was 20.07 with an average of 11.28. The indoor and outdoor annual effective dose rate (in μSv/y units) and internal and external hazard indexes were calculated. A comparison with the world wide average indicated that the study area does not form dangerous from the radiological protection point view.

Key words: natural radioactivity , gamma-ray spectroscopy technique. Soil of Kufa City

الخلاصة:

تم تحديد النشاط الإشعاعي الطبيعي في التربة باستخدام تقنية مطيافية أشعة كاما. بينت النتائج بان معدل ومدى قيم النشاط الإشعاعي النوعي بوحدات (Bq/kg) هي (8.73) (1.82 – 24.71)، (4.75) (1 – 9.44)، (103.05) (47.27 – 206.67) لليورانيوم والثوريوم والبوتاسيوم على التوالي. قيم الفعالية المكافئة للراديوم أيضا بوحدات (Bq/kg) تراوحت من 11.54 إلى 42.61 وبمعدل 23.47. حسابات الجرعة الممتصة بوحدات (nGy/h) بينت بان القيمة الصغرى هي 5.57 في حين العظمى كانت 20.07 وبمعدل 11.28. كما تم قياس معدل الجرعة السنوية المؤثرة الخارجية والداخلية وكذالك معاملي الخطورة الخارجي والداخلي. قورنت النتائج مع المعدلات العالمية المسموح بها وبينت النتائج بان المنطقة المدروسة أمينة من وجهة نظر الحماية الإشعاعية.

الكلمات المفتاحية: النشاط الاشعاعي الطبيعي ، تقنية مطياف اشعة كاما ، تربة مدينة الكوفة

Introduction:

Radioactivity of soil environment is one of the major sources of exposure to human [1]. The ^{238}U, ^{232}Th series and ^{40}K radionuclide are the main source of natural radioactivity in soil [2]. Since these natural occurring radionuclide materials (NORMs) have very long half-lives (up to 10^{10} years), their presence in soils and rocks can simply be considered as permanent. Exposure of public to radiation from any sources is unlikely. It is known that even a small amount of radiation substance may produce a damaging biological effects and that ingested and inhaled radiation can be a serious health risk [3]. Based on these facts, one can certify that the knowledge of (NORMs), such as ^{238}U, ^{232}Th and ^{40}K, is an important pre-requisite for evaluation of the rate of exposure and absorbed dose by the population in order to estimate their radiological impacts and to establish a data base that can be used as a reference to radiation observer in the studied area [4]. The importance and originality of this work lies in the fact that the region has not been previously studied and for the first time has been investigated. Additionally, this area is dedicated by the "Investment Commission of Najaf Province" to be residential neighborhood. Therefore this study aims to evaluate the natural specific activity in soil and making a continuous monitoring of soil contamination in order to keep health and safety of people far from the radiations due to radioactivity of NORMs in soil.

Theoretical par:

Specific activity:

The specific activity were estimated from the 1765 keV gamma transition energy of ^{214}Bi, 2614 keV gamma transition energy of ^{208}TI and 1460 keV gamma transition energy for ^{238}U, ^{232}Th and ^{40}K respectively [5]. The specific activity is calculated by equation below.

$$A(Bq/kg) = C/(\xi\, I_\gamma\, t\, m) \quad \ldots 1$$

Where A is the specific activity of the radionuclide, C is the net area (background subtracted), ξ is the counting efficiency, I_γ is the percentage of gamma emission probability of the radionuclide under study, t is the counting time in second and m is the mass of the sample in kg [6].

Radium equivalent activity (Ra_{eq}):

A common radiological index has been introduced. This index is called radium equivalent activity and is mathematically defined by [7].

$$Ra_{eq}\,(Bq/kg) = A_U + 1.43A_{Th} + 0.077\,A_K \quad \ldots 2$$

Where A_U, A_{Th} and A_K are the specific activities of Uranium, Thorium and potassium respectively. This equation is based on the estimation that 10 Bq/kg of ^{238}U equal 7 Bq/kg of ^{232}Th and 130 Bq/kg of ^{40}K produces equal gamma dose[8].

Annual effective dose rate:

The annual effective dose rates were estimated using a conversion coefficient (0. 7 Sv/Gy) from absorbed dose in air to effective dose. Based on outdoor occupancy of 20% and 80% for indoor the annual effective dose was determined in units of (μSv/y) as following [9]. The annual indoor effective dose rate (IAEDR) is calculated from equation 3 whereas the outdoor (OAEDR) is calculated from equation 4.

$$IAEDR\,(\mu Sv/y) = AD(nGy/h) \times 8760h \times 0.8 \times 0.7 \times 10^{-3}\,Sv/Gy \quad \ldots 3$$

$$AOEDR\,(\mu Sv/y) = AD(nGy/h) \times 8760h \times 0.2 \times 0.7 \times 10^{-3}\,Sv/Gy \quad \ldots 4$$

Hazard indexes:

To reflect the external exposure, a widely used are the external (H_{ex}) and internal (H_{in}) hazard indexes which are defined as following [10].

$$H_{ex}=A_U/370+A_{Th}/259+A_k/4810 \quad \ldots 5$$

$$H_{in}=A_U/185+A_{Th}/259+A_k/4810 \quad \ldots 6$$

The value of each one must be less than the unity in order to keep the radiation hazard to be insignificant corresponds to the upper limit of radium equivalent activity (370 Bq/kg).

Experimental part:

The identification of radioisotopes present in soil such as ^{238}U, ^{232}Th and ^{40}K, has been measured by using an NaI(TI) detector of (3"x3") crystal dimensions supplied by (ORTIC) company. In order to reduce the background radiation due to different radiation hazard, the detector was maintained in vertical position and shielded by a cylindrical lead chamber of 10 cm thick. The spectrometer was calibrated for energy and counting efficiency by acquiring a spectra from radioactive standard sources of known energies like ^{22}Na, ^{60}Co, ^{57}Co and ^{137}Cs.

Area of Study:

The soil samples were collected in an area of 0.04 km^2 located in the Eastern of Najaf province, versus the technical institute of Kufa, on the road leading to the abbasia quarter. The latitude and longitude of this area are 32° 3° 2.97" N and 44° 25' 0.49" E. The area was systematically divided as square grids with dimensions of 200x200 meter as a distance between each two points as shown in Figure 1 .

Figure 1: Samples distribution of the studied area

Sample Collection and Preparation:

In order to measure the NORMs In soil surface, 56 soil samples were collected in systematically selection as matrix distribution. One sample average from each point, was taken by digging a hole at a depth of 10cm before the ground surface. The soil texture for all samples was very similar. The analysis of this soil revealed that the content range, sand is 78.4%, mud 8.9% and clay 12.7%. According to the total mixture, the soil regarded a heterogeneous sandy so that the influence of water and air are speedy [11]. A 1.4 ℓ polyethylene marinelli beaker was used as a sampling and measuring container. The soil samples were prepared for analysis by drying and kept moisture free by keeping them for 24 hours in the oven at 100C^0. Thy were mechanically crushed and sieved through 0.8mm pore size diameter sieve to get homogeneity. About 1kg of each sample was packed in a standard marinelli beaker that was hermetically sealed dry weighted, then each sample was placed in face to face geometry over the detector for a long time measurement.

Result and discussions:

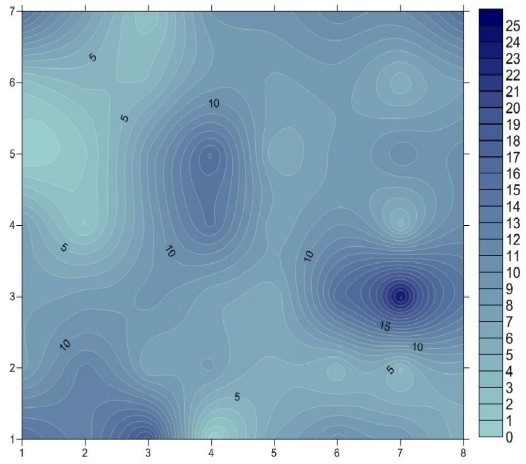
Specific activity of ^{238}U:

As shown in Table 1, the value ranged from 1.82 (in sample S42) to 24.71 (in sample S27) with an average value of 8.73 which equals approximately 0.25 of the worldwide average. The map and frequency distribution of specific activity was plotted in Figure 2-a,b respectively. It is clear that the statistical distribution is governed by Gaussian distribution. The odd that found in the Gaussian frequency distribution may be related to the misuse of fertilizers in cultural lands. All values are lower than the worldwide average which is 35 Bq/kg for ^{238}U as recommended in [7]. These results are due to the relativity low contents of ^{238}U in soil of studied area which is virgin where the sand-claying soil dominated. Finally from the radiation protection point of view the low ^{238}U contents in the investigated area does not form any risk to dwellers and public.

Table 1. Specific activity and radium equivalent activity (in Bq/kg).

Sample code	Specific activity			Ra_{eq})
	^{238}U	^{232}Th	^{40}K	
S11	15.24±0.95	5.00±0.53	89.70±7.37	29.29
S12	12.35±0.85	4.39±0.49	127.88±8.80	28.48
S13	19.71±1.08	4.33±0.49	101.82±7.86	33.74
S14	<LD	2.94±0.40	101.82±7.86	12.05
S15	7.12±0.65	2.28±0.36	121.82±8.59	19.75
S16	10.59±0.79	5.22±0.54	78.79±6.91	24.12
S17	9.12±0.73	2.72±0.39	113.33±8.29	21.74
S18	5.53±0.57	5.94±0.57	123.03±8.64	23.50
S21	7.65±0.67	7.83±0.66	151.52±9.58	30.52
S22	12.41±0.85	4.61±0.51	175.76±10.32	32.54
S23	7.06±0.64	7.22±0.63	122.42±8.61	26.81
S24	8.24±0.70	2.39±0.36	86.06±7.22	18.28
S25	5.82±0.59	4.33±0.49	106.67±8.04	20.23
S26	4.29±0.50	6.72±0.61	146.06±9.41	25.15
S27	3.76±0.47	2.50±0.37	54.55±5.75	11.54
S28	7.29±0.66	2.17±0.35	53.33±5.69	14.50
S31	7.76±0.68	1.00±0.24	91.52±7.45	16.24
S32	8.53±0.71	3.00±0.41	81.21±7.02	19.07
S33	9.41±0.74	2.22±0.35	80.61±6.99	18.80
S34	7.24±0.65	4.56±0.50	206.67±11.19	29.66
S35	6.24±0.61	2.44±0.37	121.82±8.59	19.11
S36	15.76±0.96	<LD	96.97±7.67	23.23
S37	24.71±1.21	6.78±0.61	106.67±8.04	42.61
S38	14.41±0.92	2.39±0.36	146.67±9.43	29.12
S41	7.71±0.67	6.83±0.62	120.00±8.53	26.72
S42	1.82±0.33	2.83±0.40	134.55±9.03	16.24
S43	8.41±0.70	6.11±0.58	116.97±8.42	26.16
S44	14.29±0.92	8.56±0.69	112.12±8.24	35.16
S45	7.29±0.66	9.44±0.72	<LD	20.80
S46	10.06±0.77	6.11±0.58	101.21±7.83	26.59
S47	4.35±0.51	3.17±0.42	75.15±6.75	14.67
S48	11.06±0.81	5.39±0.55	87.27±7.27	25.48
S51	<LD	1.89±0.32	127.88±8.80	12.55
S52	1.82±0.33	8.94±0.70	135.76±9.07	25.07
S53	9.12±0.73	7.50±0.65	112.12±8.24	28.48
S54	16.35±0.98	4.33±0.49	115.15±8.35	31.42

S55	6.06±0.60	4.67±0.51	113.94±8.31	21.51
S56	8.41±0.70	7.61±0.65	74.55±6.72	25.04
S57	11.00±0.80	3.33±0.43	122.42±8.61	25.19
S58	10.59±0.79	5.78±0.57	121.21±8.57	28.18
S61	2.47±0.38	9.39±0.72	61.21±6.09	20.61
S62	4.35±0.51	2.94±0.40	74.55±6.72	14.30
S63	4.12±0.49	2.83±0.40	47.27±5.35	11.81
S64	8.53±0.71	7.94±0.66	73.94±6.69	25.58
S65	7.71±0.67	6.11±0.58	121.21±8.57	25.78
S66	8.59±0.71	3.06±0.41	93.33±7.52	20.14
S67	5.12±0.55	4.50±0.50	113.33±8.29	20.28
S68	7.82±0.68	2.89±0.40	47.88±5.39	15.64
S71	14.76±0.93	5.72±0.56	108.48±8.11	31.30
S72	8.06±0.69	6.00±0.58	87.88±7.30	23.41
S73	1.94±0.34	2.28±0.36	121.82±8.59	14.58
S74	9.24±0.74	2.67±0.38	106.67±8.04	21.26
S75	9.41±0.74	7.22±0.63	75.15±6.75	25.53
S76	11.82±0.83	2.6±0.38	100.00±7.78	23.26
S77	10.94±0.80	8.94±0.70	83.03±7.09	30.13
S78	15.59±0.96	5.61±0.56	98.18±7.71	31.17
Minimum	1.28	1.00	47.27	11.54
Maximum	24.71	9.44	206.67	42.61
Average	8.37	4.75	103.05	23.47



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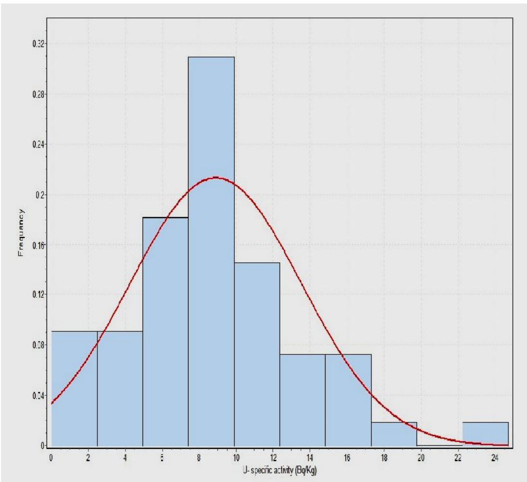
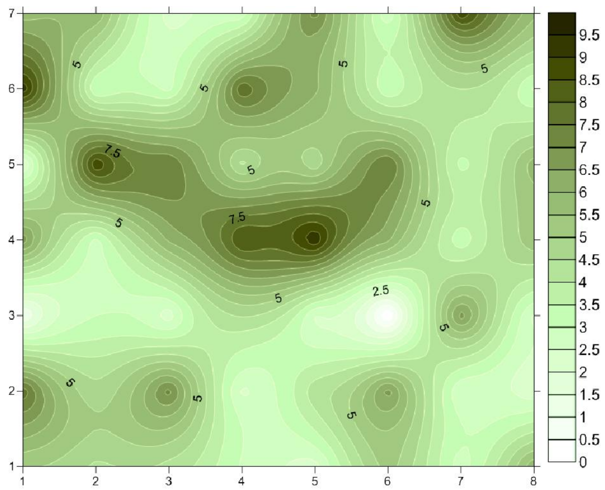


b

Figure 2-a, b: Map and frequency distribution of ^{238}U specific activity

Specific activity of ^{232}Th (in Bq/kg):

The results obtained of specific activity for ^{232}Th radionuclide in the soil samples are presented in Table 1. It can be seen that the value varied from 1.00 (in sample S31) to 9.44 (in sample S45) with an average value of 4.75. Figure 2-a,b represents the map and frequency distribution of specific activity of ^{232}Th radionuclide respectively. Figure 3-a shows that the specific activity is subject to the normal distribution and showed an odd in a few number of soil samples under study but in general this distribution refers to the homogenous mixture of the soil. Our results showed that the average value of specific activity of ^{232}Th is slightly less than half of those belonging to the ^{238}U which can be related to the ability of Uranium to be dissolved efficiently more than Thorium, hence faced treatment and processing as dragged from the mountains to the Euphrates river and subsequently sediment in soil of the middle and south of Iraq. To estimate the risk of radiation due to contents of ^{232}Th in soil samples, a comparison with the worldwide average recommended by [7] which is 30 Bq/kg, has been done and indicated that all values are less than it. The odd that found in the frequency distribution may be related to the usage of fertilizers in cultural lands. This causes the elevation of the levels of ^{232}Th and accordingly with the type of used fertilizer.



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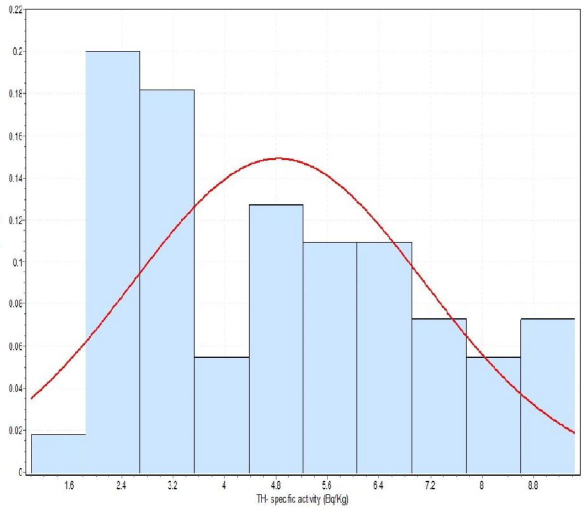

b

Figure 3-a, b : Map and frequency distribution of ^{232}Th specific activity.

Specific activity of ^{40}K (in Bq/kg):

The results for the specific activity of ^{40}K radionuclide together with their average values in 56 soil samples were detected and reported in Table 1. The values were found to be in a range from 47.27 (in sample S63) to 206.67 (in sample S34) with an average value of 103.05. The obtained values are lower than the worldwide average which is of 370 Bq/kg reported by [12]. Figure 4-a,b shows the map and frequency distribution of specific activity of ^{40}K respectively. It may be concluded that all values are in the range of the permissible limit. The maximum value of specific activity for the ^{40}K radionuclide can be explained in term that, this sample is located in the agricultural field of the studied area. Thus the high usage of chemical fertilizers is the major cause of this augmentation.

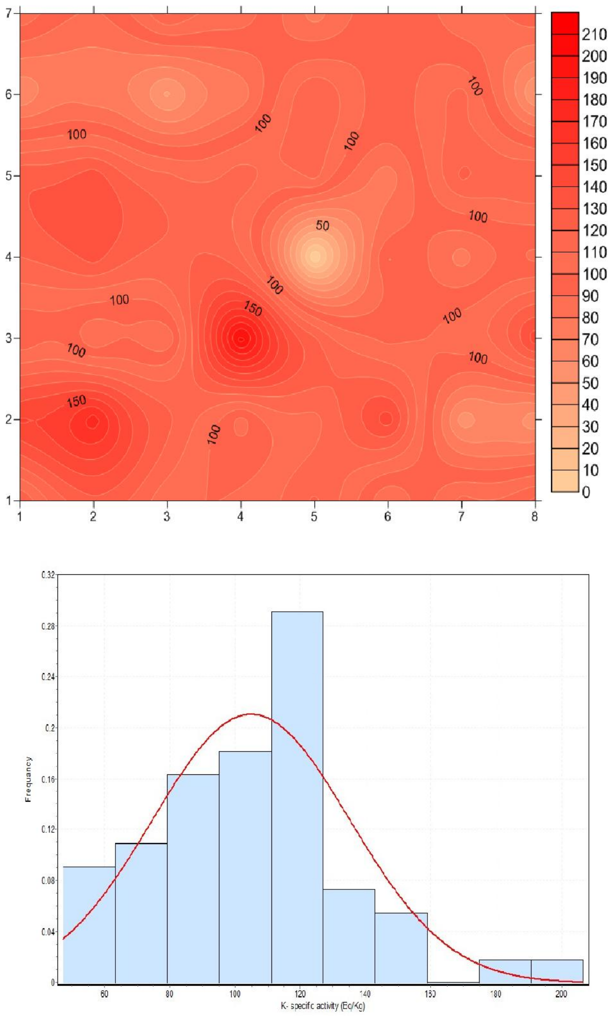

Figure 4 Map and frequency distribution of ^{40}K specific activity.

Radium equivalent activity (Ra_{eq}) (in Bq/kg):

The radium equivalent activity has been calculated by using equation (2). The results obtained are listed in Table 1 and mapped in Figure 5. This factor is ranged from 11.54 (in sample S27) to 42.61 (in sample S37) with an average of 23.47. All value are less than the world wide average which is 370 Bq/kg [7].

b

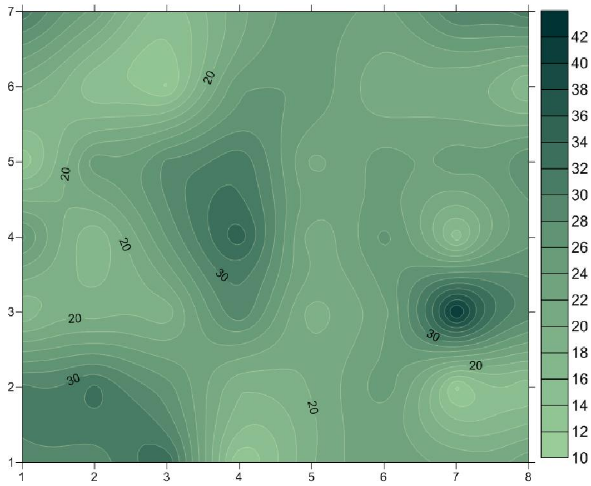

Figure 5: Map of Radium equivalent activity distribution.

Absorbed dose rate (AD) (in nGy/h):

The absorbed dose rate in (nGy/h) in air one meter above the ground was calculated using equation (2). The values were listed in Table 2 and illustrated in Figure 6. As shown in Table 2 the value is ranged from 5.57 (in sample S27) to 20.07 (in sample S37) with an average value of 11.54 which is small in comparison with the daily absorbed dose rate of world average (55 nGy/h) as reported in UNSCEAR[7].

Table 2: Absorbed dose rate, annual effective dose rate and hazard index.

Sample code	Absorbed Dose (nGy/h)	Annual effective dose (μSv/y)		Hazard index	
		indoor	outdoor	H_{ex}	H_{in}
S11	13.88	68.11	17.03	0.08	0.12
S12	13.77	67.53	16.88	0.08	0.11
S13	16.04	78.69	19.67	0.09	0.14

S14	6.07	29.80	7.45	0.03	0.03
S15	9.78	47.99	12.00	0.05	0.07
S16	11.42	56.02	14.01	0.07	0.09
S17	10.63	52.14	13.04	0.06	0.08
S18	11.38	55.81	13.95	0.06	0.08
S21	14.72	72.19	18.05	0.08	0.10
S22	15.93	78.13	19.53	0.09	0.12
S23	12.85	63.04	15.76	0.07	0.09
S24	8.88	43.55	10.89	0.05	0.07
S25	9.83	48.22	12.05	0.05	0.07
S26	12.25	60.09	15.02	0.07	0.08
S27	5.57	27.31	6.83	0.03	0.04
S28	6.94	34.04	8.51	0.04	0.06
S31	8.02	39.36	9.84	0.04	0.06
S32	9.19	45.08	11.27	0.05	0.07
S33	9.09	44.59	11.15	0.05	0.08
S34	14.79	72.55	18.14	0.08	0.10
S35	9.48	46.50	11.62	0.05	0.07
S36	11.33	55.57	13.89	0.06	0.11
S37	20.07	98.46	24.62	0.12	0.18
S38	14.26	69.94	17.49	0.08	0.12
S41	12.81	62.83	15.71	0.07	0.09
S42	8.21	40.29	10.07	0.04	0.05
S43	12.56	61.61	15.40	0.07	0.09
S44	16.59	81.40	20.35	0.09	0.13
S45	9.23	45.30	11.33	0.06	0.08
S46	12.66	62.12	15.53	0.07	0.10
S47	7.11	34.89	8.72	0.04	0.05
S48	12.09	59.33	14.83	0.07	0.10
S51	6.51	31.91	7.98	0.03	0.03
S52	12.06	59.15	14.79	0.07	0.07
S53	13.55	66.45	16.61	0.08	0.10
S54	15.05	73.82	18.45	0.08	0.13
S55	10.45	51.26	12.81	0.06	0.07
S56	11.72	57.50	14.37	0.07	0.09
S57	12.26	60.13	15.03	0.07	0.10
S58	13.53	66.39	16.60	0.08	0.10
S61	9.52	46.72	11.68	0.06	0.06
S62	6.95	34.08	8.52	0.04	0.05
S63	5.63	27.63	6.91	0.03	0.04
S64	11.96	58.66	14.66	0.07	0.09
S65	12.41	60.88	15.22	0.07	0.09
S66	9.76	47.87	11.97	0.05	0.08
S67	9.88	48.49	12.12	0.05	0.07
S68	7.41	36.33	9.08	0.04	0.06
S71	14.90	73.09	18.27	0.08	0.12
S72	11.11	54.52	13.63	0.06	0.08
S73	7.39	36.26	9.06	0.04	0.04

S74	10.37	50.87	12.72	0.06	0.08
S75	11.97	58.71	14.68	0.07	0.09
S76	11.25	55.21	13.80	0.06	0.09
S77	14.07	69.03	17.26	0.08	0.11
S78	14.78	72.51	18.13	0.08	0.13
Average	11.28	55.36	13.48	0.06	0.09
Minimum	5.57	27.31	6.83	0.03	0.03
Maximum	20.07	98.46	24.62	0.12	0.18

Indoor and out door annual effective dose rate (in mSv/y):

They were calculated by applying equations 3 and 4. The results were listed in Table 2. The (average) and (range) values are (55.36) (27.31 to 98.64) and (13.48)(6.83 to 24.62) for indoor and out door annual effective dose rate respectively. The minimum of these two operators are noted in S27 whereas their maximum values are recorded in S37. According to the radiation protection report [13], soil of the study area is safe and has not any significant radiological risk to the population. In addition, the International Commission on Radiological Protection (ICRP) has recommended that the annual effective dose equivalent limit of 1 mSv/y for the individual members of the public and 20 mSv/y for the radiation workers [14]. These doses limits have been established on the utilization pattern approach by assuming that there is no threshold dose below which there would be no effect. The world wide average of annual effective dose is approximately 0.5mSv and the results for individual countries being generally within the 0.3 - 0.6 mSv range [15].

External and Internal Hazard Indexes (H_{ex} and H_{in}):

The values of external and internal indexes were calculated by applying equations 5 and 6 and tabulated inTable2. The (average) and range of hazard indexes are 0.06(0.03 to 0.12) and 0.09(0.03-0.18) for external and internal indexes respectively. The maximum values of these two factors were recorded in sample S14 whereas the minimum values were found in sample S37. Obviously, all values of these operators for all samples studied in this area are less than unity which is the maximum value of the permissible safety limit recommended by UNSCEAR [7]. To give a global view, Figure 7 represents a comparison between the values obtained for the different radiological factors and the recommended permissible limits for each one. As shown in Figure 7 all measured values are less than the international permissible limits. Table 3 shows a comparison of our results with those conducted in other countries. Generally, as shown from this Table the results obtained in this work are near or around other results.

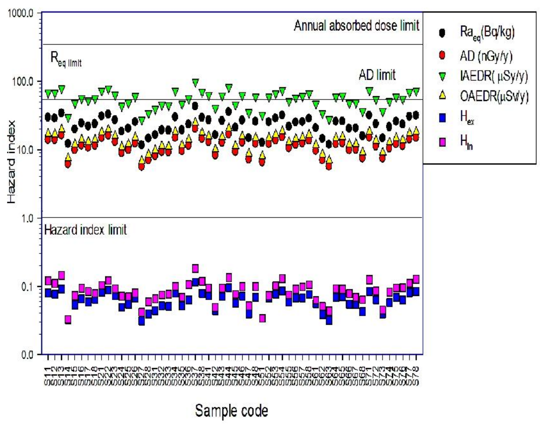

Figure 7 : A comparison of radiological operates with the permissible limits.

Table 4: Comparison of our results with other international studies.

Country	^{238}U Bq/kg	^{232}Th Bq/kg	^{40}K Bq/kg	Ra_{eq} Bq/kg	Reference
Taiwan	30.00	44.00	431.00	123.09	[16]
Japan	-	54.00	794.00	-	[17]
Ireland	-	30.00-60.00	400.00-800.00	-	[18]
France	38.00	38.00	599.00	134.27	[19]
Spain	46.00	49.00	650.00	161.57	[20]
Egypt	17.00	19.00	316.00	66.29	[21]
Syria	22.20	18.40	247.00	65.80	[22]
Mediterranean Sea	5.00	2.10	46.00	11.22	[23]
Greece	25.00	21.10	355.00	80.02	[24]
Rio Grands ,Brazil	29.20	47.80	704.00	146.83	[25]
Sudan	28.31	20.12	280.29	76.70	[26]
Turkey (Istanbul)	21.00	31.00	342.00	89.27	[27]
Costa Rica	10.00	8.00	175.00	33.69	[28]
South India	35.00	29.80	117.50	85.84	[29]
Viti leveu Fiji	3.60	2.80	160.00	18.80	[30]
Kuwait	36.00	6.00	227.00	60.47	[31]
Oman	29.70	16.00	225.00	68.33	[32]
Norway	43.30	21.20	283.00	93.43	[33]
Cyprus	7.10	5.00	104.60	21.57	[34]
China	33.00	41.00	440.00	122.43	[12]
Hong Kong	84.00	95.00	530.00	256.95	[12]
Kazakhstan	37.00	60.00	300.00	143.80	[12]
Vietnam	19.60	31.00	34.60	66.35	[35]
Southern west Cameroon	14.00	30.00	103.00	64.11	[36]
Saudi	14.50	11.20	225.00	46.27	[37]
North west Libya	7.50	4.20	24.50	15.22	[38]
Indonesia	13.00	15.00	43.00	37.46	[39]
Beach sand of Egypt	-	177.00	815.00	-	[40]
Beach sand of Egypt red sea	23.10	7.20	338.00	57.06	[41]
Hungary	28.67	27.96	302.40	89.82	[6]
Nigeria	16.00	24.00	35.00	52.77	[42]
North coast of India	7.82	24.52	274.87	62.12	[43]
Nigeria, Abeokuta	13.93	18.67	866.00	101.25	[44]
Iraq- Kufa	8.37	4.75	103.05	23.47	Present work

Conclusions:

The above results of the specific activities is usually based on the evaluation of radionuclide distributions in the soil of the three primordial ratio nuclide ^{238}U ^{232}Th and ^{40}K. The distribution are strongly influenced by the geology of the site and other modifying factors in the environment such as soil utilization pattern, climate conditions, application of fertilizers. A comparison of our results with permissible limits indicated that the study area does not form dangerous from the radiological protection point view.

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