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MEASUREMENT OF RADON-222 CONCENTRATIONS IN SELECTED SOIL SAMPLES IN AL-MOTHAFEEN AREA (KERBALA, IRAQ) BY USING THE CN-85 DETECTOR

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Abstract. In this work, alpha emitters in the twenty soil samples in Al-Mothafeen sites were measured using the CN-85 detectors. The results show that the average values of radon concentration in the air space of the tube and in the sample were 163.15±3.37 Bq/m^3 and 5090.54±155.3 Bq/m^3, respectively, while the results of annual effective dose were varied from 10.2±0.3 mSv/y to 2.1±0.1 mSv/y with a mean value of 4.1±0.2 mSv/y, radium content were varied from 0.3±0.06 Bq/kg^{-1} to 0.06 ± 0.02 Bq/kg with a mean value of 0.12±0.03 Bq/kg, and uranium contractions were varied from 9.29±0.33 Bq/kg to 1.90±0.15 Bq/kg with an average of 3.72±0.21 Bq/kg. Also, the average values of mass and surface exhalation rates were 0.95±8.64 mBq/kg.h and 44.59±0.79 mBq/m^2.h, respectively. The results were within the normal limits of radiation, according to the International Commission on Radiological Protection (ICRP).

Keywords: alpha emitters, ^{222}Rn, ^{226}Ra, ^{238}U, annual effective dose, soil, CN-85, Kerbala University

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INTRODUCTION

Environmental pollution means the presence of materials in the air in such concentration, which are harmful to man. The various environment sources of pollution, such as radioactive substances, which are released by nuclear explosions and explosives are extremely harmful to health (Abojassim *et al*. 2021). The sources of radioactivity in the environment permanently include natural or made-man sources. The natural sources include cosmic rays (atom fragments from the sun, planets and stars that rain down on the earth and interact with the earth's atmosphere and produce different isotopes), environment (terrestrial sources, e.g. rocks, air, and water) and living organisms (internal sources) (Almayahi *et al*. 2016). Made-man sources are produced by the bombing of the nuclei of stable isotopes of different types of nuclear particles (Merkel and Hasche-Berger 2006). Radionuclides have been present in the earth's crust since the formation of earth and remain radioactive until now. They decay automatically without exposure to any external effect. They are either single or in the form of chains (Abojassim *et al*. 2021). The chains are a group of radioactive elements formed as a result of the sequential series of radiological decay starting the daughter nucleus and the end of the stable nucleus (daughter nucleus). The determination of radionuclides in soil samples is a crucial task in relation to the protection of human health. Therefore, several techniques appeared to calculate the concentrations of radioactive materials in the soil samples and to examine the impact of these materials on living organisms (Abdulwahid *et al*. 2020). The background radiation (alpha, beta, and gamma) can be detected by detectors of nuclear radiations. These include, *inter alia*, Geiger counter, gamma ray spectrometry, X-ray fluorescence, neutron activation analysis, solid state nuclear track detectors (Abojassim *et al*. 2021). There are many unstable nuclei that undergo transformations accompanied by the emission of alpha energetic, called alpha particle (^{4}He), that can be emitted from the parent atom and product nucleus which contains less nucleons than a parent in two protons and two neutrons. Alpha particles are one type of ionizing radiation, which is the least penetrating of the radiations emitted from an unstable heavy metal. These particles are more harmful to living tissues than other types of ionizing radiation because of the more massive and highly charged particles. Alpha particles are emitted from radioactive sources. There are three natural radioactive series called "uranium", "thorium", and "actinium". All three series contain alpha emitters. Many researchers have studied the emission of radionuclides (alpha emitters) in soil samples by using the plastic nuclear track detector in some Iraqi areas (El-Araby *et al*. 2021, Bem *et al*. 2021, Abojassim *et al*. 2017, Abojassim 2018, Al-Gharabi and Al-Hamzawi 2020). The aim of this study was to measure the annual effective dose due to radon and radioactivity for radium and uranium of soil samples in Al-Mothafeen sites. This is done by measuring the concentration

of radon in the soil samples. Finally, the map of ^{222}Rn, ^{226}Ra, and ^{238}U concentrations in the study area, using the GIS technique, was drawn as a reference to be used in future studies.

STUDY AREA

Kerbala University is situated in the city of Kerbala, in Al-Mothafeen sites of Kerbala governorate; it lies between 44°00'E longitude and 32°36'N latitude (Ibrahim *et al*. 2021a). It consists of six colleges – College of Medicine, Applied Medical Sciences, Dentistry, Pharmacy, Nursing, and Physical Education. The soil was of a sandy type: It contains small particles of rocks and minerals, and usually, the composition and structure of that soil is composed of sand consisting of rocks broken down by erosion factors, as it contains either a high or low percentage of organic matter and includes sand formation to more than 35% and less than 15% of clay and silt. It has a high rough texture and it should be noted that the percentage of sand, clay, and silt is determined after the disposal of organic matter in the soil. The soil under study is dry and suffers from a lack of nutrients, it dries quickly, and it has a light texture, which leads to its rapid drainage and low ability to save water, which leads to lower fertility rates in the soil. However, with the addition of fertilizers and rotting leaves, it can provide a satisfactory growth process for the plant.

MATERIALS AND METHODS

Twenty soil samples were collected from different locations of the University of Kerbala in the Al-Mothafeen site. The sample sites were determined by GPS which is shown in Table 1 and Figure 1 and the sealed can technique was utilized to measure the alpha radioactivity in this study. Twenty soil samples were taken at a depth of 15 cm from the ground surface of each site. The soil samples were dried at 120°C for 3 hours in an oven to ensure complete moisture removal. All samples were crushed to a fine powder form, and then they were crushed. To eliminate the larger grains and make them more homogeneous, they were then sieved through a small mesh. Dried samples (92 g) were placed at the bottom of a cylindrical sealed can of 7 cm height and 5 cm in diameter following the sealed cup technique. Solid-state nuclear track detector (SSNTD) with sheet thickness of 12 μm, which is usually known as a CN-85 plastic detector, was used in this study. A piece of a 1 × 1 cm detector was fixed on the top of the inner surface of the can in such a way that it is a sensitive surface that always faces the soil sample. The can was sealed airtight with adhesive tape and exposed for about 172 days (from 23 December 2019 to 6 July 2020). During

the exposure period, the sensitive side of the detector always faced the sample and was exposed freely to the emergent radon from the water sample in the can, so that it could record alpha particles resulting from the decay of radon in the remaining volume of the can (Ibrahim *et al*. 2021b). Radon and its daughters reached equilibrium in about four weeks and hence the equilibrium activity of emergent radon could be obtained from the geometry of the can and time of the exposure (Al-Kharouf *et al*. 2008). The detectors were collected and chemically etched using (2.5N) NaOH at 70°C for 3 h after exposure (Ibrahim *et al*. 2021b). These SSNTDs were dried and scanned after this chemical procedure, using an optical microscope (A.KRÜSS-opsonic) at 400x magnification to count the number of tracks per cm^2 in each detector.

Table 1. Locations of the soil samples collected from different sites of Kerbala University

No.	Location name	Sample code	Coordinates
1	College of Physical Education	U81	32°36'31.36"N, 44°00'05.58"E
2		U82	32°36'32.95"N, 44°00'06.04"E
3	College of Pharmacy	U83	32°36'33.25"N, 44°00'07.16"E
4		U84	32°36'33.85"N, 44°00'15.42"E
5	College of Engineering	U85	32°36'31.16"N, 44°00'03.9"E
6		U86	32°36'29.25"N, 44°00'04.75"E
7		U87	32°36'29.94"N, 44°00'04.7"E
8		U88	32°36'27.51"N, 44°00"30.57"E
9	College of Applied Sciences	U89	32°36'33.65"N, 44°00'08.93"E
10		U90	32°36'35.63"N, 44°00'09.28"E
11		U91	32°36'35.63"N, 44°00'09.28"E
12	College of Nursing	U92	32°36'33.43"N, 44°00'12.83"E
13	College of Dentistry	U93	32°36'33.43"N, 44°00'11.94"E
14		U94	32°36'32.69"N, 44°0010.35"E
15		U95	32°36'37.23"N, 44°00'10.3"E
16	College of Medicine	U96	32°36'35.2"N, 44°00'15.33"E
17		U97	32°36'35.07"N, 44°00'14.87"E
18		U98	32°36'36.83"N, 44°00'13.39"E
19	Gate of Campus	U99	32°36'34.68"N, 44°00'15.17"E
20		U100	32°36'33.67"N, 44°00'15.1"E

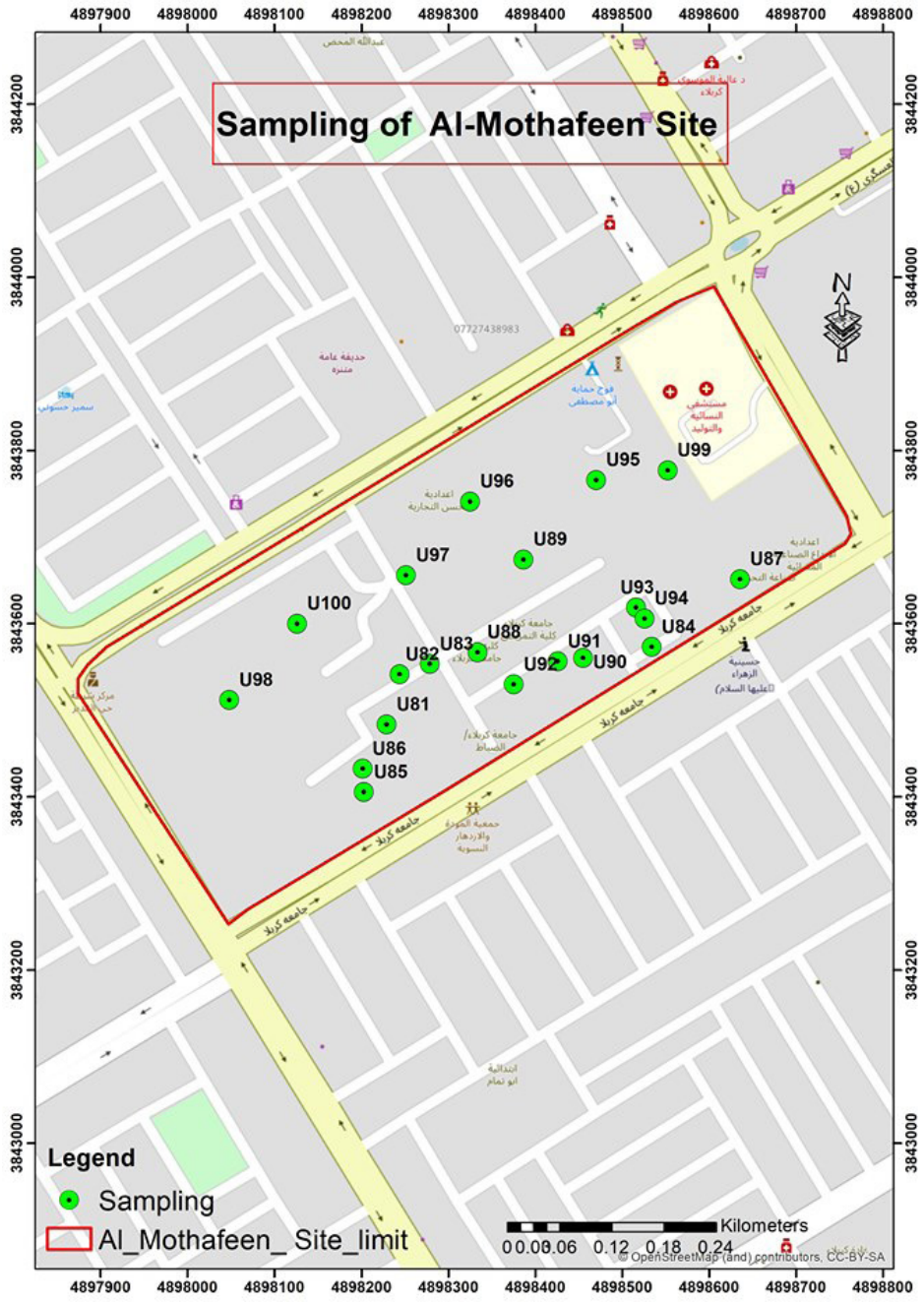

Fig. 1. Location of samples in the Al-Mothafeen-site (Kerbala University)

THEORATICAL EQUATIONS

The radon concentration in the airspace of the tube (C) was calculated using the following equation (Ibrahim *et al*. 2021b):

$$C\left(\frac{Bq}{m^3}\right) = \frac{\rho}{K\,t} \tag{1}$$

where ρ is the number of track in the standard sample, t is the exposure time measured in days (172d), and K was a calibration factor of CN-85 plastic track detector (which was 0.256 track.cm^{-2}/Bq.m^{-3}.d) (Hashim and Nayif 2019).

The concentration in sample C_{Rn} was calculated using the following equation (Ibrahim *et al*. 2021b).

$$C_{R_n}\left(\frac{Bq}{m^3}\right) = C\left(\frac{\lambda h t}{L}\right) \tag{2}$$

where C_{Rn} is concentration radon gas in sample (Bq/m^3), λ – the radon constant decays which equals to 0.1814 days^{-1}, h – thickness of the sample (3.5 cm), and L – distance between sample to detector (3.5 cm).

In this work, an effective radiation balance (about 98%) between radium and radon had to be reached within 4 weeks in the decay series given that the half-life of radium and radon. Once the auditory balance was reached, alpha-radon decomposition can be used to determine the concentration of radium activity. Using the following equation, radon concentration increases over time, after closing of the can (Khan *et al*. 2012).

$$C_{Rn} = C_{Ra}(1-e^{-\lambda_{Rn}T}) \tag{3}$$

The annual effective dose (AED) in terms of (mSv/y) units was obtained using the following relation (Ibrahim *et al*. 2021b):

$$\text{AED (m Sv/y)} = C \times F \times H \times T \times D \tag{4}$$

where F was the equilibrium factor (0.4), T is the time in hours in a year T = 8,760 h/y, H is the occupancy factor which is equal to (0.8), and D is the dose conversion factor that is equal to [9 × 10^{-6} (m Sv)/(Bq.h.m^{-3})].

The radium content of the soil samples can be calculated by the relation (Khan *et al*. 2012):

$$C_{Ra}(Bq.\text{kg}^{-1}) = \left(\frac{\rho}{KT_{eff}}\right)\left(\frac{hA}{M}\right) \tag{5}$$

where C_{Ra} was the effective radium content of soil (Bq/kg), M was the mass of soil sample, A was the area of cross section of the cylindrical can, h was the distance between the detector and top of the solid samples and T_{eff} was the time of actual exposure.

The real exposure time T and the constant of decay λ_{Rn} for ^{222}Rn was calculated using the following equation (Abojassim 2018).

$$T_{eff} = [\, T - \lambda_{Rn}^{-1} \ (1 - e^{-\lambda_{Rn} T})] \tag{6}$$

Further, the mass exhalation rate (E_M) of the soil samples for the release of radon gas was calculated using the equation (Khan *et al*. 2011):

$$E_M = \frac{CV\lambda}{MT_{eff}} \tag{7}$$

The surface exhalation rate of (E_A) the soil samples for the release of radon gas was calculated as follows (Khan *et al*. 2011):

$$E_A = \frac{CV\lambda}{AT_{eff}} \tag{8}$$

The concentration of uranium C_U of the soil samples was calculated using the following formula (Khan *et al*. 2011):

$$C_U(ppm) = \frac{W_U}{W_S} \tag{9}$$

where W_U is the weight of uranium in the soil sample, and W_S is the weight of soil sample and uranium concentration unit in relation to the activity unit in Bq.kg^{-1} of ^{238}U (Ibrahim *et al*. 2021b).

$$1 \text{ ppm of Uranium} = 12.35 \text{ Bq.kg}^{-1} \tag{10}$$

RESULTS AND DISCUSSIONS

The results of radon concentration and annual effective dose in soil samples are presented in Table 2. The radon gas concentration was found from (406.97±2.24) Bq/m^3 in U94 to (83.57±1.01) Bq/m^3 in U98 with a mean value of (163.15±3.37). The results of radon concentration in soil was found from (12698±12.52) Bq/m^3 in U94 to (2607.62±5.67) Bq/m^3 in U98 with a mean value of (5090.54±155.31). Figure 2 shows the geographical distribution of C_{Rn} for the present study that was drawn using the GIS technique. The radon concentrations were classified into six ranges of color, where different colors were used to differ-

entiate between high, medium, and low concentrations. Also, the annual effective dose varies from the highest value (10.26±0.35) mSv/y in U94 to the lowest value (2.10±0.16) mSv/y in U98 with a mean value of (4.11±0.22) mSv/y. Based on the measurement results in the studied area, the soil radon concentration is lower than the accordable limit, which usually ranges from 0.4 to 40 kBq/m^3 (Buttafuoco *et al*. 2007). The latter indices values are found to be slightly smaller than the levels of 3–10 mSv/y recommended by the ICRP (1993). The values of radium content in terms of mass and radon exhalation rates in terms of area as well as the uranium concentration in the sample are presented in Table 3. The radium activity varies from the highest value (0.31±0.06) Bq/kg in U94 to the lowest value (0.06±0.02) Bq/kg in U98 with a mean value of (0.125±0.03). The geographical distribution of C_{Ra} at the Al-Mothafeen site is shown in Figure 3. Different ranges of concentration were used to differentiate between high, medium, and low concentrations using the GIS technique. The values of radon exhalation rate at mass varied from (2.37±0.17) mBq/kg.h in U94 to (0.48±0.07) mBq/kg.h in U98 with an average of (0.95±8.64) mBq/kg.h. Similarly, the values of radon exhalation rate at surfaces varied from (111.22±1.17) mBq.m^2.h in U94 to (22.84±0.53) mBq/m^2.h in U98 with an average of (44.59±0.79) mBq/m^2.h. The values of radium content in samples were less than the level of permissible limit of 370 Bq·kg^{-1} which was recommended by the OECD (1979). The values of radon exhalation rate in terms of mass and radon exhalation rate in terms of area was much less than the world average of 57.6 Bq/m^{-2}.h (UNSCEAR 1996). Uranium concentration varies from the highest value (9.29±0.33) in U94 to the lowest value (1.90±0.15) in U98 with a mean value of (3.72±0.21). The specific activities of ^{238}U uranium in soil samples are less than the allowed limit (33) Bq/kg from UNSCEAR (2000). Figure 4 shows the geographical distribution of C_U at the Al-Mothafeen site. The concentrations of radon were classified into six ranges, where different colors were used to differentiate between high, medium, and low concentrations.

Table 2. Radon concentration (C), radon concentration in soil sample (C_{Rn}), and annual effective dose (AED), for the soil samples under study

Sample	C Bq/m^3	C_{Rn}Bq/m^3	AED mSv/y
U81	119.91±1.21	3741.37±6.79	3.02±0.19
U82	109.01±1.16	3401.25±6.48	2.75±0.18
U83	138.08±1.30	4308.25±7.29	3.48±0.20
U84	116.27±1.19	3628±6.69	2.93±0.19
U85	257.99±1.78	8049.62±9.96	6.50±0.28
U86	163.51±1.42	5101.87±7.93	4.12±0.22
U87	163.51±1.42	5101.87±7.93	4.12±0.22
U88	116.27±1.19	3628±6.69	2.93±0.19
U89	163.51±1.42	5101.87±7.93	4.12±0.22

Sample	C Bq/m^3	C_{Rn}Bq/m^3	AED mSv/y
U90	174.41±1.46	5442±8.19	4.40±0.23
U91	236.19±1.70	7369.37±9.53	5.95±0.27
U92	207.12±1.59	6462.37±8.93	5.22±0.25
U93	214.39±1.62	6689.12±9.08	5.40±0.25
U94	406.97±2.24	12698±12.52	10.26±0.35
U95	87.20±1.03	2721±5.796	2.20±0.16
U96	101.74±1.12	3174.50±6.26	2.56±0.17
U97	130.81±1.27	4081.50±7.09	3.30±0.20
U98	83.57±1.01	2607.62±5.67	2.10±0.16
U99	145.34±1.34	4535±7.48	3.66±0.21
U100	127.18±1.25	3968.12±6.99	3.20±0.19
Max.	406.97 ±2.24	12698±12.52	10.26±0.35
Min.	83.57±1.01	2607.62±5.67	2.10±0.16
Average±S.D	163.15±3.37	5090.54±155.3	4.11±0.22

Table 3. Radium activity (C_{Ra}), mass (E_M) and surface (E_S) exhalation rates, uranium concentration (C_U) for the soil samples under study

Sample	C_{Ra} Bq/kg	E_M mBq/kg.h	E_S mBq/m^2.h	C_U Bq/kg
U81	0.093±0.03	0.69±0.09	32.77±0.63	2.73±0.18
U82	0.084±0.03	0.63±0.08	29.79±0.60	2.48±0.17
U83	0.107±0.03	0.80±0.10	37.73±0.68	3.15±0.19
U84	0.090±0.03	0.67±0.09	31.77±0.62	2.65±0.18
U85	0.199±0.05	1.50±0.13	70.51±0.93	5.88±0.27
U86	0.126±0.03	0.95±0.10	44.68±0.74	3.73±0.21
U87	0.126±0.03	0.95±0.10	44.68±0.74	3.73±0.21
U88	0.090±0.03	0.67±0.09	31.77±0.62	2.65±0.18
U89	0.126±0.03	0.95±0.10	44.68±0.74	3.73±0.21
U90	0.135±0.04	1.01±0.11	47.66±0.76	3.98±0.22
U91	0.182±0.04	1.37±0.13	64.55±0.89	5.39±0.25
U92	0.160±0.04	1.20±0.12	56.60±0.83	4.72±0.24
U93	0.165±0.04	1.25±0.12	58.59±0.85	4.89±0.24
U94	0.314±0.06	2.37±0.17	111.2±1.17	9.29±0.33
U95	0.067±0.02	0.50±0.07	23.83±0.54	1.99±0.15
U96	0.079±0.03	0.59±0.08	27.80±0.58	2.32±0.16
U97	0.101±0.03	0.76±0.09	35.7±2.66	2.98±0.19
U98	0.064±0.02	0.48±0.07	22.84±0.53	1.9±0.15
U99	0.112±0.03	0.84±0.10	39.72±0.70	3.31±0.20
U100	0.098±0.03	0.74±0.09	34.75±0.65	2.90±0.18
Max.	0.31±0.06	2.37±0.17	111.22±1.17	9.29±0.33
Min.	0.06±0.02	0.48±0.07	22.84±0.53	1.90±0.15
Average±S.D	0.125±0.03	0.95±8.64	44.59±0.79	3.72±0.21

The present study showed that the average of all values of alpha radioactivity in soil samples collected from the University of Kerbala site are lower than the one found in Pakistan (Rafique *et al*. 2011), Lebanon (Hashim *et al*. 2016),

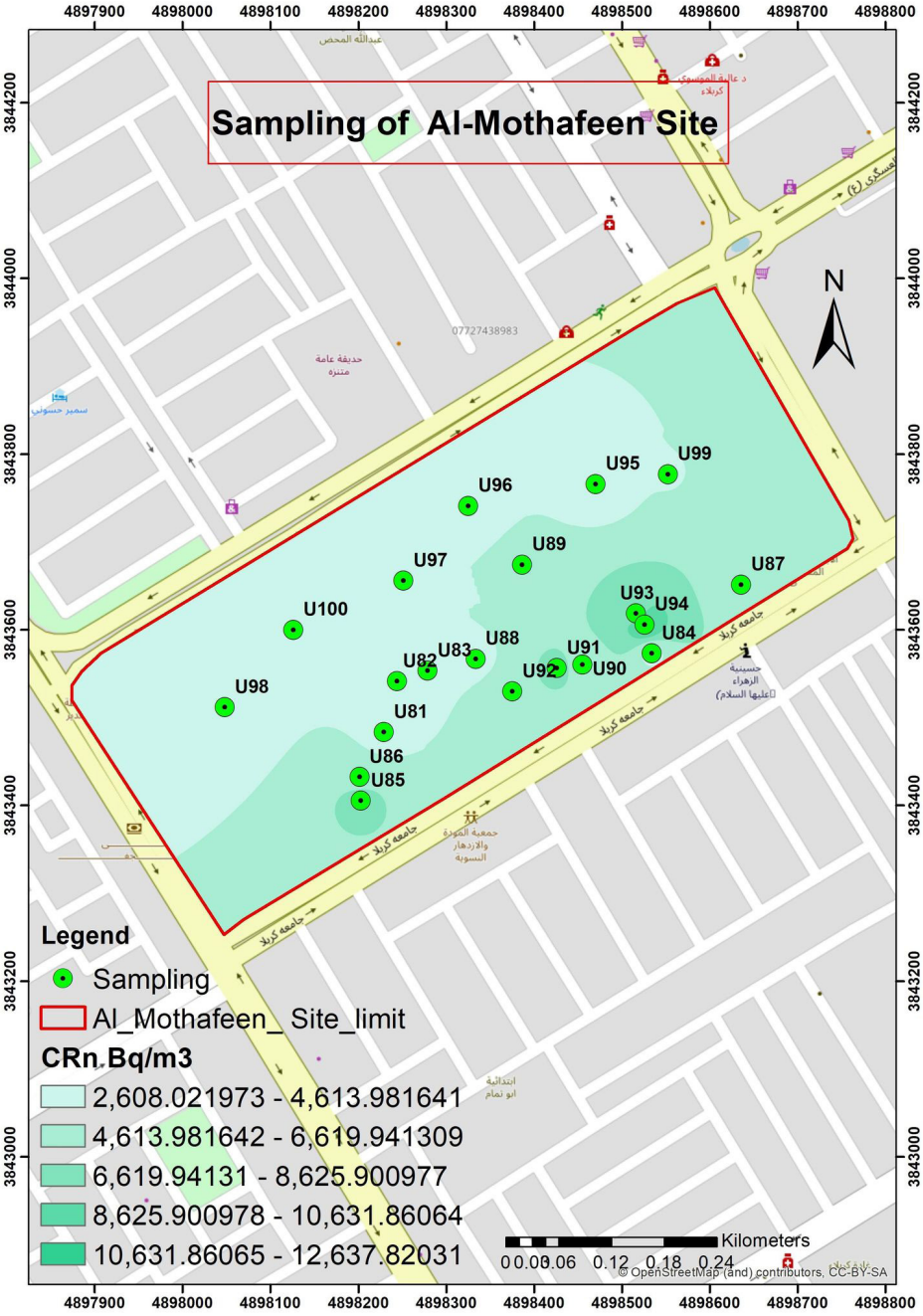

Fig. 2. The choropleth map of the values of C_{Rn} for different soil samples

Turkey (Tabar *et al*. 2013), Bulgaria (Kunovska *et al*. 2013), India (Kakati *et al*. 2013), Saudi Arabia (Farid 2016), Egypt (Korany *et al*. 2013), Sudan (Abd-El-moniem *et al*. 2014), Iraq (Al-Najaf) (Abojassim 2018), Iraq (Tikreet) (Moham-

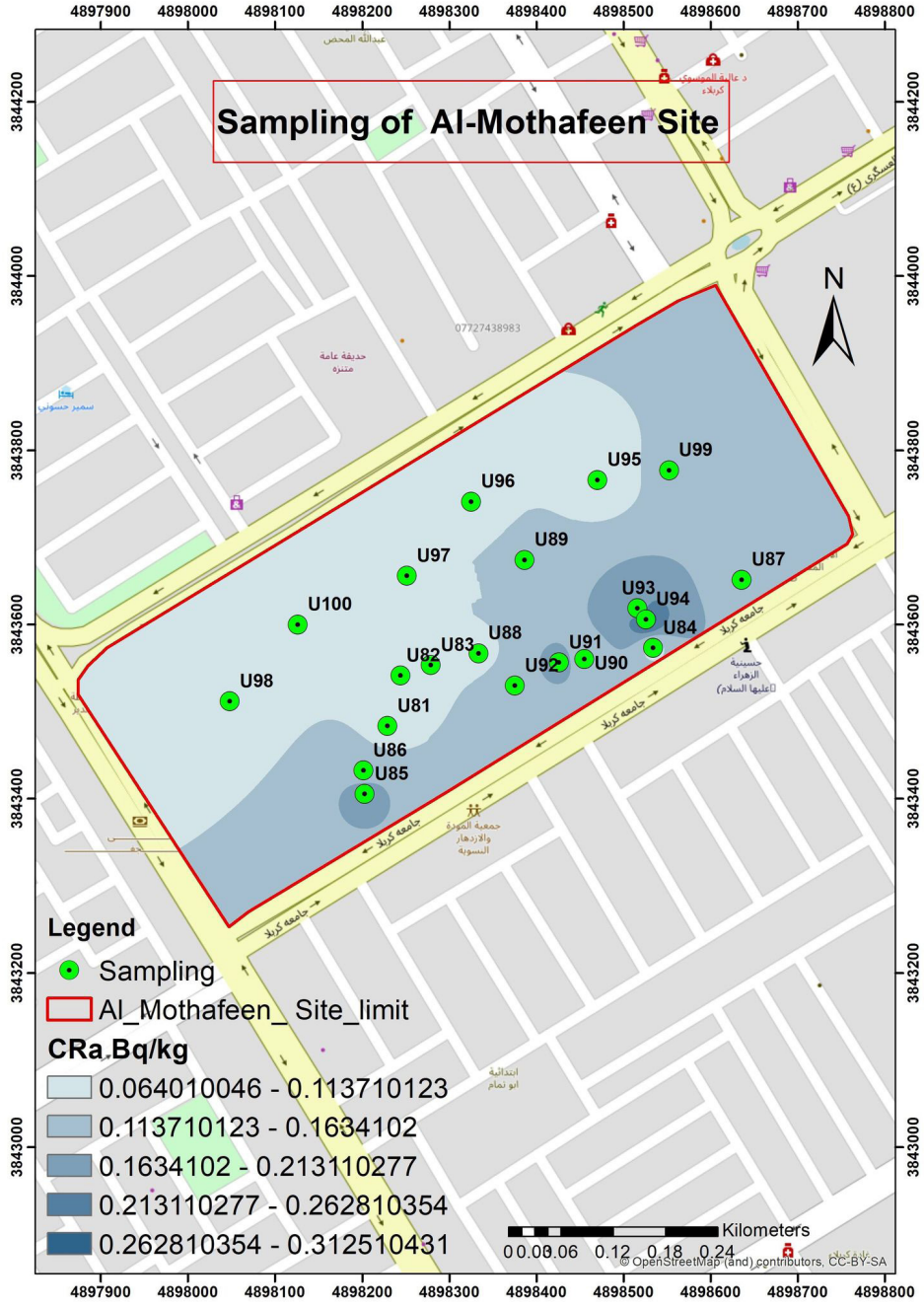

Fig. 3. The choropleth map of the values of C_{Ra} for different soil samples

mad 2011), France (Baixeras *et al*. 1996), Italy (SE Sicily) (Antoci *et al*. 2007), as shown in Table 4. Therefore, it can be concluded that there is no radiological hazard due to alpha particles concentration in the soil of the studied area.

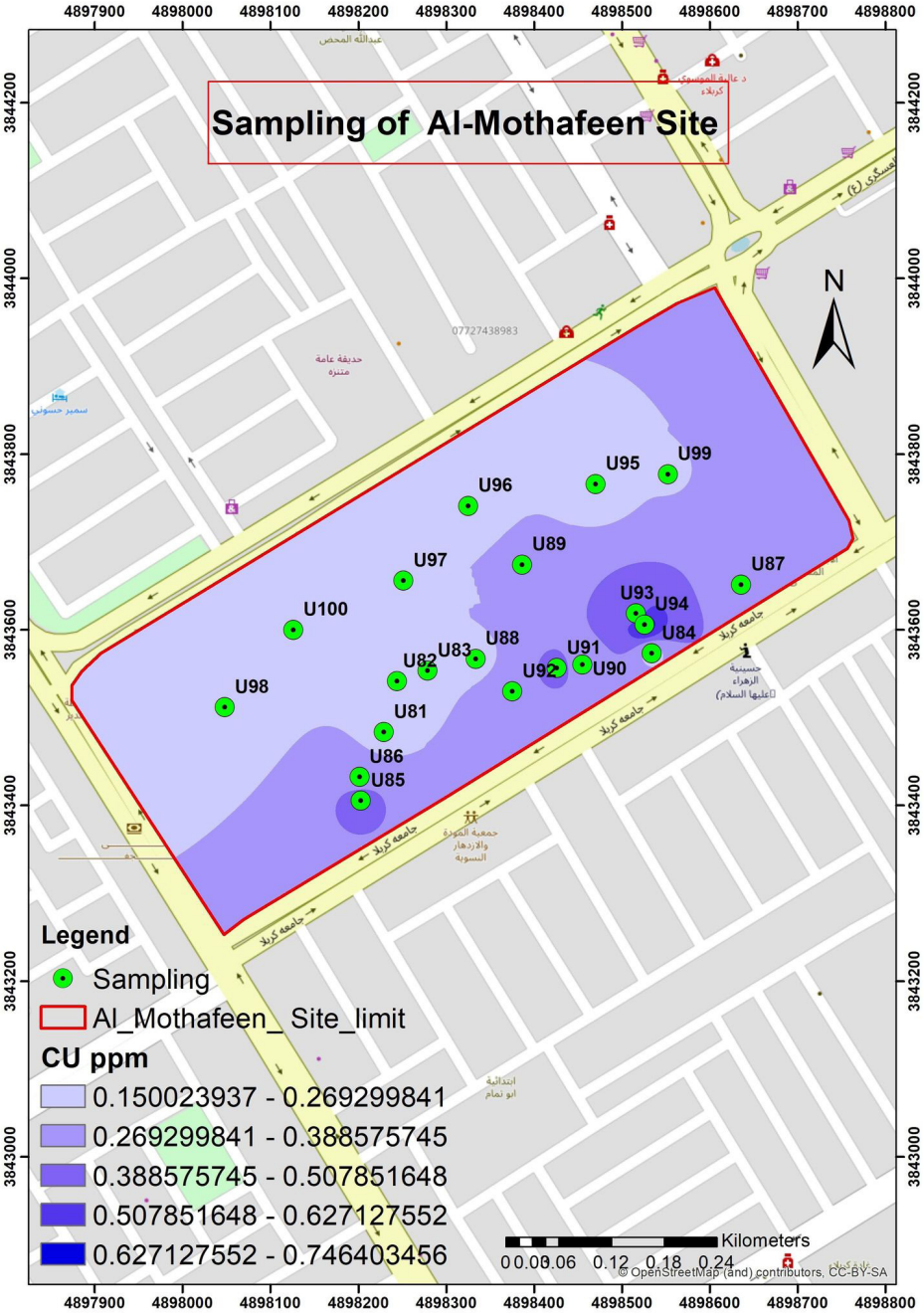

Fig. 4. The choropleth map of the values of U for different soil samples

Table 4. Comparison of the research results with those obtained in different countries

No.	Country	^{222}Rn (kBq/m^3)	^{226}Ra (Bq/kg)	C_U Bq/kg	Ref.
1	Pakistan	48	-	-	(Rafique *et al*. 2011)
2	Turkey	1.92	-	-	(Tabar *et al*. 2013)
3	Bulgaria	26	-	-	(Kunovska *et al*. 2013)
4	India	-	-	37.05	(Kakati *et al*. 2013)
5	Iraq (Al Najaf)	894.21	136.18	18.52	(Abojassim 2018)
6	Lebanon	-	1.079	18.11	(Hashim *et al*. 2016)
7	Iraq (Tikreet)	0.17	-	-	(Mohammad 2011)
8	Saudi Arabia	6.71	-	-	(Farid 2016)
9	Sudan	8.20	-	-	(Abd-Elmoniem *et al*. 2014)
10	Egypt	4.35	-	-	(Korany *et al*. 2013)
11	France	2.71	-	-	(Baixeras *et al*. 1996)
12	Italy (SE Sicily)	18	-	-	(Antoci *et al*. 2007)
13	Al-Mothafeen site	5.09	0.12	3.72	present study

CONCLUSIONS

The present study showed that the annual effective dose, the radium activity, the radon concentration levels, the uranium concentrations and the radon exhalation rates in this study were lower than the permissible limits as recommended by the ICRP32 and UNSCEAR (2000). This study showed the efficiency of nuclear impact detector CN-85 in the counting of alpha particles. What is more, the nuclear impact detector CN-85 is suitable for the study of radioactivity as it is easy to use and does not need a complex electronic system. Therefore, it can be concluded that all the locations of soil samples of the University of Kerbala (Al-Mothafeen site) are safe.

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