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Younis Mohamed Atiah Al-zahy
University of Misan

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Investigating the Level of Radon ^{222}Rn and Radium ^{226}Ra in Soil Samples Taken From Al-Amarah in the South of Iraq

Younis M Atiah Al-zahy[1] and Murtadha M zahiwat[2]

[1]Dentistry College, Misan University, Iraq
[2]Engineering College, Misan University, Iraq

E-mail: younisal_zahy72@yahoo.co.uk

Abstract. Radon (^{222}Rn) is created in the soil by radioactive decay of Radium (^{226}Ra) and then emitted from the ground into the atmosphere (exhalation), environmental assessments of radon gas (^{222}Rn) are keys to the assessment of air pollution. The major objective of the current study was to examine the (^{222}Rn) exhalation rates and the (^{226}Ra) concentrations in the soil samples. Thirty soil samples have been collected from ten streets in the region. The (^{222}Rn) exhalation rate and concentrations of (^{226}Ra) in soil samples were calculated using "Can Technique". The measurements have shown that the surface and mass exhalation rate were varied from 3.9∓0.3 to 18.3∓0.3 μBq.kg^{-1}.s^{-1}, with a mean value of 7.8∓0.3 μBq.kg^{-1}.s^{-1}, and 12.9∓0.5 to 60.7∓1 μBq.m^{-2}.s^{-1}, with a mean value of 25.5∓0.9 μBq.m^{-2}.s^{-1}, respectively. In addition, the results showed that the values for ^{226}Ra concentrations ranged from 1.8∓ 0.04 to 8.7∓0.1 Bq.kg^{-1}, with a mean value of 3.7∓0.1 Bq.kg^{-1}. Overall, the indications showed that the levels of (^{226}Ra) in soil samples are less than the hazardous levels of human health 370 Bq.kg^{-1}.

Keywords :CR-39 detectors, Soil, Radium, Radon exhalation rates

1. Introduction

The terrestrial element of the natural environment depends on the composition of soil and rock, which contain natural radionuclides [1,2]. Generally, the soil contains a small concentration of ^{238}U, whereas the granitic rocks have tens of ppm of ^{238}U. Decay of ^{238}U into a sequence of shorter-lived radionuclides inevitably creates ^{226}Ra, which has a half-life of 1,620 years.^{226}Ra decays directly into ^{222}Rn through alpha-particle emission [3]. Being a noble gas, ^{222}Rn is chemically unreactive and it moves freely in the air spaces between rocks and in soils. It becomes a risk factor for cancer and lung cancer because of indoor accumulation [4–8]. In addition, ^{226}Ra exposure can cause serious adverse effects, including sores, anaemia and bone cancer as ^{226}Ra can displace calcium from the bones and it can substitute for calcium inside the body [9].

Therefore, exposure doses for the public should remain within the lower limits, and assessments of ^{222}Rn and ^{226}Ra sources are of particular importance [10].

Up to now, several studies have measured ^{222}Rn, ^{226}Ra and their progenies in different samples, including spring water [11], surface and drinking water [12–14], houses [15], building materials [16,17], phosphorus fertilizer [18], indoor air [19], soil [20–22] and phosphate rocks [23].

Many techniques have been employed that use Solid-state nuclear track detector made from Poly-Allyl-Diglycol-Carbonate (PADC) for recording alpha-particle emission from ^{222}Rn, ^{226}Ra and their progeny [24,25]. During recent years, CR 39 detectors have become increasingly interested in detecting high-energy particles generated in Pd / D co-deposition [26]. CR-39 also has the benefit of being susceptible to various energy alpha particles (6.0, 7.7, 11.0, 12.8, 16.7 and 20.0 MeV) and photon irradiation insensitivity [27]. For these reasons, CR-39 has become the important tool for scientific research, especially for ^{222}Rn and ^{226}Ra measurements.

There are two major pathways that ^{226}Ra can become airborne and contaminate the surrounding air: 1.) first pathway is the resuspension of residual radionuclides that were in soil contaminated by wind and sandstorms and 2.) second pathway is outdoor ^{222}Rn concentrations, which originate from contaminated soil [28, 29]. Therefore, wind, dust and sandstorms loaded with contaminated soil can cause health risks [30].

Sandstorms are characteristic of the cities in southern Iraq, specifically Al-Amarah city (Centre of Misan province). The soil can be transferred by sandstorms to the city streets. But vehicle movement over the streets represents a source of fugitive soil, especially during the summer. Fugitive soil is a concern because heavy vehicle movement creates dust that can migrate to nearby residential areas.

Soil movement may cause an increase in background radiation levels; soils transferred by the wind and the sandstorms cause many problems regarding health, especially to the respiratory system.

This is, to our knowledge, the first research to make a survey of ^{222}Rn and making a map showing the distribution of radium within Al-Amarah city (Centre of Misan province). The main motivation for this work has to measure^{222}Rn exhalation rates of Radon, also to estimate ^{226}Ra concentrations of soil samples from the streets of Al-Amarah.

2. Materials and methodologies

2.1. Region of study

Thirty samples of the soil were collected from different locations of streets of Al-Amarah, Al-Amarah is the busy administrative capital city of Misan and a big economic centre for the surrounding agricultural area. The city locates at latitude (31.873222˚N), and longitude (47.136194°E), with a total area roughly (16,072 km^2) and an estimated population of 511,542 as of 2012[31]. The main streets of this city always crowded with people and soils of different heights are distributed on both sides of these streets as illustrated in Figure1.

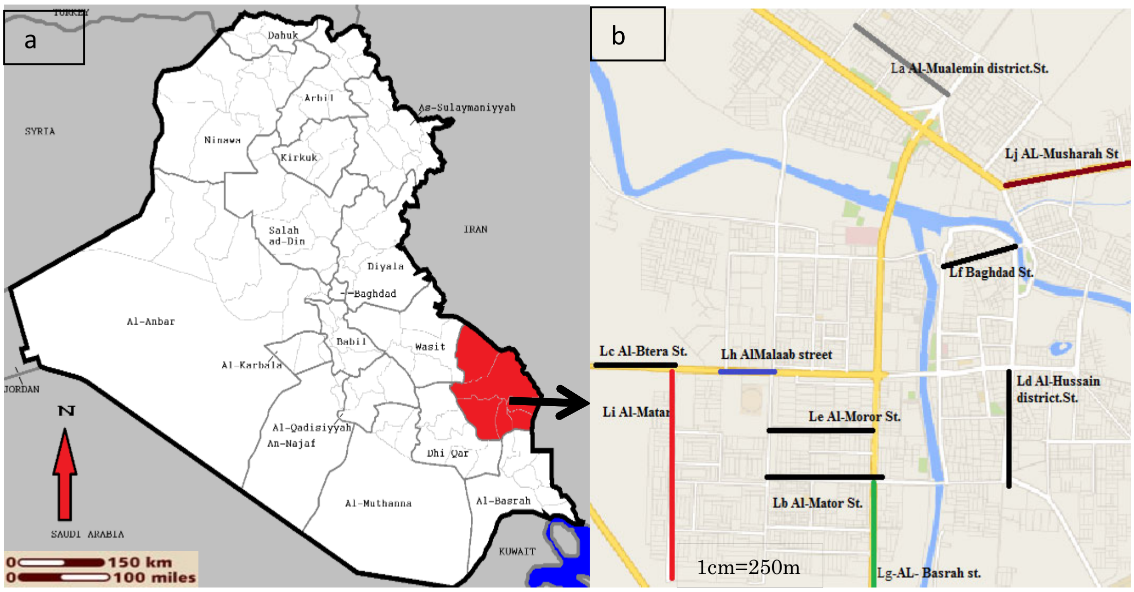

Figure 1. Sketch map of the locations of Region of study a) Iraq b) street of Al-Amirah city.

2.2. Samples collection

In this project ten streets were monitored, and thirty soil samples were taken, at surface level (0–10) cm in depth, from various sites of the streets (three samples for each street). The serial numbers, symbols and locations of the samples are presented in Table 1.

Table 1. Symbol, location, latitude and longitude of study areas in Al -Amarah city

SN.	Symbol	Location name	Latitude/Longitude	
1	La	Al-Mualemin district.St.	31°52'07.54 ″N	47º08'53.91 ″E
2	Lb	Al-Mator St.	31°49'47.62″N	47º08'04.40″E
3	Lc	Al-Btera St.	31º49'55.72″N	47º08'06.03″E
4	Ld	Al-Hussain district.St.	31º50'29.57 ″N	47º09'30.92″E
5	Le	Al-Moror St.	31º49'55.72 ″N	47º08'06.03 ″E
6	Lf	Baghdad St.	31º51'10.49″N	47º09'03.24″E
7	Lg	Al- Basrah St.	31º49'29.60″N	47º08'29.58″E
8	Lh	AlMalaab St.	31º50'17.75″N	47º07'42.58″E
9	Li	Al-Matar St.	31º50'06.79″N	47º07'02.67″E
10	Lj	AL-Musharah St.	31º51'31.73″N	47º09'55.72″E

2.3. Samples preparation

In the laboratory, all samples were grinded and dried in the oven (110°C) for 4 hours to be free from moisture; a mesh was used to sieve the soil. About 100 ± 0.05% g of the sample has been enclosed in a plastic can. Then, samples were stored for three-weeks to maintain a radioactive balance between the ^{226}Ra and its daughters such as ^{222}Rn, ^{218}Po,^{214}Pb,^{214}Bi and ^{214}Po [32]. The closed can technique consists of can with diameter of 4.8 cm and height 10 cm coated with a 0.5 cm thick compressed sponge to flush out dust and thoron. [33-35].The CR-39 dimensional detector (1cm×1 cm) has been retained in a tight, closed plastic can over the sample in direct contact with the soil surface as shown in Figure 2. The CR-39 detectors were left for 30 days with the soil sample. Thus, the detector captured alpha-particle tracks emitted by ^{222}Rn($T_{1/2}$= 3.82 days) of gas produced by decay of ^{226}Ra. Unexposed control (1cm× 1cm) CR-39 detectors were used for calculation of the backgrounds in the same environment of the experiments.

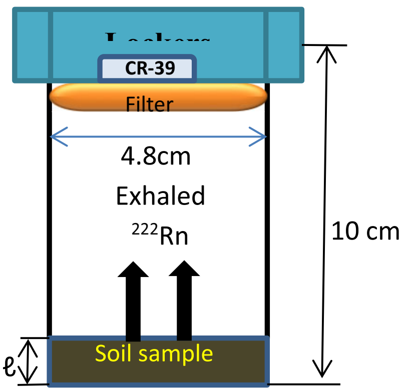

Figure 2. Arrangement of the can technique.

2.4. Method of etching and scanning

CR-39 was etched at a constant temperature of 70°C water bath with a control accuracy of 0.1 over 6 hours to detect tracks with solution of NaOH (6.25 N) after completion of the exposure time. Then all detectors has been washed in distilled water for at least15 min [36-38]. The tracks of alpha have been observed and counted using an optical microscope type BEL-Photonics Odel Bio 3T, Italy, at a magnification of 100X.

2.5. Measurements of ^{222}Rn exhalation rate in soil gas

C_{Rn} is the concentration of ^{222}Rn in the air space between the sample and the face of the CR-39 plastic detector and given by following equation [18, 39]:

$$C_{Rn} = \rho/\delta\, T \quad (1)$$

ρ is a net track density (track /cm^2), $\rho = \rho_1 - \rho_2$. Whereas, ρ_1 and ρ_2, are track densities recorded from the exposed and unexposed CR-39, respectively. δ is the factor of sensitivity (track /cm^2.day^1 for one Bq/m^3), which depends on the critical angle θc and T is the time of exposure. The sensitivity factor is computed using the following equation [40, 41]:

$$\delta = (r/4)[2\cos\theta_c - (r/R_\alpha)] \quad (2)$$

As r (cm) is the radius of the can, R_α (cm) is the alpha particle range in the air. The parameter values are shown in Table 2.

Table 2. The parameters and its values of sensitivity factor.

SN.	Symbol	Symbol value
1	T	30 days
2	Θc	35°
3	r	2.4 cm
4	Rα	4.15 cm
5	δ	0.636 cm=0.0569 (track cm^{-2} day^{-1} Bq^{-1} m^{3})
6	h	5.6-6.9 cm
7	l	3.1-4.4 cm

The surface exhalation rate of ^{222}Rn is determined using the following expression [42, 43].

$$\varphi^{s}_{Rn} = (\rho V/\delta A T_e)\lambda_{Rn} \quad (3)$$

$$T_e = \left[T - \lambda^{-1}_{Rn}\left(1 - e^{-\lambda_{Rn}T}\right)\right] \quad (4)$$

λ_{Rn} is the constant of decay of the gas ^{222}Rn (s^{-1}) V is the effective volume of the can (m^3) T is the period of exposure (s) A is the cross section area of the can (m^2) T_e is the period for effective exposures the time of effective exposure (s), Exhalation is the amount of ^{222}Rn atoms emitted by emanation and diffusion from the surface of a particular substance. The mass exhalation rate of ^{222}Rn is as follows [44].

$$\varphi^{m}_{Rn} = \varphi^{s}_{Rn}(A/m) \quad (5)$$

m is mass of the soil sample.

2.6. Measurements of the ^{226}Ra concentration
After the radioactive balance has been formed in the closed can, the ^{222}Rn gas is used to calculated the concentration of ^{226}Ra (Bq kg^{-1}) in soil samples.
According to "closed can technique" introduced by Somogyi 1986 [44], the ^{226}Ra concentration is calculated by the following formula:

$$C_{Ra} = (\rho/\delta T_e)(hA/m) \quad (6)$$

where h (cm) is diameter of space between the soil surface and the detector in the Can.

3. Results and Discussion

φ^{s}_{Rn}, and φ^{m}_{Rn} are estimated for the samples by Eqs. 3 and 5, respectively, and the results of the ^{222}Rn exhalation rate for soil samples in form of surface area and mass are set out in Table 3. The mass exhalation rate was found to range from 3.9∓0.3 to 18.3 ∓ 0.3 μBq.kg^{-1}.s^{-1} with a mean value of 7.8 ∓ 0.3 μBq.kg^{-1}.s^{-1}. The minimum value for the ^{222}Rn exhalation rate was found in sample Le with value 3.9∓0.3 μBq.kg^{-1}.s^{-1}, while a maximum of ^{222}Rn exhalation rate was found in Lh with value18.3 ∓ 0.3 μBq.kg^{-1}.s^{-1} as shown in Figure 3.

As seen in Table 3, the mass exhalation rate in the samples Lc, Ld, and Lg lies between 8.4∓0.5 μBq.kg^{-1}.s^{-1} and 8.7∓0.3 μBq.kg^{-1}.s^{-1}. In addition, the three locations Lb, Le, and Li approximately have the same values; this may be because the composition of ^{238}U is identical in the Earth's crust. The values found in the analyzed samples of the mass exhalation rate are less or identical to those reported in the Singh *et al.* 9.03 μBq.kg^{-1}.s^{-1}, Somogyi *et al.*20.3 μBq.kg^{-1}.s^{-1}, Chauhan 6.88 μBq.kg^{-1}.s^{-1}, Zubair *et al.* 5.52 μBq.kg^{-1}.s^{-1} and Mir A. Feroz 92 μBq.kg^{-1}.s^{-1}[43-48].

As seen in Table 3, surface exhalation values were calculated to vary from 12.9∓0.5 Li, to 60.7∓1 Lh μBq.m^{-2}.s^{-1} with a mean value of 25.5 ∓ 0.9 μ Bq.m^{-2}.s^{-1}. The value of the surface exhalation rate in the sample Lf is approximately equal to that of Lg as shown in Figure 4.

A possible reason for these results may be due to the nature of the soil and its properties. The mean value of surface exhalation rate in this study is low compared to Somogyi *et al.* 50 μBq.m^{-2}.s^{-1} [45] and greater than Chauhan 14.6 μBq.m^{-2}.s^{-1}[46], Zubair *et al.* 14.3μBq.m^{-2}.s^{-1} [47].The surface and mass exhalation rate in the sample Lh is high compared to other streets, this difference can be referred to the change in the nature of the soil and crowding of this street.

Table 3. Mass and surface exhalation rates for 30 street soil samples.

SN.	Symbol	Track density ∓SEM,Tr.cm^{-2}	φ^{m}_{Rn} (μBq.kg^{-1}.s^{-1})		φ^{S}_{Rn} (μBq.m^{-2}.s^{-1})	
			Value∓SEM	**Average∓SEM**	**Value∓SEM**	**Average∓SEM**
1	La1	2328∓30	8.2∓0.10		24.2∓0.3	
2	La2	1640∓37	5.8∓0.10	6.6∓0.10	17.0∓0.4	19.4∓0.4
3	La3	1646∓37	5.8∓0.10		17.1∓0.4	
4	Lb1	1271∓65	3.7∓0.20		12.4∓0.6	
5	Lb2	1762∓16	5.1∓0.05	4.1∓0.1	17.2∓0.2	13.8∓0.3
6	Lb3	1200∓7.0	3.5∓0.02		11.7∓0.07	
7	Lc1	2347∓28	7.5∓0.09		23.6∓0.3	
8	Lc2	3004∓387	9.6∓1.00	8.4∓0.50	30.3∓4.0	26.5∓1.5
9	Lc3	2549∓35	8.1∓0.10		25.7∓0.4	
10	Ld1	2306∓66	8.3∓0.20		22.9∓0.7	
11	Ld2	2345∓4.0	8.4∓0.02	8.6∓0.10	23.3∓0.04	23.8∓0.4
12	Ld3	2535∓48	9.1∓0.20		25.2∓0.5	
13	Le1	1996∓24	3.6∓0.04		16.8∓0.2	
14	Le2	2400∓31	4.3∓0.05	3.9∓0.30	20.2∓0.3	18.2∓1.4
15	Le3	2077∓463	3.7∓0.80		17.5∓3.9	
16	Lf1	3541∓570	11.9∓2.0		35.7∓5.7	
17	Lf2	3364∓30	11.3∓0.1	10.6∓0.8	33.9∓0.3	31.7∓2.2
18	Lf3	2536∓77	8.6∓0.30		25.5∓0.8	
19	Lg1	2192∓82	6.1∓0.20		21.8∓0.8	
20	Lg2	2275∓140	6.3∓0.40	8.7∓0.30	22.6∓1.0	31.3∓0.9
21	Lg3	4996∓52	13.8∓0.1		49.6∓0.5	
22	Lh1	6376∓90	18.8∓0.3		62.3∓0.9	
23	Lh2	4858∓35	14.3∓0.1	18.3∓0.3	47.5∓0.3	60.7∓1
24	Lh3	7400∓184	21.8∓0.5		72.3∓2.0	
25	Li1	1271∓28	3.8∓0.08		12.4∓0.3	
26	Li2	1501∓74	4.5∓0.20	4.0∓0.10	14.7∓0.7	12.9∓0.5
27	Li3	1200∓44	3.6∓0.10		11.7∓0.4	
28	Lj1	1753∓20	4.2∓0.05		15.8∓0.2	
29	Lj2	1737∓38	4.2∓0.09	4.5∓0.10	15.7∓0.3	17.0∓0.5
30	Lj3	2160∓115	5.2∓0.30		19.5∓1.0	
			Max value	18.3∓0.3	Max value	60.7∓1
			Min value	3.9∓0.30	Min value	12.9∓0.5

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Average value	7.8 ∓ 0.3	Average value	25.5 ∓ 0.9

SEM: Standard Error of the mean

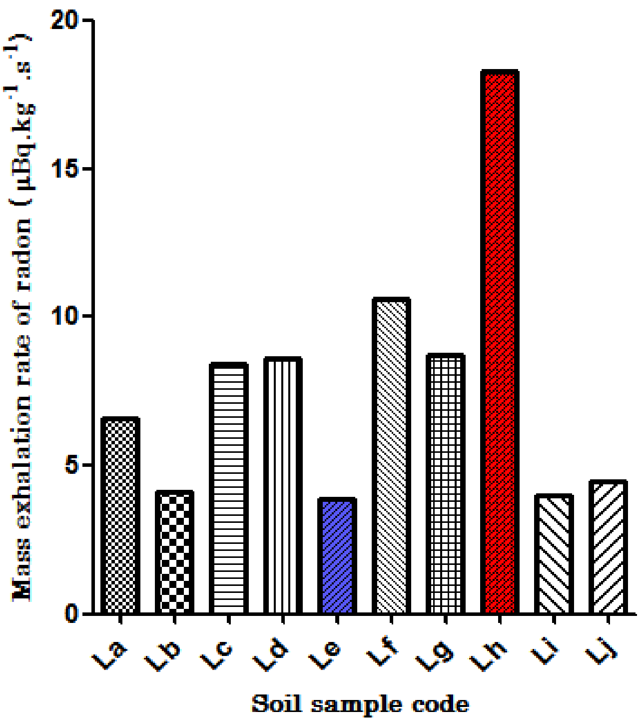


Figure 3. Histogram demonstrating the change in the rate of mass exhalation in soil samples for all regions studied in Al-Amarah.

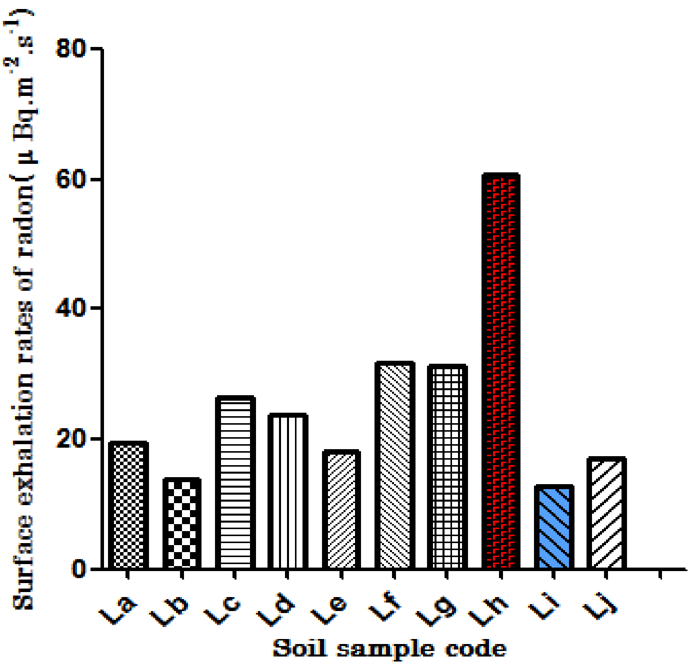


Figure 4. Histogram demonstrating the change in the rate of surface exhalation in soil samples for all regions studied in Al-Amarah.

The amount of ^{226}Ra concentration was determined in all samples by using Eq.6. in 10 samples for different streets are presented in Table 4. The ^{226}Ra concentrations were varied from 1.8∓0.04 to 8.7∓0.10 Bq.kg^{-1} with a mean value of 3.7∓0.1 Bq.kg^{-1} Figure 5.

Table 4. ^{226} Ra concentrations in the 30 samples collected from streets in Al- Amarah district of Misan Province, Iraq.

SN.	Symbol	C_{Ra} ∓SEM (Bq.kg^{-1})	Average C_{Ra} ∓SEM (Bq.kg^{-1})
1	La1	3.9∓0.05	
2	La2	2.8∓0.06	3.2∓0.06
3	La3	2.8∓0.06	
4	Lb1	1.8∓0.09	
5	Lb2	2.4∓0.02	2.0∓0.04
6	Lb3	1.7∓0.01	
7	Lc1	3.6∓0.04	
8	Lc2	4.6∓0.60	4.0∓0.20
9	Lc3	3.9∓0.05	
10	Ld1	3.9∓0.10	
11	Ld2	4.0∓0.01	4.1∓0.07
12	Ld3	4.3∓0.08	

13	Le1	1.7∓0.02	
14	Le2	2.0∓0.03	1.8∓0.04
15	Le3	1.8∓0.40	
16	Lf1	5.7∓0.90	
17	Lf2	5.4∓0.05	5.1∓0.40
18	Lf3	4.0∓0.10	
19	Lg1	2.9∓0.10	
20	Lg2	3.0∓0.20	4.1∓0.10
21	Lg3	6.7∓0.07	
22	Lh1	8.9∓0.10	
23	Lh2	6.8∓0.05	8.7∓0.10
24	Lh3	10.4∓0.2	
25	Li1	1.8∓0.04	
26	Li2	2.1∓0.10	1.9∓0.07
27	Li3	1.7∓0.06	
28	Lj1	2.0∓0.02	
29	Lj2	2.0∓0.04	2.2∓0.07
30	Lj3	2.5∓0.10	
		Max value	8.7∓0.10
		Min value	1.8∓0.04
		Average value	3.7 ∓ 0.1

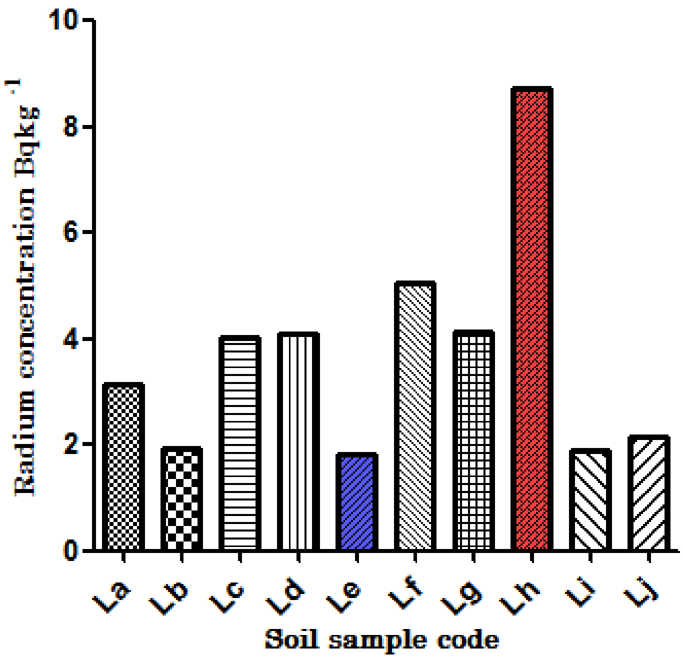


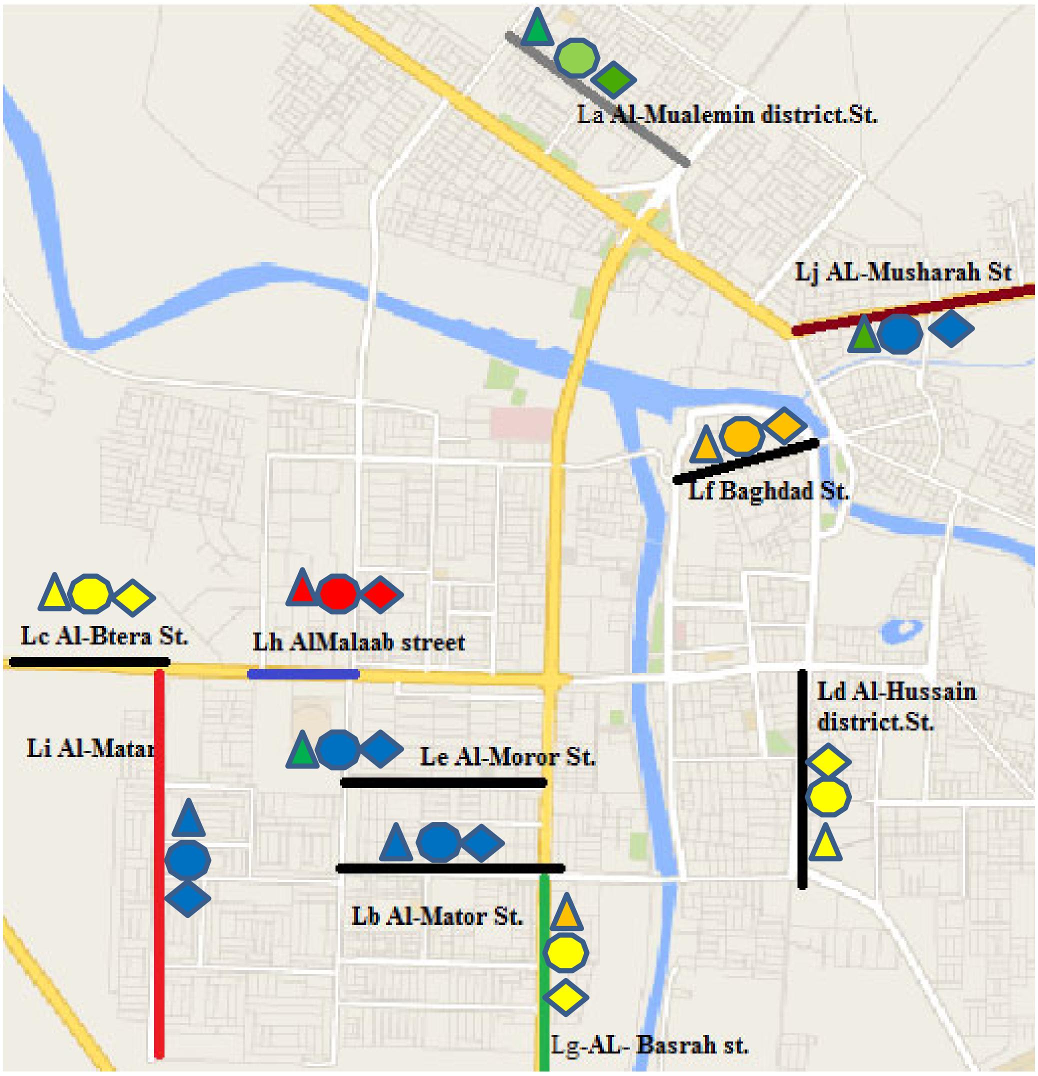
Figure 5. Histogram demonstrating the change in ^{226}Ra concentration in soil samples for all regions studied in Al-Amarah.

The ^{226}Ra concentrations in all samples were slightly less than recorded by both Singh *et al*.[43] *and* Zubair *et al*.[47], but the value of the ^{226}Ra in the sample Lh3 is approaching to those reported by Zubair *et al*.[47]. The results of our study are compared to the results of other studies [43-48] in Table 5.

Table 5. Literature curated by country the mass, surface exhalation rate and ^{226}Ra concentrations in soil samples.

Authors	**Sample code**	φ_{Rn}^{m} μ**Bq.kg^{-1}.s^{-1}**	φ_{Rn}^{S} μ**Bq.m^{-2}.s^{-1}**	**C_{Ra} Bq.kg^{-1}**
Somogyi *et al* [45]	A-7	20.30	50.0	-
	A-11(1)	47.00	40.0	-
Singh *et al* [43]	Raja ka Talab	9.03	29.9	24.72
	Dehri	8.05	26.6	22.06
Chauhan [46]	S-1	6.88	14.6	-
	S-2	7.94	16.6	-
Zubair *et al* [47]	Soil-1	5.52	14.3	12.10
	Soil-2	6.75	17.5	14.80
Mir, F. A. [48]	Cherawan	92.00	-	06.68
Present study	Al-Amarah	7.8 ∓ 0.3	25.5 ∓ 0.9	3.7∓0.1

The heterogeneous distribution of the ^{226}Ra concentrations and exhalation rate of radon will become more apparent if we arrange our data on a map, as shown in the Figure 6.



φ^S_{Rn} μBq.m^{-2}.s^{-1}		φ^m_{Rn} μBq.kg^{-1}.s^{-1}		C_{Ra} Bq.kg^{-1}	
Red triangle	60	Red octagon	18	Red diamond	8.7
Orange triangle	31	Orange octagon	10.6	Orange diamond	5
Yellow triangle	24-27	Yellow octagon	8.7-8.4	Yellow diamond	4
Green triangle	17-19	Green octagon	6.6	Green diamond	3.2
Blue triangle	13-14	Blue octagon	4-4.5	Blue diamond	1.8-2.2

Figure 6. Map showing the average ^{226}Ra concentration and exhalation rate of radon for each street in study.

4. Conclusions

The average value of the mass exhalation rate and the surface exhalation rate in all soil samples are in safety level according to UNSCEAR (2000)and ICRP (1993) [49, 50].

The ^{226}Ra concentration in all soil samples of (Al- Amarah) streets was lower than the average value of activity in soil samples as considered by UNSCEAR(2000) [49]. Finally, a lower level of the radon exhalation rate and the ^{226}Ra concentration under the studied areas does not mean that all areas of (Al-Amarah) city are safe from the radiation. We need more researches to get a clear radiation map for more different regions of this city.

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