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Correlation of Radon Gas Concentrations and Associated Radiological Risks in Soil Using SSNTDs with GIS and SPSS at Najaf Governorate, Iraq

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ORIGINAL STUDY

Correlation of Radon Gas Concentrations and Associated Radiological Risks in Soil Using SSNTDs With GIS and SPSS at Najaf Governorate, Iraq

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Abstract

All human beings are affected by soil directly or indirectly. This study focuses on the effect of radon gas and related radiological risks using SSNTDs, specifically CR-39 detectors, in eighty secondary schools in Najaf and Kufa cities, Najaf Governorate, Iraq. As we recognize the importance of soil and its strong connection to humans, the study focused on areas where public and private schools were built, where students are present, and the potential for radiation risks to affect students' health. The results show that the average concentrations of C, C_{Rn} were 64.329 $\pm$ 59.149 Bq/m^3 and 3150.699 $\pm$ 2897.036 Bq/m^3 respectively, and for C_{Ra} and C_U were 4.425 $\pm$ 4.077 Bq/Kg and 1.993 $\pm$ 1.881 ppm. At the same time, radiological risk values of AED, E_M, E_s, and ELCR were 0.264 $\pm$ 0.241 mSv/yr, 0.815 $\pm$ 0.750 (mBq/Kg.h), 62.153 $\pm$ 57.149 (mBq/m^2.h), and 0.923 $\pm$ 0.843, respectively. So that all values were under acceptable limits, except for twenty-eight samples for C and eight samples for $C_{Rn.}$ Meanwhile, the concentrations of radiological risks were all under acceptable limits according to the World Health Organization. Radiation maps were drawn using GIS techniques, and a statistical analysis with SPSS was used pearson correlation, which shows that the p-value is significant at $p < 0.05$. Finally, all values were under permissible limits according to UNSCEAR, WHO, and ICRP and did not pose any danger to human health.

Keywords: Radon gas, Soil, CR-39, Radiological risks, Najaf, Iraq

1. Introduction

The number one source of ongoing radiation publicity for people is soil, generally ranked as the third most crucial environmental thing behind air and water. Natural radioactivity is widely distributed across the earth's surroundings and may be discovered in soils, rocks, water, and sand, among other materials. In a few conditions, those certainly occurring radioactive substances can reach risky radiological renges [1]. The significance of soil in widespread lies within the truth that it's far the number one center of many unique organisms, including vegetation, microorganisms, and animals, and it is the first and maximum vital component inside the production of meals that is essential for human life anywhere it exists. Any adverse effect or pollutants of any type at once affect all living things that are linked to them, as well as the human beings who stay there [2].To offer critical information about radiation, it is required to observe the radiation levels and the distribution of radionuclides in the environment. Understanding the amount of radiation that people are exposed to from each natural and artificial resource is necessary for growing radiation laws and regulations [3]. Since it exists as a noble gas and radioactive isotope, Radon is an unprecedented natural detail. Radon gas may additionally gather in soils, groundwater, and buildings [4–8]. Radon decay with ^{238}U can produce ^{226}Ra, which has a half-life of 1600 years, in 4 intermediate conditions. It then decays to produce ^{222}Rn gas, which has a half-existence of 3.82 days [9]. In the past several years, numerous surveys

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have been performed globally to determine the stages of radiation and Radon in both natural and man-made environments. Additionally, epidemiological studies have been conducted to confirm the terrible results of Radon exposure on human health [10–15]. Because solid polymeric detectors are smooth-to-use electric gadgets that could create a nuclear tune internal them, they're currently the quality devices for detecting ionizing radiation. Because SSNTDs are transparent, touchy to both charged and uncharged particles (protons and alpha), and are unaffected by using ambient elements. They can measure the concentration and geographical distribution of radioactive isotopes.

The emission of heavily charged debris can both at once engage with covalent polymer bonds, or result in latent damage. This is how nuclear tracks are created: insulators in narrow tracks (~five-100A°) are broken through by powerfully charged particles [12]. For all mentioned above, the wars that the country went through, which continued for many years, led to the possibility of the presence of radioactive isotopes, which are already found naturally in the soil, which leads to an increased possibility for the population living in these areas to contract cancerous diseases as a result of emissions from the products of radioactive isotopes, the most important and dangerous of which is Radon gas, which It is one of the products of radioactive uranium −238. The increase in population numbers in Iraq, especially in Najaf Governorate, during the last twenty years is a result of several reasons, the most important of which is the search to improve living conditions and religious character, it led to an increase in population numbers, which made schools in the governorate attract large numbers of school students at various educational levels. Accordingly, the current study covered all schools, Private and government secondary schools in the cities of Najaf and Kufa, so the question here is: 1. Are the Radon levels in all these secondary schools within the acceptable levels approved by the World Health Organization? 2. How can the high levels of Radon gas and other radiation factors associated with it (if any) be reduced in these places? 3. Does the presence of school students during school hours have a health impact on them or not?. The main objective of this study is to investigate Radon gas concentrations in all secondary schools at Kufa and Najaf cities in Iraq by using CR-39 detectors to find related radiological risks and compare them with the international organization's accepted values, then mapping with geographic information system named GIS technique.

2. Methodology

2.1. Description of investigation site

One of the most significant administrations included two important cities, Najaf and Kufa. Najaf, one of the provinces in southern Iraq, lies on the edge of Iraq's western plateau southwest of Baghdad, approximately 161 km away. It is located near the Euphrates River, 182 km southeast of Baghdad, latitude 32°01′44 "north, longitude 44°27′89″ east [13]. The present administrative divisions include three districts: the Najaf district, middle, bounded to the north by the Al-Haidariya vicinity, to the east by the Kufa district, and to the west by the Manatharah district [14]. Fig. (1) below shows the area of study.

2.2. Collection and preparation of samples

In the Al-Najaf governorate of Iraq, eighty soil samples have been gathered from various sites in Najaf and Kufa cities in the months of September and October. Table (1) reports and illustrates the eighty places' GPS (Global Positioning System) coordinates using a GIS method. It has to be mentioned that the drilling intensity varied from ten to 15 cm beneath the soil's surface. Every soil sample. All samples were crushed, dried, and ground to a smooth and homogeneous consistency in preparation for preservation and storage, then numbered, categorized, and saved in a plastic pouch based on the in which it was taken. One kilogram of soil samples was measured, saved for 90 days, and then subjected to the following chemical etching step to measure alpha particles of Radon gas.

3. The chemical of etchant solution

The current study used a CR-39 detector (ASTRAK Analysis System, Ltd., UK: TASTRACK) with a thickness of one mm, density of 0.32 g/m^3, and dimensions of 2.5 cm × 2.5 cm to detect the Radon concentrations in the soil Each detector was affixed to the top of a plastic container that measured 6 cm in radius and 12 cm in height. Soil samples were placed at the lowest of the containers, which were tightly sealed with a cowl for an exposure duration to Radon for ninety days. After the end of the publicity time, detectors were accrued from the containers and placed in a solution of NaOH at 6.25 N in a water bath at a temperature of 98 °C for 1 h [15]. After that, the detectors were taken out of the bath, rinsed, and wiped clean very

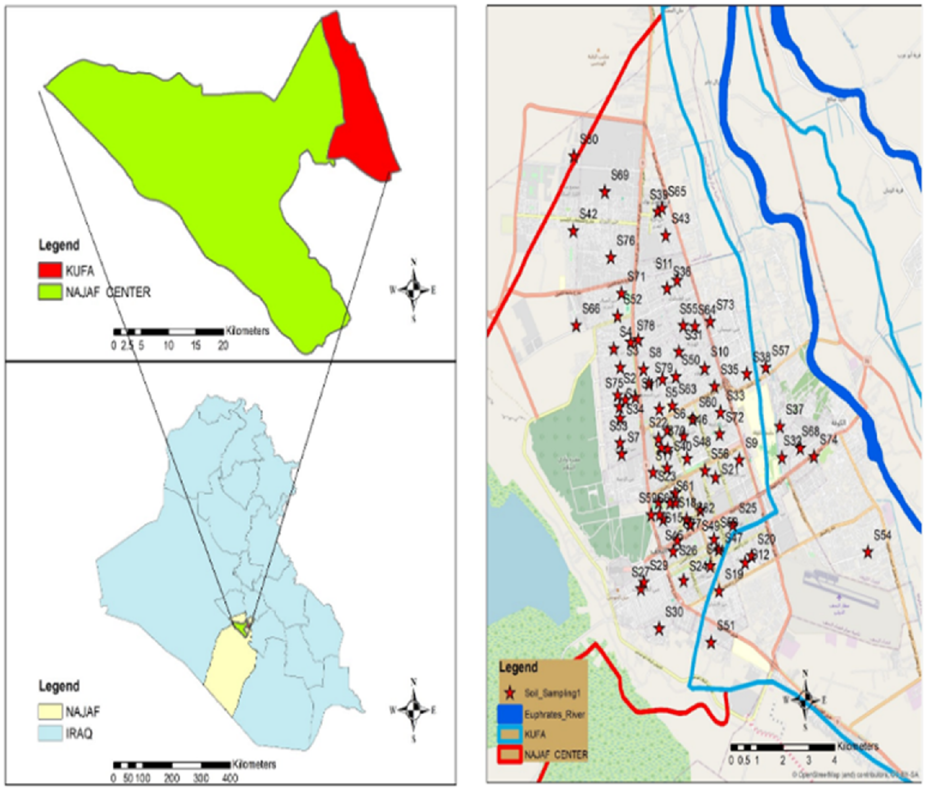

Fig. 1. Area map of Najaf and Kufa city.

well with distilled water to eliminate any dirt left over on the floor; then, they were dried out. Finally, alpha particle tracks at the surface of the detector had been calculated using the TASLIMAGE, all steps are shown in Fig. (2).

4. Calibration of irradiation source

Using a standard source of ^{226}Ra at exposure times 0.5, 1, 1.5, 2, 2.5, and 3 days, the ^{222}Rn gas concentration (C) in the container space was calculated based on track density (ρ), exposure time T, and calibration factor (K = 0.28 ± 0.043 Track. cm^{-2}/Bq.m^{-3}.day), as follows [16,17]:

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

5. Theoretical calculations

^{222}Rn gas concentration within the soil samples, (C_{Rn}) and the specific activity of radium-226 (C_{Ra}),

Were found using the equations below [18,21,22]:

$$C_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{C\,\lambda_{Rn}\,h\,T}{l} \tag{2}$$

$$C_{Ra}\left(\frac{Bq}{kg}\right) = \frac{C\,h\,A}{M} \tag{3}$$

$$C_U(ppm) = \frac{M_U(mg)}{M\,(kgm)} \tag{4}$$

Where, the value of C (Bq/m^3), exposure time (T), Radon decay constant (λ_{Rn}), and the distance (h) between the soil sample and CR-39 detector, thickness (l) of the soil sample in the container, surface area, (A) of the sample in the container, and mass (M).

The annual effective dose (AED) was determined according to the following relation [19,20]:

$$AED\left(\frac{mSv}{y}\right) = C \times F \times H \times T \times D \tag{5}$$

where F is the equilibrium parameter equivalent to (0.4), (H) the occupancy parameter equivalent to (0.13) [3], (T) the hour in a year, (T = 8760 h/y), and (D) the transition dosage factor equivalent to [9 × 10^{-6} (mSv)/(Bq·h·m^{-3})].

Also, Radon surface exhalation rate (E_S), mass exhalation rate (E_M), and effective time (T_e), which is the actual exposure, have been evaluated using the following formulas [23,24]:

Table (1). Sample name with codes and coordinates for all samples under study.

NO.	Code sample	Name of Samples	Latitude	Longitude
1	S1	Al Farazdaq Secondary School for Girls	32° 2′16.87″N	44°18′48.77″E
2	S2	Hamza bin Abdul Muttalib Intermediate School for boys	32° 2′27.74″N	44°18′46.93″E
3	S3	Mahd Al-Hadharat Secondary School for Girls	32° 2′52.63″N	44°18′49.79″E
4	S4	Umm Al-Kitab Intermediate School for Girls	32° 3′10.96″N	44°18′40.36″E
5	S5	Nazik Al Malaika Secondary School for Girls	32° 2′14.39″N	44°19′47.01″E
6	S6	Ammar Ibn Yasser Intermediate School for Boys	32°1′55.93″N	44°19′57.89″E
7	S7	Dr. Mahdi Al-Makhzoumi Secondary School for Girls	32° 1′31.38″N	44°18′53.01″E
8	S8	Al-Asil Preparatory School for Girls	32° 2′50.23″N	44°19′24.42″E
9	S9	Almutamayizat Secondary School for Girls	32° 1′27.83″N	44°21′45.05″E
10	S10	Nour Al Hussein Secondary School for Girls	32° 2′54.13″N	44°20′55.44″E
11	S11	Asma Bint Umais Secondary School for Girls	32° 4′14.52″N	44°20′13.67″E
12	S12	Abi Dhar Al-Ghafari Intermediate School	31°59′52.68″N	44°21′54.78″E
13	S13	Dr. Anad Ghazwane Secondary School for Boys	32° 2′42.45″N	44°19′52.46″E
14	S14	Al-Wahda Preparatory School for Boys	32° 0′48.30″N	44°20′12.56″E
15	S15	Khawla Bint Al Azwar Secondary School for Girls	32° 0′47.65″N	44°19′48.30″E
16	S16	Shams Al-Hurriya Secondary School for Girls	32° 1′20.33″N	44°19′59.20″E
17	S17	Dr. Abdul Razzaq Muhyiddin Intermediate School for Boys	32° 1′15.10″N	44°19′41.65″E
18	S18	Lattakia Secondary School for Girls	32° 0′33.64″N	44°20′29.74″E
NO.	Code sample	Name of Samples	Latitude	Longitude
19	S19	Dr. Ali Al-Wardi Preparatory School for Boys	31°59′25.24″N	44°21′16.99″E
20	S20	Ouras Intermediate School for Girls	31°59′59.01″N	44°22′3.84″E
21	S21	Al-Balad Al-Amin Intermediate School for Girls	32° 1′11.39″N	44°21′10.91″E
22	S22	Institute of Fine Arts	32° 1′46.61″N	44°19′47.03″E
23	S23	Samia Intermediate School for Girls	32° 0′57.09″N	44°20′10.27″E
24	S24	Maysaloun Secondary School for Girls	31°59′36.69″N	44°20′25.02″E
25	S25	Al-Sajidat Secondary School	32° 0′28.21″N	44°21′36.35″E
26	S26	Al-Amir Secondary School for Girls	32° 0′3.57″N	44°20′9.26″E
27	S27	Al-Kawthar Vocational Secondary School for Girls	31°59′27.86″N	44°19′22.41″E
28	S28	Sheikh Ali Al Sagheer Intermediate School for Girls	32° 3′18.83″N	44°19′16.15″E
29	S29	Najaf Secondary School for Boys	31°59′35.02″N	44°19′26.43″E
30	S30	Al-Karamah Secondary School for Girls	31°58′51.31″N	44°19′49.38″E
31	S31	Amerli Secondary School for Girls	32° 3′9.16″N	44°20′18.63″E
32	S32	Fadak Secondary School for Girls	32° 1′31.66″N	44°22′47.90″E
33	S33	Nasser Hussein Al-Ankoushi Intermediate School for Boys	32° 2′12.33″N	44°21′16.85″E
34	S34	Al-Shadhrawan Intermediate School for Girls	32° 2′12.76″N	44°18′49.21″E
35	S35	Rayat Al-Nasr Intermediate School for Girls	32° 2′35.52″N	44°21′9.29″E
36	S36	Al-Hatem Intermediate School for Boys	32° 4′7.58″N	44°19′57.92″E
37	S37	Imam Zain Al-Adabdin Intermediate School for Boys	32° 1′59.79″N	44°22′44.59″E
38	S38	Al Qawarir Intermediate School for Girls	32° 2′48.34″N	44°21′55.01″E
39	S39	Al-Amirat Intermediate School for Girls	32° 5′19.55″N	44°19′43.33″E
40	S40	Al-Shahba Intermediate School for Girls	32° 1′38.57″N	44°19′59.00″E
41	S41	Asimat Thaqafah Secondary School	32° 2′25.45″N	44°19′12.97″E
42	S42	Newton Secondary School	32° 4′59.55″N	44°17′40.33″E
43	S43	Sama Iraq Secondary School	32° 4′55.92″N	44°19′55.78″E
NO.	Code sample	Name of Samples	Latitude	Longitude
44	S44	Haroof Secondary School	31°59′50.26″N	44°21′4.55″E
45	S45	Al Qassim Secondary School	32° 0′32.59″N	44°19′53.04″E
46	S46	Elia Secondary School	32° 0′37.33″N	32° 0′37.33″E
47	S47	Al Farazdaq Secondary School	32° 0′5.01″N	44°21′15.58″E
48	S48	Imam Ali Secondary School	32° 1′29.01″N	44°20′28.50″E
49	S49	Ibn Al-Haytham Secondary School	32° 0′42.03″N	44°20′49.29″E
50	S50	Ibn Hayyan Secondary School	32° 2′45.99″N	44°20′11.10″E
51	S51	Dar Al Zahraa Schools	31°58′38.06″N	44°21′5.40″E
52	S52	Jinna Road Secondary School Al-	32° 3′39.81″N	44°18′46.33″E
53	S53	Al Khalid Secondary School	32° 1′41.96″N	44°18′51.46″E
54	S54	Al-Qaswa Secondary School	32° 0′4.29″N	44°24′54.90″E
55	S55	Ali Bin Yaqtin Intermediate School	32° 3′32.73″N	44°20′21.88″E
56	S56	Al-Amtiaz Secondary School	32° 1′18.77″N	44°20′55.61″E
57	S57	Al Aqila Secondary School for Girls	32° 2′54.46″N	44°22′23.86″E
58	S58	Secondary Nabras Al-Elm	32° 0′15.95″N	44°21′7.89″E

(*continued on next page*)

Table (1). (continued)

NO.	Code sample	Name of Samples	Latitude	Longitude
59	S59	Al-Rabab Secondary School for Girls	32° 0′34.29″N	44°19′52.19″E
60	S60	Baniqia Secondary School	32° 2′6.88″N	44°20′36.92″E
61	S61	Al Farahidi Secondary School	32° 0′46.95″N	44°20′4.41″E
62	S62	Al-Nakhba Secondary School for Boys	32° 0′28.83″N	44°20′33.37″E
63	S63	Al-mawahib Secondary School	32° 2′18.12″N	44°20′5.61″E
64	S64	Dark Intermediate	32° 3′31.71″N	44°20′39.53″E
65	S65	Ishtar Secondary School for Boys	32° 5′21.74″N	44°19′50.39″E
66	S66	Al-tuwr Intermediate	32° 3′32.49″N	44°17′44.75″E
67	S67	Al Furqan Secondary School	32° 0′38.39″N	44°19′35.50″E
68	S68	ruaad alsalam Secondary School	32° 1′38.90″N	44°23′15.49″E
NO.	Code sample	Name of Samples	Latitude	Longitude
69	S69	Shuhada' Al-Iraq Secondary School for Boys	32° 5′36.93″N	44°18′25.69″E
70	S70	Safi Al Safa Secondary	32° 1′38.70″N	44°19′58.94″E
71	S71	Anwar Al Diaa Intermediate School	32° 4′1.61″N	44°18′52.34″E
72	S72	Beit Al-Hikma Intermediate School	32° 1′52.93″N	44°21′15.59″E
73	S73	Al-Khoranq Secondary School	32° 3′35.63″N	44°21′2.05″E
74	S74	Al Rahman Secondary School	32° 1′32.44″N	44°23′34.42″E
75	S75	Qabas Al-Ghari Intermediate School	32° 2′23.38″N	44°18′58.62″E
76	S76	Baqir Al-Ulum Intermediate School	32° 4′35.07″N	44°18′36.44″E
77	S77	Buratha Secondary School	32° 0′14.92″N	44°20′14.88″E
78	S78	Al-Anwar Al-Muhammadiyah Intermediate School	32° 3′15.88″N	44°19′5.41″E
79	S79	Bilad Al-nahrayn Secondary School	32° 2′38.87″N	44°19′30.94″E
80	S80	Al-HaSanain Intermediate School	32° 6′8.53″N	44°17′41.77″E

$$E_S = \frac{C\,V\,\lambda}{A\,T_e} \quad (6)$$

$$E_M = \frac{C\,V\,\lambda}{M\,T_e} \quad (7)$$

$$T_e = T - \frac{1}{\lambda}\left(1 - e^{-\lambda T}\right) \quad (8)$$

The Excess Lifetime Cancer Risk (ELCR) due to exposure to ^{222}Rn gas concentrations from soil samples has been determined using the results of AED, the duration time (DL), and risk factor (RF),

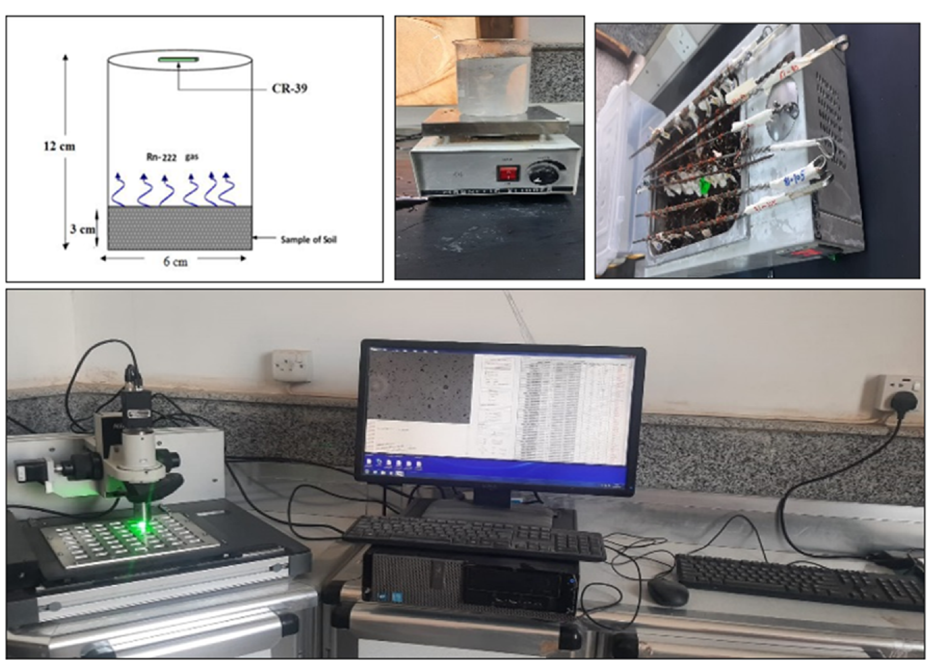

Fig. 2. Sample container, water bath, chemical etching and TASLIMAGE.

the values of DL and RF are 70 years and 0.055 Sv^{-1}, respectively, as in the following formula [25,26]:

$$ELCR = AED \times DL \times RF \quad (9)$$

6. Results and discussion

All results of Radon gas concentrations and also radiological associated risks are found in Table (2). The minimum and maximum values of Radon in the air space tube (C) were 0.12 Bq/m^3 and 180 Bq/m^3 in sample code S33 (Nasser Hussein Al-Ankoushi Intermediate School for Boys), with an average value of 64.33 Bq/m^3, and the minimum and maximum values for Radon concentration in the sample(C_{Rn}) were 5.83Bq/m^3 in sample code S15 (Khawla Bint Al Azwar Secondary School for Girls), and the maximum value was 8816.04 Bq/m^3 in sample code S33 (Nasser Hussein Al-Ankoushi Intermediate School for Boys), with an average valu of 3150.70 Bq/m^3. At same time, the minimum and maximum values of Radium concentration in the sample (C_{Ra}) were 0.0008 Bq/Kg in sample code S15 (Khawla Bint Al Azwar Secondary School for Girls), and 12.0941 Bq/Kg in code sample S34 (Al-Shadhrawan Intermediate School for Girls, with average values of 4.4254 Bq/Kg and for Uranium the minimum value was 0.0033 ppm in sample code S7 (Dr. Mahdi Al-Makhzoumi Secondary School for Girls) and the maximum value was 6.6835 ppm in sample code S34 (Al-Shadhrawan Intermediate School for Girls) with average value 1.9932 ppm, respectively.

For associated radiological risks, the minimum and maximum values of Annual Effective Dose (AED) were 0.0005 (mSv/yr) in sample code S15 (Khawla Bint Al Azwar Secondary School for Girls), and 0.738 (mSv/yr) in sample code S33 (Nasser Hussein Al-Ankoushi Intermediate School for Boys) with average value 1.623 (mSv/yr). At the same time, the minimum values of Radon mass exhalation rate (E_M) was 0.0.002 (mBq/Kg.h) in code sample S15 (Khawla Bint Al Azwar Secondary School for Girls) and code sample S53 (Al Khalid Secondary School) and 0.011 (mBq/Kg.h) in sample code S15 (Khawla Bint Al Azwar Secondary School for Girls), while the maximum was in sample code S34 (Al-Shadhrawan Intermediate School for Girls) with average value 0.815 (mBq/Kg.h), the minimum

Table (2). Radon in air space tube (C), Radon concentration in the sample(C_{Rn}), Radium concentration in the sample(C_{Ra}), Uranium concentration in the sample(C_U), Annual Effective Dose(AED), Radon surface exhalation rate (E_S), mass exhalation rate (E_M), and Excess live cancer risk (ELCR).

Sample Code	C (Bq/m^3)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/kg)	C_u (ppm)	AED (mSv/y)	E_M (mBq/kg.h)	E_S (mBq/m^2.h)	ELCR X10^{-3}
S1	119.25	5840.43	0.1685	3.6991	0.4889	1.520	115.213	1.711
S2	124.52	6098.93	0.1515	2.8652	0.5105	1.367	120.312	1.787
S3	1.39	68.03	0.0017	0.0335	0.0057	0.016	1.342	0.020
S4	1.75	85.52	0.0025	0.0542	0.0072	0.022	1.687	0.025
S5	3.33	163.26	0.0043	0.0872	0.0137	0.039	3.221	0.048
S6	152.26	7457.48	0.2361	5.6899	0.6242	2.130	147.112	2.185
S7	0.16	7.77	0.0002	0.0033	0.0007	0.002	0.153	0.002
S8	138.57	6786.95	0.1655	3.0698	0.5681	1.493	133.885	1.988
S9	129.25	6330.21	0.1900	4.3404	0.5299	1.714	124.875	1.855
S10	3.73	182.70	0.0046	0.0892	0.0153	0.042	3.604	0.054
S11	145.91	7146.51	0.1903	3.8568	0.5982	1.717	140.978	2.094
S12	138.13	6765.57	0.1963	4.3331	0.5663	1.771	133.463	1.982
S13	88.06	4312.79	0.1160	2.3760	0.3610	1.047	85.078	1.263
S14	87.10	4266.14	0.1351	3.2550	0.3571	1.219	84.157	1.250
S15	0.12	5.83	0.0002	0.0039	0.0005	0.002	0.115	0.002
S16	83.37	4083.44	0.1152	2.4751	0.3418	1.040	80.553	1.196
S17	0.71	34.98	0.0010	0.0205	0.0029	0.009	0.690	0.010
S18	3.69	180.75	0.0050	0.1061	0.0151	0.045	3.566	0.053
S19	75.95	3720.00	0.1178	2.8383	0.3114	1.063	73.384	1.090
S20	2.46	120.50	0.0034	0.0747	0.0101	0.031	2.377	0.035
S21	3.21	157.43	0.0048	0.1118	0.0132	0.043	3.106	0.046
S22	128.33	6285.51	0.2053	5.1021	0.5261	1.852	123.993	1.841
S23	0.60	29.15	0.0009	0.0193	0.0024	0.008	0.575	0.009
S24	109.92	5383.69	0.1580	3.5264	0.4506	1.425	106.203	1.577
S25	104.37	5111.59	0.1295	2.4960	0.4279	1.168	100.836	1.498
S26	2.94	143.82	0.0040	0.0853	0.0120	0.036	2.837	0.042
S27	91.63	4487.71	0.1195	2.4219	0.3756	1.078	88.528	1.315
S28	70.95	3475.11	0.0945	1.9548	0.2909	0.852	68.553	1.018
S29	4.05	198.24	0.0057	0.1228	0.0166	0.051	3.911	0.058

(continued on next page)

Table (2). (continued)

Sample Code	C (Bq/m^3)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/kg)	C_u (ppm)	AED (mSv/y)	E_M (mBq/kg.h)	E_S ($mBq/m^2.h$)	ELCR $X10^{-3}$
S30	149.40	7317.55	0.1910	3.7919	0.6125	1.723	144.352	2.144
S31	97.26	4763.69	0.0990	1.5641	0.3987	0.893	93.973	1.396
S32	84.13	4120.37	0.1216	2.7297	0.3449	1.097	81.282	1.207
S33	180.00	8816.04	0.2435	5.1187	0.7379	2.197	173.912	2.583
S34	141.75	6942.44	0.2469	6.6835	0.5811	2.227	136.952	2.034
S35	107.50	5265.14	0.1677	4.0666	0.4407	1.513	103.864	1.543
S36	103.97	5092.16	0.1349	2.7201	0.4262	1.217	100.452	1.492
S37	3.06	149.66	0.0044	0.0969	0.0125	0.039	2.952	0.044
S38	0.99	48.59	0.0014	0.0301	0.0041	0.013	0.959	0.014
S39	50.16	2456.67	0.0701	1.5220	0.2056	0.632	48.462	0.720
S40	7.38	361.50	0.0101	0.2168	0.0303	0.092	7.131	0.106
S41	110.04	5389.52	0.1435	2.9086	0.4511	1.295	106.318	1.579
S42	110.20	5397.30	0.1467	3.0360	0.4518	1.324	106.472	1.581
S43	5.36	262.38	0.0066	0.1257	0.0220	0.059	5.176	0.077
S44	4.13	202.13	0.0057	0.1212	0.0169	0.051	3.987	0.059
S45	95.04	4654.85	0.1389	3.1551	0.3896	1.253	91.825	1.364
S46	163.21	7993.91	0.2118	4.2702	0.6691	1.911	157.694	2.342
S47	5.40	264.33	0.0073	0.1535	0.0221	0.066	5.214	0.077
S48	7.02	344.01	0.0097	0.2085	0.0288	0.088	6.786	0.101
S49	161.55	7912.28	0.2446	5.7528	0.6623	2.206	156.084	2.318
S50	4.01	196.30	0.0058	0.1315	0.0164	0.053	3.872	0.058
S51	3.57	174.92	0.0056	0.1351	0.0146	0.050	3.451	0.051
S52	5.00	244.89	0.0088	0.2424	0.0205	0.080	4.831	0.072
S53	0.20	9.72	0.0003	0.0054	0.0008	0.002	0.192	0.003
S54	3.65	178.81	0.0051	0.1108	0.0150	0.046	3.527	0.052
S55	1.47	71.91	0.0021	0.0471	0.0060	0.019	1.419	0.021
S56	119.33	5844.32	0.1909	4.7439	0.4892	1.722	115.290	1.712
S57	45.52	2229.28	0.0737	1.8559	0.1866	0.665	43.977	0.653
S58	70.36	3445.95	0.1000	2.2070	0.2884	0.902	67.978	1.010
S59	5.24	256.55	0.0063	0.1194	0.0215	0.057	5.061	0.075
S60	3.13	153.54	0.0039	0.0742	0.0129	0.035	3.029	0.045
S61	0.36	17.49	0.0006	0.0149	0.0015	0.005	0.345	0.005
S62	2.34	114.67	0.0029	0.0577	0.0096	0.027	2.262	0.034
S63	1.27	62.19	0.0021	0.0524	0.0052	0.019	1.227	0.018
S64	19.88	973.73	0.0318	0.7904	0.0815	0.287	19.209	0.285
S65	107.14	5247.64	0.1594	3.6827	0.4393	1.438	103.519	1.537
S66	0.56	27.21	0.0008	0.0200	0.0023	0.008	0.537	0.008
S67	95.28	4666.52	0.1496	3.6489	0.3906	1.349	92.056	1.367
S68	150.32	7362.25	0.1991	4.0983	0.6163	1.796	145.234	2.157
S69	2.94	143.82	0.0050	0.1312	0.0120	0.045	2.837	0.042
S70	132.46	6487.64	0.1970	4.5530	0.5430	1.777	127.981	1.901
S71	144.56	7080.43	0.1585	2.6995	0.5927	1.430	139.674	2.074
S72	71.47	3500.37	0.1076	2.5150	0.2930	0.970	69.051	1.025
S73	128.13	6275.79	0.1689	3.4574	0.5253	1.523	123.801	1.839
S74	140.91	6901.62	0.1969	4.2757	0.5777	1.776	136.147	2.022
S75	65.00	3183.57	0.1088	2.8277	0.2665	0.981	62.802	0.933
S76	132.38	6483.75	0.1791	3.7645	0.5427	1.616	127.904	1.900
S77	2.06	101.07	0.0034	0.0863	0.0085	0.031	1.994	0.030
S78	77.42	3791.91	0.1100	2.4286	0.3174	0.992	74.802	1.111
S79	82.94	4062.06	0.1226	2.8177	0.3400	1.106	80.132	1.190
S80	124.17	6081.44	0.1891	4.4748	0.5090	1.706	119.967	1.782
Average ± S.D	64.329 ± 6.571	3150.699 ± 321.867	4.425 ± 0.082	1.993 ± 0.209	0.264 ± 0.026	0.815 ± 0.083	62.153 ± 6.349	0.923 ± 0.094

and maximum values of surface exhalation rate (E_S) were 0.115 ($mBq/m^2.h$) in code sample S15(Khawla Bint Al Azwar Secondary School for Girls), with 173.912 ($mBq/m^2.h$) in sample code S33 (Nasser Hussein Al-Ankoushi Intermediate School for Boys) with average value of 62.153 ($mBq/m^2.h$). Lastly, the minimum, maximum, and average values of Excess live cancer risk (ELCR) were 0.002×10^{-3}, 15.894×10^{-3} and 2.583×10^{-3} respectively.

According to the values and findings in results, For C and C_{Rn} the acceptable limit is the world average of radon gas in air between (100–300) Bq/m^3 according to WHO (World Health Organization), so about twenty-eight samples (S1, S2, S6, S8,

S9, S11, S12, S22, S24, S25, S30, S33, S34, S35, S36, S41, S42, S46, S49, S56, S65, S68, S70, S71, S73, S74, S76, and S80) exceeded the standard acceptable limit of radon gas in air, and 7400 Bq/m^3 according to UNSCEAR 2008 so that eight sample (S6, S11, S30, S33, S46, S49, S68 and S71) exceed the pre-assemble acceptable limit of C_{Rn} [22,27]. The activity concentration of radon can fluctuate due to various geological and environmental factors. The Geological factors could be changes in soil moisture; increased soil moisture can lead to higher radon emanation, while dry soil can reduce radon activity. Also, tectonic activity such as Earthquakes, fault movements, or volcanic activity can alter the radon migration pathways, leading to changes in activity concentrations. The environmental factors include human activities like Construction, mining, or drilling can alter the soil and rock structure, leading to changes in radon activity concentrations. Groundwater flow then made Changes in groundwater flow or level can impact radon migration and activity concentrations. And if we know that the soil of the city of Najaf is sandy and the soil of the city of Kufa is clayey, as it is considered an agricultural area [25]. This means, these factors can interact with each other in complex ways, making it challenging to pinpoint a single reason for changes in radon activity concentrations. At the same time, C_{Ra} and C_U were below 35 Bq/Kg and 11 ppm [26,27]. The AED was under the acceptable limit according to ICRP [28]. Also, Es, $E_{M,}$ and ELCR were below the recommended health organization [29]. Finally, when compared the average values in this study with other similar related studies, it could be said that these values were lower the acceptable limits [1,5,30–32].

All these values were plotted and mapped using the GIS (ArcGIS 10.7.1.) technique, showing the minimum, intermediate, and maximum values, as in Figs. (3) and (4).

7. Descriptive statistics

All variables in areas under study were analyzed and drawn with the SPSS program version 26.0, using pearson correlation, and all variable statistics were shown in Table (3). Also, Fig. (5) show the Dual-axis of radon concentration in air with radium and uranium concentrations, which show a true and significant relation at p-value <0.05, and in Fig. (6), show the Simple 3-D Scatter plot pervasion of Radon Concentration in Air (Bq/m^3) by (AED (mSv/year) by ELCR $X10^{-3}$) and (E_M(mBq/kg.h) by E_A($mBq/m^2.h$)), respectively which also show a true and significant relation at p-value <0.05.

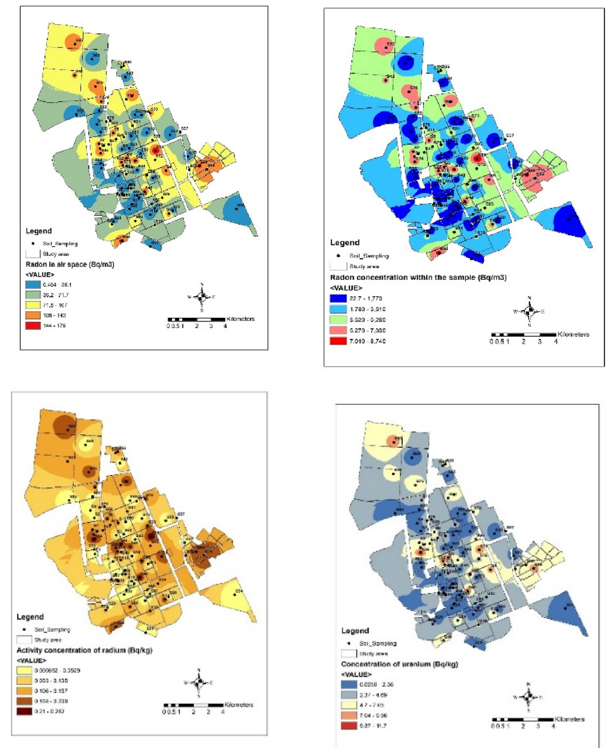

Fig. 3. Radiation maps of radon in air space (C), Radon concentration within sample (C_{Rn}), Activity concentration of Radium and Concentration of Uranium (U).

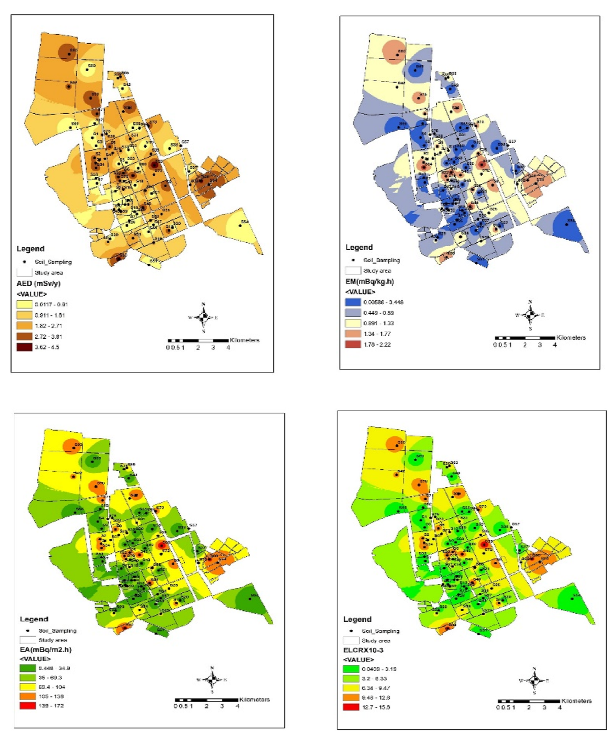

Fig. 4. Radiation-associated radiological risks maps of Annual Effective Dose (AED), Radon surface exhalation rate (ES), mass exhalation rate (EM), and Excess Live Time risk (ELCR).

Table (3). Descriptive Statistics for all variables under study.

		Sample Code	C (Bq/m^3)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/Kg)	U (ppm)	AED (mSv/year)	E_M(mBq/kg.h)	E_A(mBq/m^2.h)	ELCR X10^{-3}
N	Valid	80	80	80	80	80	80	80	80	80
	Missing	0	0	0	0	0	0	0	0	0
Mean			64.329	3150.699	0.090	1.993	0.263	0.815	62.153	0.92309
Median			71.210	3487.740	0.103	2.291	0.291	0.936	68.802	1.02150
Mode			2.94	143.82	0.0002[a]	0.0033[a]	0.012	0.0020	2.837	0.002[a]
Std. Deviation			59.149	2897.036	0.083	1.881	0.242	0.7509613	57.149	0.848
Variance			3498.639	8392821.822	0.007	3.540	0.059	0.564	3266.038	0.720
Range			179.88	8810.21	0.246	6.680	0.737	2.225	173.797	2.581
Minimum			0.12	5.83	0.0002	0.003	0.001	0.002	0.115	0.002
Maximum			180.00	8816.04	0.246	6.683	0.738	2.227	173.912	2.583
Sum			5146.33	252055.92	7.228	159.453	21.098	65.211	4972.262	73.847

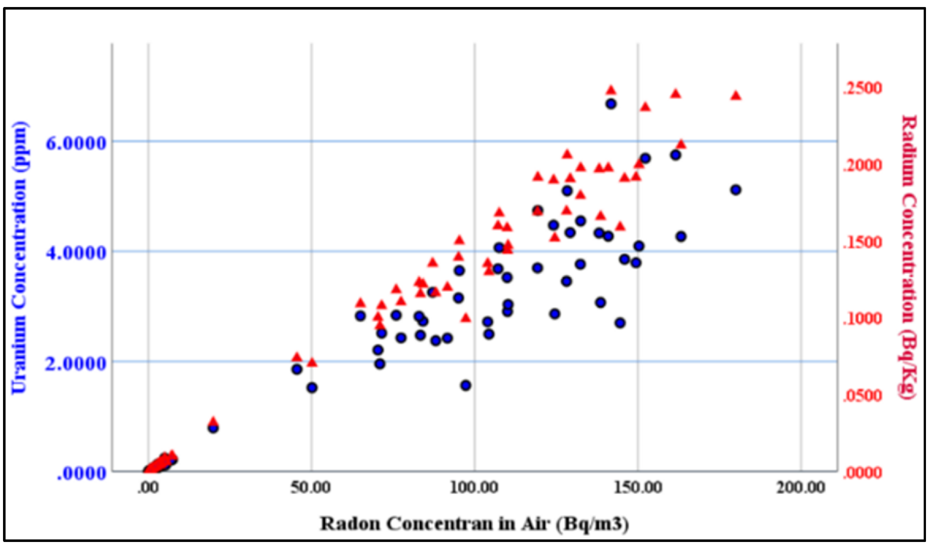

Fig. 5. Dual-axis of radon concentration in air with radium and uranium concentrations.

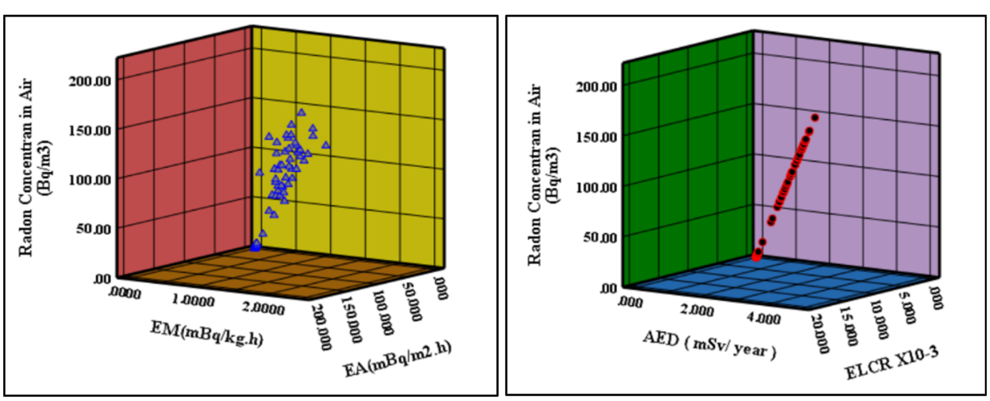

Fig. 6. Simple 3-D Scatter of Radon Concentration in Air (Bq/m^3) by (AED (mSv/year) by ELCR X10^{-3}) and (E_M(mBq/kg.h) by E_A(mBq/m^2.h)), respectively.

8. Conclusion

The study of radon concentration in soil containers for soil samples in the secondary schools in Najaf and Kufa cities indicates normal levels. The average values of C and C_{Rn} were higher than the internationally acceptable limits for some samples, whereas C_{Ra} and C_U values were significantly lower than the worldwide limit. The surface exhalation rate Es and mass exhalation rate E_M results are lower than the global limit. The measurements of (AED) for studied secondary schools are lower than those of ICRP and lower than the results of UNSCEAR, respectively. As a result, the occupants of these secondary schools (children and staff) are not at risk of radiological exposure from their immediate surroundings. Further research, periodically scan and monitoring with expanding the area to other cities in al-Najaf goernorate would be necessary to understand the specific causes of changes in a particular area.

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Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval

All soil samples were collected from public areas with no disturbance to private property. No human or animal subjects were involved, and all radiation safety procedures were followed.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions

Each author Rafal Mohamed Abdulsada and Lubna A.Alasadi subscribes to conceiving and designing the analysis; collecting the data; Contributing data or analysis tools; performing the analysis, and writing the paper.

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