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Radon gas in the indoor air of primary schools of Al-Najaf city, Iraq

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Abstract: The indoor radon concentration of 100 primary schools in Al-Najaf province, Iraq, was measured to determine students' and staff's safety in these schools using a CR-39 nuclear track detector based on the sealed can improve technique. The results of indoor radon concentration for all schools vary from (7.47 to 44.84) Bq / m^3 with an arithmetic mean (AM) of 22.26 Bq /, while the geometric mean (GM) was 20.67 Bq / m^3. The concentration of ^{222}Rn was lower than the worldwide level. Some radiological parameters like annual effective dose (AED), potential alpha energy (PAEC), exposure to radon progeny (EP), and lung cancer cases per year per million people (CPPP) were also determined. The results of these parameters point toward normal levels in the primary schools, according to ICRP, UNCER, and NCRP data.

Keywords: Indoor radon, CR-39 detector, annual effective dose, primary schools, Al-Najaf province.

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1. INTRODUCTION

Radon is the naturally occurring radioactive gas formed by uranium's radioactive decay. Natural uranium (mainly ^{238}U) is found among most earthen construction materials and is present in the earth's crust at an average of 33Bq/m^3 (1). There are two primary radioisotopes for radon in nature: - ^{222}Rn (also known as radon with half-live $T_{1/2}$=3.82 day) with its short-lived daughters: ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, ^{210}Po (uranium sequence). The second isotope is ^{220}Rn (commonly known as thoron with a half-live T1/2=55.6s with its daughters: ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po, and ^{208}Tl (thorium sequence) (2). Although radon evaporates quickly if released into the open air, it could concentrate and accumulate to dangerous levels throughout the built environment. Indoor radon can have both external and internal sources. The external source is primarily outdoor air, while internal sources include soil, construction materials, basement air, and water. In most cases, higher indoor radon concentrations result from increased radon formation and mobility in soils, as well as fissures in floor slabs and other pores in the building's foundation. Typically, the radon concentration in outdoor air at 1 meter above ground is between 4 and 15 Bqm^{-1}. Depending on factors like uranium content and the soil's moisture, humidity, winds, and building materials, the radon concentration in indoor air might change from region to region. Because of the elevated radon concentrations in indoor areas of closed buildings, inhalation of air is one of the main causes of radiation exposure for humans. Radon and its daughters are in secular equilibrium in a closed system. However, this equilibrium cannot be conserved in a residential environment because daughters are constantly eliminated from the interior air through radioactive disintegration, surface deposition, and ventilation. The main causes of variation in indoor radon concentrations are often variations in ventilation rate, pressure, and temperature. The rate of air exchange between indoor and outdoor settings is affected by the ventilation rate. When radon becomes trapped indoors, particularly during temperature inversions or when homes are not vented (naturally or artificially), it will accumulate to unsafe levels. The radon concentration in the environment varies with time, meteorological circumstances, and the air mass source at a sample site (2, 3). Long-term radon exposure may irradiate lung tissue, raising the risk of developing cancer. Inhalation of the short-lived radon daughters is predicted to produce roughly half the effective dosage of natural sources. As a result, radon is currently the most "popular" issue in environmental radioactivity research (4). When radon and its daughters were breathed, the α−particles released by the depositing radon progeny predominated the radiation dosage for lung tissue. These progenies, particularly those adhering to tiny aerosols or those that stay unattached, cause harm to sensitive lung cells, raising the developing cancer risk. As a result, radon primarily serves as the origin of its daughters, which provide the lung dose (5). Lung cancer risk is elevated by 8.4% for every 100 Bq/m^3 (2.7 pCi/L) elevation in detected radon. Domestic studies show a link between radon exposure at home and an increased risk of lung cancer. WHO (the World Health Organization) and USEPA (the United States Environmental Protection Agency) list radon as one of the primary causes of lung cancer, next to smoking. According to studies on radon's behavior in the geological environment, there is a clear relationship between indoor radon levels and soil gas concentrations. As a result, conducting radon concentration studies at as many home and school locations as feasible would be one of the more efficient and expedient methods of lowering potential threats for children in schools and other facilities. Radon exposure in schools could have significant public health effects. The risk of lung cancer from radon exposure in children may be up to three times higher than that of adults exposed to the same amount of radon due to morphologic distinctions between children's and adults' lungs and faster respiration rates in children. Children are more susceptible to environmental risks as well as spending extra time inside. (6, 7). For these reasons, there has been a rise in interest in indoor radon assessments in primary schools. As a result, assessing indoor radon levels in these facilities is important. Radon studies have been done widely in several countries (8–11). This study aimed to determine radon concentration and its risks to human health in one hundred primary schools in Al-Najaf province and to calculate the annual effective dose of radon for students and teachers in primary schools. Potential alpha energy concentration, exposure to radon progeny, and lung cancer cases per year per million people (CPPP) were calculated using CR-39 nuclear track detector (NTDs).

1.1. Sampling Sites

The studied area of Najaf (Figure 1) is located in southwestern Iraq, about 160 km southwest of Baghdad. It is situated at the intersection of line length 44.019E and latitude 31.059N. It is rising 70 meters above sea level (12). One hundred primary public schools were chosen to study the indoor radon concentration in these schools in Najaf city. The location of schools in the current research was identified using a GPS and plotted using a GIS approach (ArcGIS 10.7.1.) as depicted in Figure 1.

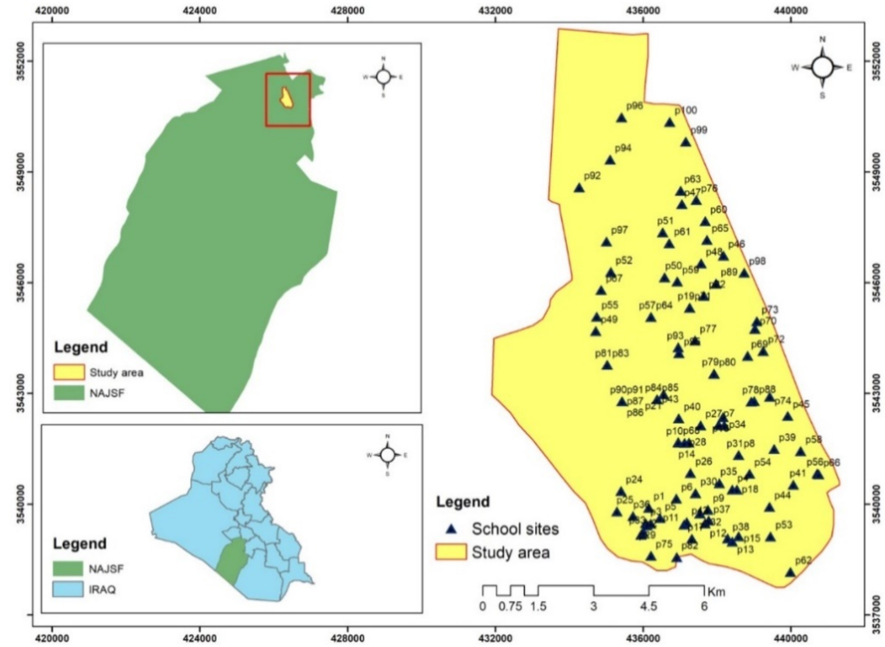

Figure 1: A map of the field of study.

2. MATERIAL AND METHOD

Radon concentration levels were assessed in 100 schools throughout the AL- Najaf city area using the solid state nuclear track detectors (SSNTDs) technique with a CR-39 detector. The dosimeter measures ^{222}Rn in a very reproducible and unambiguous manner. One detector was exposed in each school's classroom, away from the doors and windows, and located in an inaccessible area to reduce loss throughout measurement time. In each of the 100 schools, around one hundred detectors were distributed. Age, size, and construction materials vary among the school buildings. Natural ventilation is provided by windows as well as fans. A passive track detector inside a sealed hollow holder, which allows ^{222}Rn to penetrate it, is used to investigate radon concentration and the annual effective dose within elementary schools.

The hollow holder has a diameter of 5.2 cm and a height of 9 cm. A circular aperture with a radius of 0.75 cm is drilled in the middle of the lid. A 3 cm × 3 cm sponge piece with a thickness of 0.3 cm is glued onto the internal surface of the lid to enclose the aperture. A bit of CR-39 with an area of around 2.5 cm × 2.5 cm and a thickness of 1 mm, density 0.32 gm/m^3, is placed inside the holder and settled to its bottom with double-sided adhesive tape. The holder is placed around 1.5 m above the floor to represent the exhalation height inside the classrooms. The can's design guarantees that all aerosols and radon daughters are deposited from outside on the soft sponge while radon, along with other components, passes across it to the can's sensitive region. This type of detector generates data that correlate to the accurate mean radon concentration during the period of exposure, which extends from March to July 2022. The number of tracks left by alpha particles on the detector was proportional to the average radon concentration. After the end of the exposure time, the detectors were removed from the containers and placed in a solution of NaOH of about 6.25 N in a water bath at 98 C for one hour (13). The detectors were eliminated from the bath and adequately rinsed and cleaned using distilled water to eliminate surface digging leftovers. Following the chemical process, these detectors were dry. They scanned with an optical microscope at a magnification of about (400X) connected to a micro camera connected to a personal computer to count the number of tracks per cm^2 in each detector according to the following equation (14).

The density of tracks $(\rho)=\frac{number\ of\ tracks\ in\ sample}{Area\ of\ field\ view}$ (1)

2.1. Theoretical Considerations

2.1.1. Radon Concentrations

Radon concentration levels in the air of specific schools in Al-Najaf city are evaluated in the unit (Bq / m^3), in which the highest degree reference levels are calculated. The following equations are employed to calculate radon concentration (15, 16).

$$C = \frac{\rho}{k\,t} \quad (2)$$

ρ is the evaluated number of tracks for every cm^2 on the CR-39 detectors within the spread dosimeters utilized in the research, t would be the exposure time of the CR-39 detector (90 days), and k is a calibration factor equal to 0.28 Track.cm^{-2} / Bq.m^{-3}.day.

2.2.2. Annual Effective Dose (AED)

The annual effective dose (AED) in (mSv/y) units is directly affected by the occupancy factor (H), which can be calculated for students and teachers in schools by the following equation:

30 h/wk × 37 d /y = 1110 hours per year

H = 1110 / 8760 = 13%

The annual effective dose can be calculated as (17, 18):

$$AED\ (m\ Sv/y) = C \times F \times H \times T \times D \quad (3)$$

Where; F indicates the worldwide average of the equilibrium factor of radon and its daughters equal to (0.4).

T=8760 h/y, which represents the time in hours per year

D: represents the dose conversion factor and equal (9×10^{-6}(m Sv) /(Bq.h.m^{-3}))

2.2.3. PAEC, EP, CPPP

Potential Alpha Energy Concentration (PAEC) can be calculated using the following equation (19-21):

$$PAEC\ (WL) = F \times C / 3700 \quad (4)$$

The following equation can be used to evaluate Exposure to radon progeny (EP) (22):

$$EP\ (WLM\ Y^{-1}) = T\times H \times F \times C / 170 \times 3700 \quad (5)$$

170 : is the number of hours spent per month.

WL represents the working level, in which (1WL = 3.7 Bq / L= 3.7× 103PP Bq / m^3) .

Where 1 L=1000 m^3

The lung cancer cases per year per million person (CPPP) were found by using the equation (19, 23, 24):

$$CPPP = AED \times (18\times10^{-6}\ mSv^{-1}.y) \quad (6)$$

3. RESULTS AND DISCUSSION

This study covered the public primary schools in Najaf, Iraq, in which 100 classrooms on the ground floor from 100 schools were chosen to measure indoor radon using the passive technique with a CR39 detector. The study area is divided into 22 districts. The descriptive statistics of the results for indoor radon concentration are summarized in Table 1. The results of indoor radon concentrations for all schools vary from (7.47 to 44.84) Bq / m^3 with an arithmetic mean (AM) 22.26 Bq / m^{3}and standard deviation (SD) 8.43. The geometric mean (GM) was 20.67 Bq / m^3 with a geometric standard deviation (GSD) of 1.48. The Abotalib district has the maximum indoor radon concentration with an arithmetic mean (32.14) Bq / m^3 and a standard deviation of 2.25, whereas the geometric mean was 32.06 Bq / m^3 with a geometric standard deviation of 1.1. The minimum indoor radon concentration was in the AL Gari district, with AM equal to 12.74 Bq / m^3 and SD equal to 3.30, while GM was 12.24 Bq / m^3 with a GSD of 1.41. The maximum radon concentrations seemed to be below the worldwide average of radon gas in air (100) Bq/m^3 according to WHO (25), as shown in Figure (2). The variation in indoor radon results between different schools is due to geological considerations, ventilation, and the type of soil in the schools.

Table 1: Descriptive statistics of indoor radon concentrations for studied schools.

District	N°. Of Schools	AM (Bq/m^3)	SD (Bq/m^3)	Min (Bq/m^3)	Max (Bq/m^3)	GM (Bq/m^3)	GSD
old city	15	21.03	9.46	8.97	40.36	18.87	1.64
Al.Karama	4	20.55	3.72	14.95	25.41	20.19	1.25
Al.Moalmen	5	21.67	4.38	16.44	26.9	21.23	1.25
Alhussein	4	19.80	5.83	10.46	25.41	18.75	1.49
Al.Ameer	4	31.82	7.95	24.14	44.84	30.92	1.31
Al.Ansar	6	23.42	9.52	13.45	40.36	21.67	1.53
Al.Zahraa	6	20.99	4.18	13.45	25.41	20.53	1.27
AL gari	4	12.74	3.30	7.47	16.59	12.24	1.41
Aloroba	4	17.19	6.02	10.46	26.9	16.22	1.48
Al.Mothana	4	25.78	4.65	17.94	29.89	25.30	1.26
Aladala	3	27.77	3.06	23.91	31.39	27.60	1.15
Alwafaa	5	28.92	9.004	17.56	41.1	27.49	1.43
Al.Askary	6	26.90	6.85	14.95	34.38	25.88	1.38
Alnasor	2	19.24	2.81	16.44	22.05	19.04	1.23
Alresalah	3	19.06	2.42	16.81	22.42	18.91	1.16
Alnidaa	5	19.13	3.19	14.95	23.91	18.86	1.21
Aljamea	4	25.04	10.27	14.95	40.36	23.04	1.59
Alsalam	5	19.13	6.08	11.96	28.4	18.20	1.423
Alforat	3	27.77	10.263	13.45	36.98	25.38	1.74
Abotalib	2	32.14	2.25	29.89	34.38	32.06	1.10
Alrahma	4	14.95	5.69	7.47	22.42	13.77	1.62
Algahdeer village	2	16.45	1.49	14.95	17.94	16.38	1.14
All	100	22.26	8.43	7.47	44.84	20.68	1.48

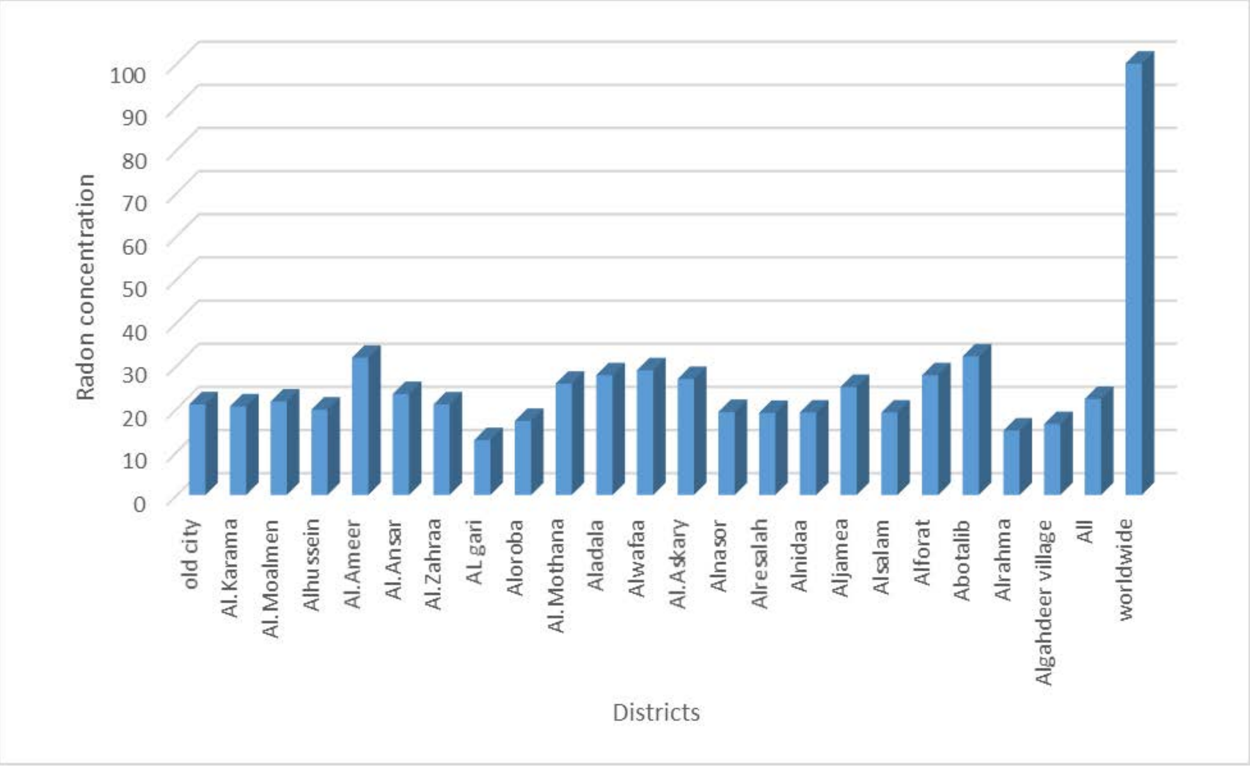

Figure 2: Indoor radon concentrations at the primary schools in the districts of AL- Najaf city.

The frequency distribution of indoor radon levels in investigated schools is illustrated in Figure (3), which explains the normal distribution of indoor radon for all schools under study. The skewness of this distribution, indicating its deviation from a symmetrical normal distribution, is 0.608, suggesting a positive skew in indoor radon levels. This skewness implies that many indoor radon test results have lower values, with means exceeding the medians. The central tendency of the positively skewed data is also illustrated in figure (4), which represents the box plot of the indoor radon concentration for the primary schools. It is clear that quartile Q2 exists nearer to quartile Q1, and the mean value is larger than the median. Also, the length of the upper whisker is greater than that of the bottom. All this refers to a positively skewed distribution. The kurtosis of this distribution, which tested whether the results were heavy-tailed or light-tailed compared to the normal distribution, is (-0.029), indicating that the distribution is a platykurtic distribution. This means that the majority of the indoor radon results are very close to the mean value. Figure (5) represents the normal quantile-quantile plot (Q-Q plot) for radon concentration for all schools under study, assessing indoor radon results relative to the normal distribution. We can see from this plot that our results are normally distributed. Also, the ends of the Q-Q plot deviated with a slight deviation from the normal distribution reference line, indicating there is a thin-tailed distribution (platykurtic distribution).

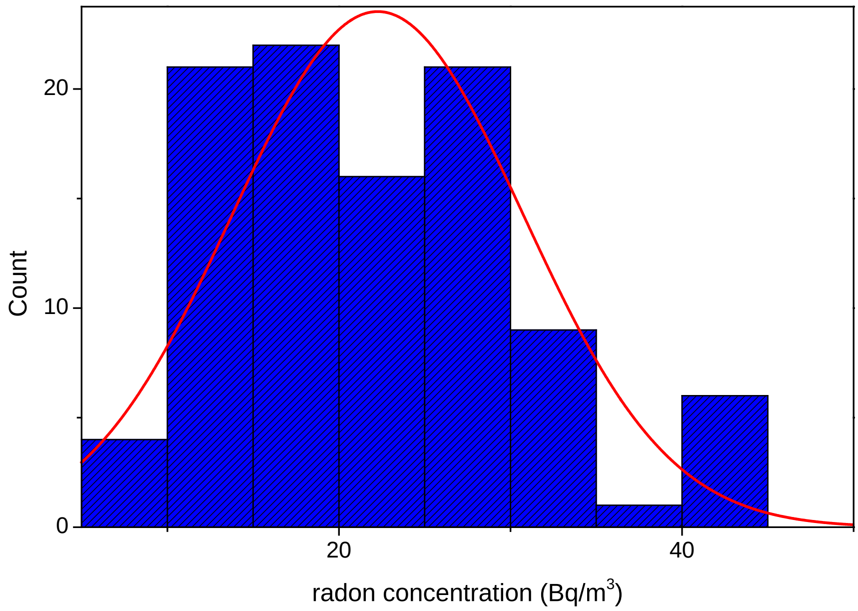

Figure 3: Histogram of indoor radon concentrations at the primary schools in the AL- Najaf city.

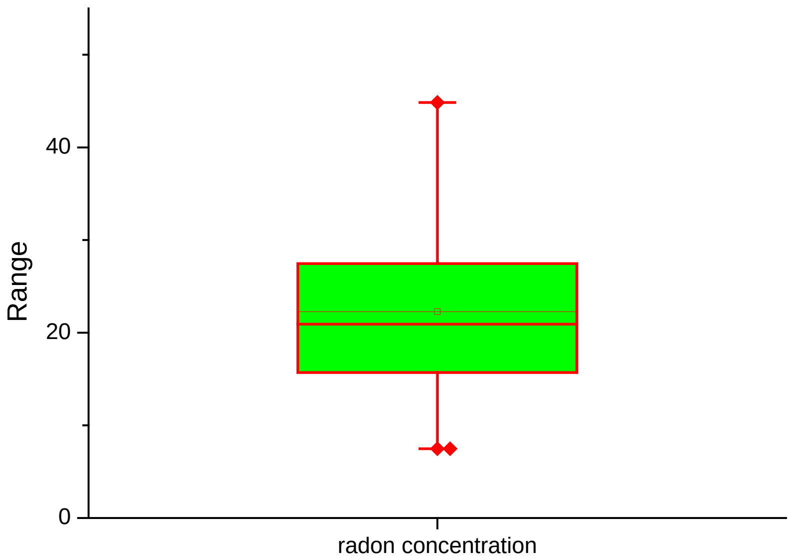

Figure 4: Box plot of indoor radon concentrations at the AL- Najaf city primary schools.

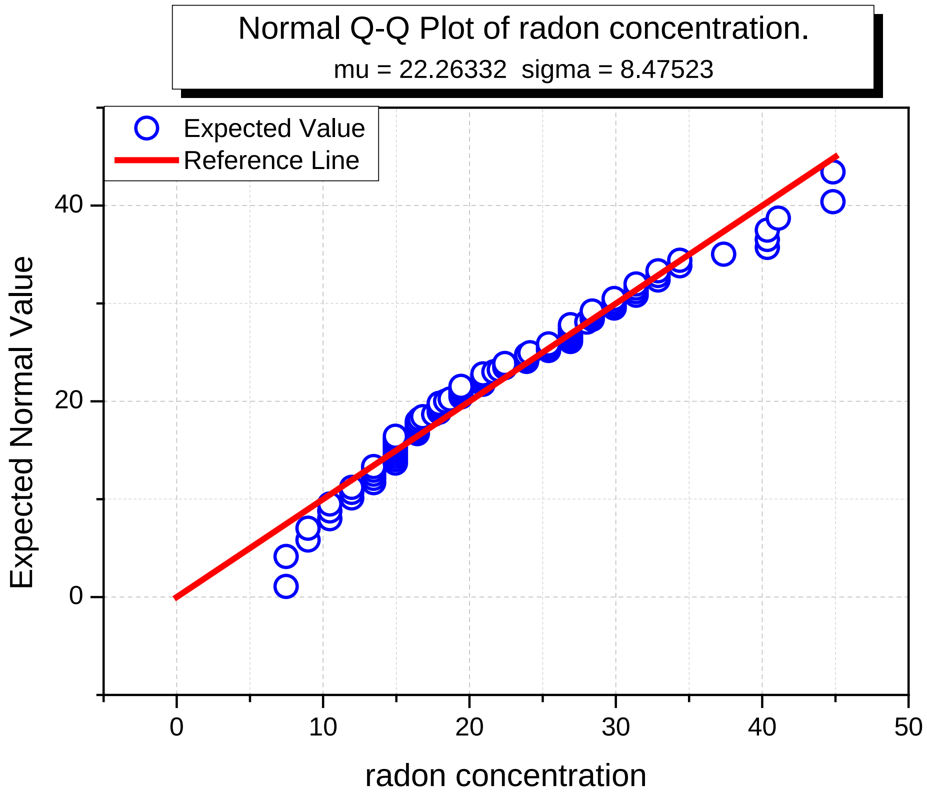

Figure 5: Normal quantile plot of indoor radon concentrations at the investigated primary schools.

Figure 6 displays the relationship between the indoor radon levels and the school buildings' age. The higher level of indoor radon was in buildings with ages between 1979 and 1999 (consisting of 36 schools), while the lower level was in schools between 1919-1939 (consisting of 3 schools).

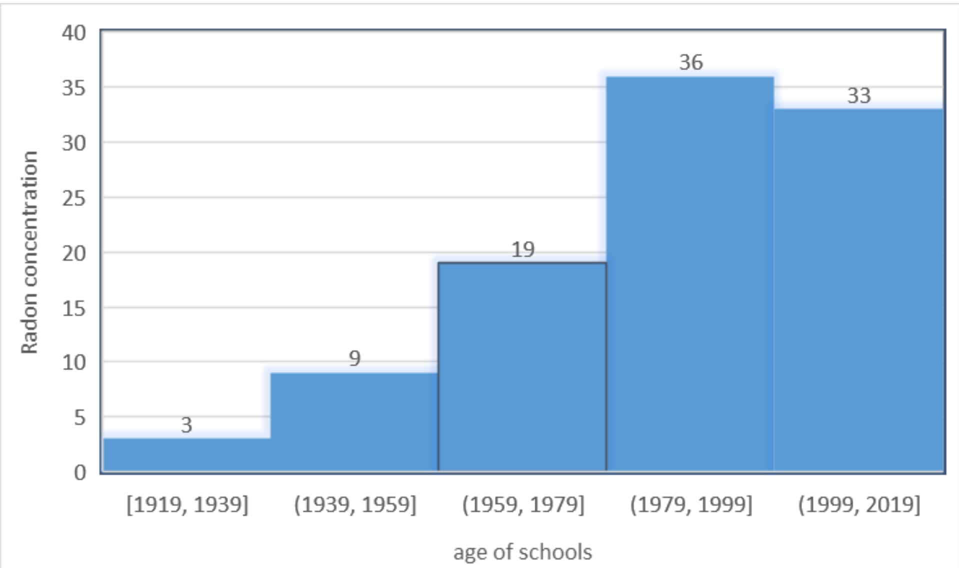

Figure 6: The relation between radon concentration in studied schools and the age of schools.

Table 2 displays the results of the annual effective dose (AED), potential alpha energy concentration (PAEC), exposure to radon progeny (EP), and lung cancer cases per year per million people (CPPP) for the primary schools in the districts of AL- Najaf city. The maximum values of AED, PAEC, EP, and CPPP were 0.132 mSv/y, 3.474 mWL, 23.272 mWLM Y^{-1}, and 2.371, respectively, found in Abotalib district. The minimum values of AED, PAEC, EP, and CPPP were 0.052 mSv/y, 1.377mWLM, 9.228 mWLM Y^{-1}, and 0.940, respectively, and found in the AL gari district. The maximum values of AED are much lower than the (ICRP,1993) limit that lies between 3 and 10 mSv/y (26). PAEC results were significantly lower than (UNCER,1993) (27) level that equals 53.33 mWL, and the measurements of EP lowered the recommended values of (NCRP,1989) (28) that range between (1-2) mWLM Y^{-1}. The results of CPPP were below the values of (ICRP ,1993) (26) limit that lies between 170 and 230 per year per million people. Figure 7 illustrates the annual effective dose and lung cancer cases per year per million people for the primary schools in the districts of AL-Najaf city.

Table 2: The annual effective dose (AED), potential alpha energy concentration (PAEC), exposure to radon progeny (EP), and lung cancer cases per year per million people (CPPP) for the primary schools in the districts of AL-Najaf city.

District	N°. Of Schools	AED (mSv/y)	PAEC (mWL)	EP (mWLM Y^{-1})	CPPP ($\times 10^{-6}$)
Old city	15	0.086	2.273	15.226	1.551
Al.Karama	4	0.084	2.222	14.883	1.517
Al.Moalmen	5	0.089	2.343	15.695	1.599
Alhussein	4	0.081	2.141	14.342	1.461
Al.Ameer	4	0.130	3.440	23.042	2.348
Al.Ansar	6	0.096	2.531	16.958	1.728
Al.Zahraa	6	0.086	2.270	15.208	1.550
AL gari	4	0.052	1.377	9.228	0.940
Aloroba	4	0.070	1.858	12.448	1.268
Al.Mothana	4	0.106	2.787	18.672	1.903
Aladala	3	0.114	3.003	20.115	2.050
Alwafaa	5	0.119	3.127	20.945	2.134
Al.Askary	6	0.110	2.908	19.483	1.985
Alnasor	2	0.079	2.080	13.936	1.420
Alresalah	3	0.078	2.060	13.801	1.406
Alnidaa	5	0.078	2.068	13.855	1.412
Aljamea	4	0.103	2.706	18.130	1.847
Alsalam	5	0.078	2.068	13.855	1.412
Alforat	3	0.125	3.286	22.009	2.243
Abotalib	2	0.132	3.474	23.272	2.371
Alrahma	4	0.061	1.616	10.824	1.103
Algahdeer village	2	0.067	1.777	11.907	1.213
All	100	0.091	2.407	16.123	1.643

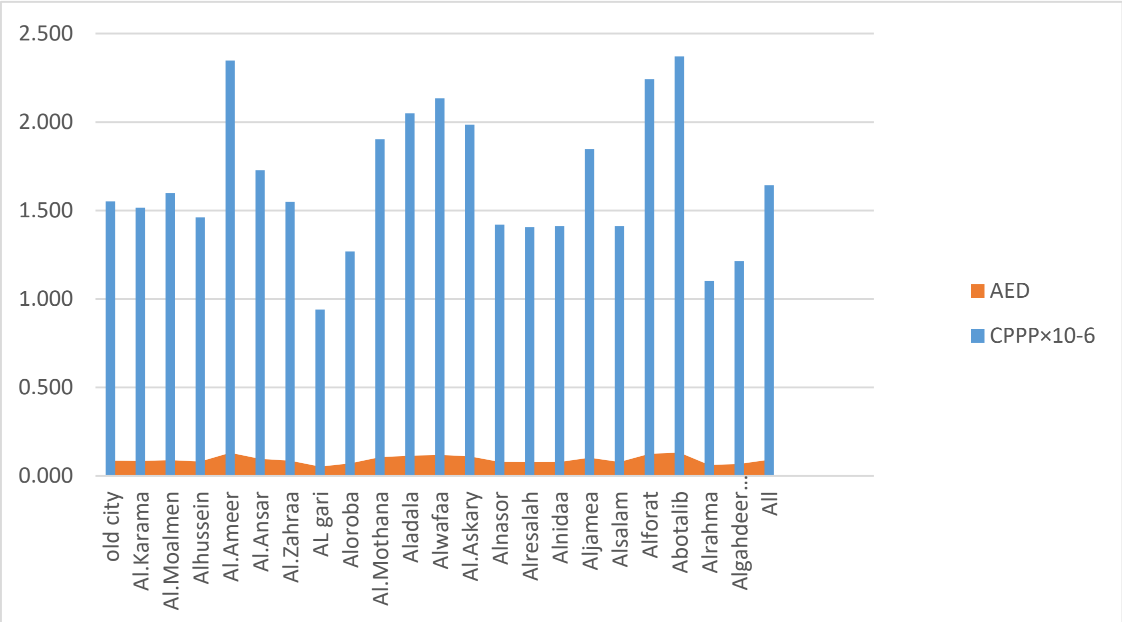

Figure 7: The annual effective dose (AED) and lung cancer cases per year per million people (CPPP) at the primary schools in the districts of AL-Najaf city.

Table 3: The average value of the indoor radon concentrations compared to other similar research in primary schools across different countries.

country	Average radon concentration	reference
Bulgaria	339	(29)
Kuwait	18	(1)
Greece.	149	(30)
Macedonia	211	(31)
Poland	49.0	(32)
Sudan	59	(33)
Serbia	119	(34)
Tunisia	26.9	(35)
Palestine	40.42	(36)
Italy	77	(37)
Iraq (Karbala)	25.4	(38)
Turkey	49	(39)
Present Study	22.26	

Table 3 compares the indoor radon measured within schools in several countries. The results vary because numerous factors influence indoor radon concentrations, including geology.

4. CONCLUSION

The study of radon levels in the primary schools in AL-Najaf city indicates a normal level. The average values of C_{Rn} are substantially below the global limit. The results of AED for the studied schools are lower than those of ICRP and lower than the results of UNSCEAR. The results of potential alpha energy concentration, exposure to radon progeny, and lung cancer cases per year per million people are lower than the global limits. As a result, the occupants of these schools (children and staff) are not at risk of radiological exposure from their immediate surroundings.

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