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RESEARCH PAPER

^{222}Rn Activity Concentration Measurement and its Radiological Risks in the Environment of Barserin Village, Erbil-Iraq

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ABSTRACT:

In the present study, ^{222}Rn activity concentrations were measured in Barserin village environment including (indoor rooms, building materials, soil and drinking water samples). The measurements were carried out using a couple of passive and active methods. The obtained results of the average indoor radon concentration in 28 dwelling rooms (living room+ kitchen) were found to be (91±09) Bq.m^{-3}, except in houses H3 and H12, which had radon activity concentrations above the limited value declared by Environmental Protection Agency 148Bq.m^{-3}. Living rooms recorded higher value of radon activity concentrations than kitchens by a factor of 1.36. Average radon activity concentrations emanated from soil and building material samples from the same region were found to be (57±12 and 45±08) Bq.m^{-3}, respectively. The higher values of radon activity concentrations were reported for black shale rock (127±08) Bq.m^{-3}and soil sample S6 (115±20) Bq.m^{-3}. For drinking water, it was found that 75% of samples had radon activity concentrations more than the maximum contaminant level 11.1Bq.l^{-1} proposed by Environmental Protection Agency. Finally, the present results of average annual effective doses for lung reported due to radon in indoor rooms were quite higher than the worldwide annual effective dose value of 1.2 mSv.y^{-1}, suggested by ICRP, while it was within the range of the action level of (3-10) mSv.Y^{-1}recommended by UNSCEAR. Simultaneously with these results, 75% of drinking water samples had their annual effective doses exceeding the annual effective dose limit of 0.1 mSv.y^{-1} suggested by WHO.

KEY WORDS: Radon; CR-39; RAD7; annual effective dose; Radiological Risks
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1.INTRODUCTION :

Radon is a noble gas with the mass number of 222 and an atomic number of 86 in a periodic table (Struempler and Johnson, 1987). Radon is a radioactive element with a half-life of about 3.824 days; it's colorless, tasteless, odorless, chemically inert, and 7.5 times denser than air. It is naturally emitted from rocks and soil as a product of the decay of radium (^{226}Ra) in the ^{238}U decay chain from Earth's crust (Abojassim et al., 2015).

When ^{226}Ra decay to ^{222}Rn in the soil, nearly 10% of the produced radon reaches the atmosphere (Vogiannis and Nikolopoulos, 2015). The radon emanation depends mainly on ^{226}Ra content and mineral grain size, its transport in the earth governed by geophysical and geochemical parameters, while exhalation is controlled by hydro meteorological conditions. (Ismail, 2004, Abdullah et al., 2015). Radon is present in trace amount almost everywhere on earth being distributed in the soil, groundwater and in the lower levels of the atmosphere. Radon which is present everywhere on the earth surface reaches by different processes and accumulates in the houses and underground mines.

Radon contributes more than 60 % of the total annual effective dose for the human body (Kadhim and Almayyali, 2014). The World Health

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Organization (WHO) reported that ^{222}Ra is the second leading cause of lung cancer in the world and cause 3% to 14% of all lung cancer cases in the world, the ratio change due to average radon level and the ratio of smoking (WHO, 2021).

For most people, the greatest exposure to radon occurs at home where people spend about 80% of their time, though indoor workplaces may also be a source of exposure (Zakariya et al., 2013). The main source of indoor radon is the soils under floor, building material (cement, sand, rocs, etc.), water consumed in routine activity at home, natural energy source like (coal, gas, etc.), and the ratio of indoor radon concentration dependent on the amount of radium content, the exhaustion ratio, and the ventilation of the dwelling (Sahu et al., 2016, Battawy et al., 2016).

The aim of the present study is to determine the radon activity concentration measurements in indoor rooms, soil, building material and drinking water samples collected from Barserin Village environment and to calculate the radiological risks derived from the radon concentrations.

2.Study Area

Barserin Village is a small village, approximately 25 families live there, and it is located in the North East of Erbil City, Iraqi Kurdistan Region. The Berserin Village is 120 km away from Erbil, which is located on the latitude line 36.6227 and 44.6589 longitude line, as shown in Fig.(1). Barserin area, covered with the layers of black shale, dolomite, calcareous shale of Barserin and Naokelekan Formation, is located at the Eastern part of Rawanduz district for about 8km. It goes back to upper Jurassic cycle (161-145 million years ago). Tectonically, this area is located in an imbricated zone because there were several up thrusting-fault at the crest of antique and cause rupturing of northern limb. The Barserin formation was first described by Wetzel and Morton in 1950 (Bellen R.C. Van, 1950). The formation was shown in Fig. (2). It consists of three parts, from top to bottom:

a- Laminated shaly bituminous limestone alternating with bituminous and find a gained limestone.
b- Fine-grained hard mostly thin bedded dolomitic limestone.
c- Thin bedded of bituminous dolomites and limestone rate of bitumen is high, with black shale.

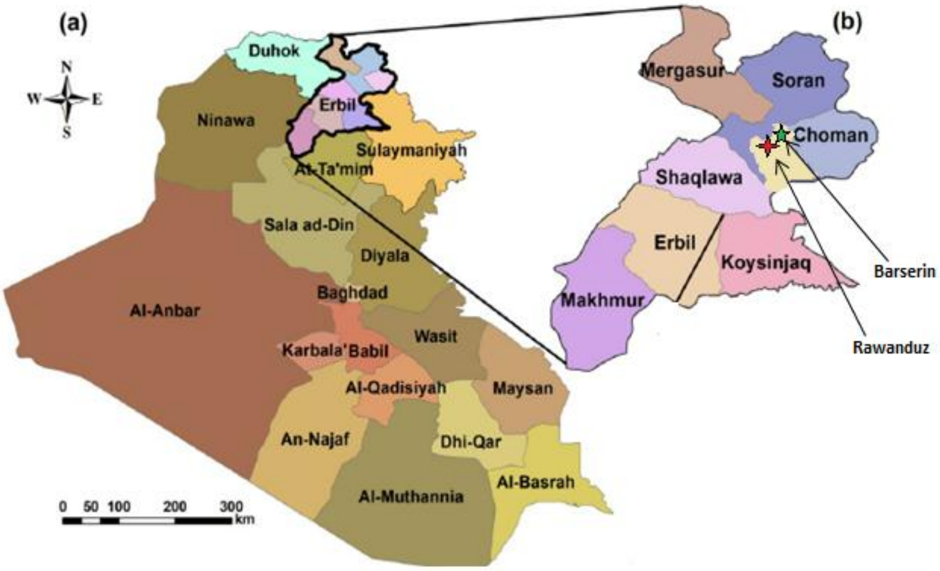


Fig.(1) Iraqi map (Barserin location) (Zakaria et al., 2013)

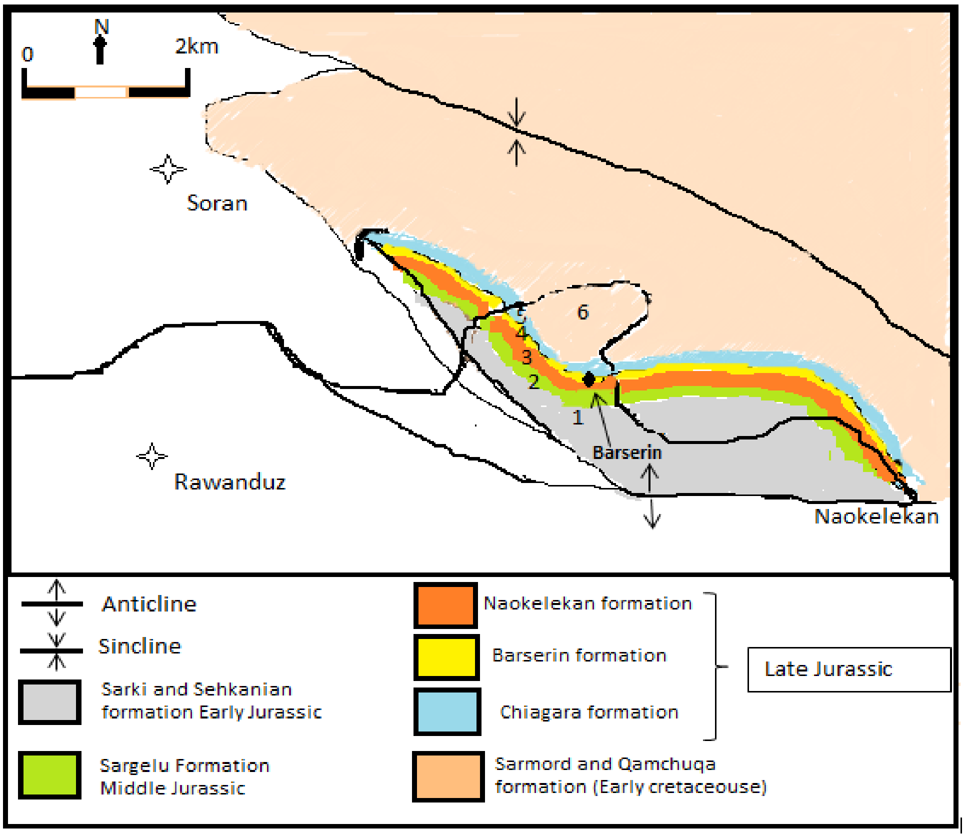


Fig.(2) The geological map of the study area.(Bellen R.C. Van, 1950).

2.1The Characteristics of Houses in Barserin Village

The dwellings under the study were built in different dates and different styles as shown in table (1). The wall of the dwellings of the village was built from shale, limestone, and cement bricks covered by gypsum. The ceiling of the houses was built with concrete and iron or by soil and wood, whereas the floor of the dwellings was covered by cement. All materials mentioned above are expected to contribute to the indoor radon.

2.2Water Resources

The sources of water for daily use and drinking in Barserin Village comes from well and springs. The only well present in this region was dug close to Serin mountain in 2011, with 137m depth and 10m away from Choman River. The others are springs named Zhnan and Piawan, and their sources are located under the mountain.

3.Detection Methods

Experimental methods for radon detection and measurements are based on alpha-counting of radon and its daughters. Both passive and active devices are available for this purpose.

3.1Passive Method-Field measurement

A closed permeable cup (as a radon dosimeter) of 3.5cm in radius and 8cm in height provided with CR-39 plastic alpha track detectors and a sponge filter was used for measuring radon activity concentration. Two cups were distributed in each house in the village: the first one was placed in the kitchen room and the other in the living room where the families spend most of their time. Measurement period is preferably winter (December to March) because radon activity concentrations are higher in the winter due to the pressure differentials caused by heating and the reduced ventilation. The dosimeter was held in rooms' ceilings and left for about 90 days. After exposure, for making the alpha tracks and to visible them under microscope, the CR-39 track detectors were immersed in 6.25 Normality NaOH solution at $70^{o}C$ for 6 hours. The average track density was observed and counted under the Motic digital microscope with a magnification of 400X. The net track density (in tracks.cm^{-2}) ρ is given by:

$$\rho_{net} = \rho_{(tr)} - \rho_B = N.n^{-1}.S^{-1} \qquad (1)$$

Where $\rho_{(\mathrm{tr})}$ is an average of track density, ρ_{B} is background track density, N is the number of tracks that counted in the total number area, n is the number of areas counted, and S is the area of field view of the microscope that is dependent on the magnification of the microscope. Then the activity concentration of radon gas (C_{Rn}) in a unit of $Bq.m^{-3}$ was determined according to the following relation (Fleischer and Mogro-Campero, 1978)

$$C_{Rn}(Bq.m^{-3}) = \rho_{net}.k^{-1}.T^{-1} \qquad (2)$$

Where K is the calibration factor (K= 0.141± 0.0251 $track.cm^{-2}$ $.d^{-1}$/ $Bq.m^{-3}$) which was calibrated previously (Samal S. F 2011) and T is the exposure time 90 days.

3.2 Active Methods -Laboratory measurement

3.2.1 Soil and Building Material Samples

The RAD7 radon detector manufactured by DURRIDGE COMPANY Inc, was used for radon concentration measurement in soil and building material samples which were taken from the environment of Barserin Village. For this purpose, we prepared 9 samples of soil taken from 30cm depth and 6 samples of building material which were used to construct the houses of the village. The samples were cleaned and then powdered using a special machine to obtain a homogeneous grain size and then dried in an oven at 110°C for 48 hours to evaporate all the moisture content and maintain the actual weight (Rehman, 2005). After drying, the powder of each sample was divided into nearly three equal volumes of $115.5cm^3$ and then put in containers 3.5cm in radius and 30cm in height. The containers were made of PVC (Poly vinyl chloride) which is an impermeable and a tight container to prevent the escape of radon gases (Mahur et al., 2008). The containers have two valves on the opposing sides to connect to the inlet and outlet of the RAD7 for measuring the active radon concentration in the sample, as shown in Fig. (3-a). The chamber is closed very tightly and held in the big cork box to be saved at room temperature for 90 days to get equilibrium between radium and radon inside the chamber. After this time interval, a close-loop is connected between chamber tube, desiccant tube, and RAD7 unit. To start measurment, the valves are opened and the RAD7 pump draws air from the container tube to the RAD7 chamber after passing in the desiccant tube. Then, the air returns to the chamber from the outlet in the RAD7. When ^{222}Rn decays in the RAD7 chamber and produces ^{218}Po and ^{214}Po, the high voltage 2500V applied to the chamber wall captures the positively charged polonium daughters and changes its alpha particle energies to electrical signals using an alpha technique that can discriminate the electrical pulse generated by alpha-particles from ^{218}Po and ^{214}Po with energies 6.0 and 7.0 MeV, respectively. In this way, it is possible to use only the ^{218}Po peak for radon which is achieved in about five times the half life of ^{218}Po. Using this approach, it is possible to measure radon activity concentrations. Using RAD7 measured radon in protocol two-day test for each sample and stored in memory, as mentioned in ref. (Durridge.com, 2021). The stored value represents the average radon gas concentration measured during each interval. A convenient data output reported on the unit allows the printer's attachment when a printout of the memory is desired.The results are reported in Tables (5 and 6).

The specific activity of ^{222}Rn obtained from a calibration factor determined from radon chambers run by the US EPA and the DURRIDGE Co. were equal to 123cpm/($Bq.L^{-1}$)for normal mode with uncertainty (2%). Furthermore, for measuring the back ground radon in a diffusion tube before sampling, the RAD7 outlet is connected to the open end of the drying tube and the diffusion tube’s valves, making a closed-loop. The measured value in this experiment was equal to 4.0±0.7 $Bq.m^{-3}$ and then subtracted from the actual measurement.

3.2.2 Drinking Water Samples

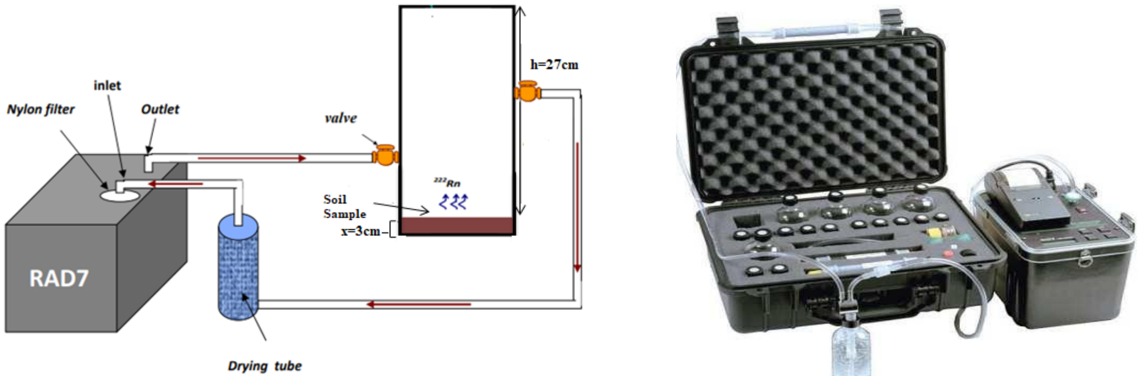
A total of four water samples coming from spring, well, and river water in a bottle size 2L of polyethylene were collected from the study area, in order to determine the radon activity concentration measurement. After being transported to nuclear lab. in Salahaddin University-Erbil, the samples were analyzed with an active RAD H_2O solid state detector. Care must be considered in taking water samples as they have never been in contact with the open air.

Due to the interval of time between sampling and testing the samples, we used the following equation to determine the corrected radon concentration $C_{(\mathrm{Rn})\mathrm{cor}}$ in the water between the sampling and running time intervals (Malakootian et al., 2014, Opoku-Ntim et al., 2019).

$$C_{(\mathrm{Rn})\mathrm{cor}} = C_{\mathrm{Rn}}.e^{\lambda t} \qquad (3)$$

Where C_{Rn} is radon concentration measured by the RAD H_2O. $\boldsymbol{\lambda}$ is the decay constant of radon ($\boldsymbol{\lambda}$ = 0.181.d^{-1}), and t is sample storage time

The RAD H_2O Set-up consist of three main components: (a) RAD7 radon monitor, (b) the water vial with aerator near the front, and (c) the small tube of desiccant as shown in Fig.(3-b). Before measurements, the RAD7 was connected to the dry unit and purged for five minutes to get out any radioactive nuclei from the RAD7 measurement chamber, after that the RAD7 was connected to the vials (bottle -250mL) containing water sample, the measurement was set-up by protocol Wat 250 having four cycles of five minute, and the test starting by bubbling water for five minutes to get out resolved radon from the water sample, the RAD7 pump cycled air between RAD7 cumber and the vials. At the end of run, the RAD7 printed out a summary of radon activity concentration in water samples from the activity of ^{218}Po source. The radon activity concentration was obtained from the calibration factor determined by Dr. Derek Lane in DURRIDGE Co.is 0.0067cpm/(Bq.m^{-3}). The corrected results are reported in table (7).



(a) (b)

Fig. (3) General set-up RAD7 measurement technique, (a) schematic diagram for measuring radon in soil and building material samples, (b) RAD H_2O accessory used to measure radon concentration in water.

4. Radiological Indices

4.1 Annual effective dose rate

The annual effective dose can be calculated from the potential alpha energy concentration(PAEC) due to radon and its progeny in unit Work level (WL), the (PAEC) can be obtained using the following equation(Mansour et al., 2005)

$$PAEC\ (WL) = F\ \frac{C_{Rn}\ Bq.m^{-3}}{3700\ Bq.m^{-3}.WL^{-1}} \qquad (4)$$

F is the equilibrium factor between radon and its progeny and the UNSCEAR suggested F=0.4, C_{Rn} is the radon concentration in unit $Bq.m^{-3}$.Then the annual effective dose equivalent (AEDE) in WLM can be expressed by the following equation (Mansour et al., 2005)

$$AEDE\ (WLM) = PAEC \times \frac{T}{170\ h.WM^{-1}} \qquad (5)$$

Where **T** is the stay time in a home per year, T=24h×365d×0.8=7008h.y^{-1}.

4.2Estimation of excess lifetime cancer risk (ELCR)

The exposures to radon make the risk to develop cancer disease in the lifetime. The estimation of excess lifetime cancer risk calculated in 14 dwellings of the village by using equation (6) based on the U.S.EPA methodology

$$ELCR = AEDE \times LE \times FR \qquad (6)$$

Where LE is the mean lifetime expectance, it was expected by WHO in report 2015 to be 70 years for Iraqi people.(Knoema, 2019), and FR is the detriment–adjusted nominal risk coefficient equal to (5.0×10^{-4}WLM^{-1}) determined by the international commission on Radiological Protection (ICRP, 2009). The results were shown in Table (3).

4.3Annual effective doses of radon in (mSv) unit

The annual effective dose due to inhalation of radon from indoor air in mSv units can be estimate from the following equation(Abuelhia, 2017, Fatimh et al., 2017).

$$AED(mSv.Y^{-1}) = C_{Rn} \times Q \times F \times D \times 8760 \quad (7)$$

Where $C_{Rn} is$ the radon concentration in Bq.m^{-3}. Q is the indoor occupation factor with the value of 0.8, F is the equilibrium factor that equal to 0.4, D is the conversion factor of $9\times 10^{-6} mSv$ per $(h.Bq.m^{-3})$ and 8760 is the number of hours in one year. (Abuelhia, 2017, Fatimh et al., 2017)

4.4 Annual Equivalent Dose for lung (AED_{lung})

The Annual Equivalent Dose for lung can be obtained from the following equation (Ocw.mit.edu, 2021)

$$AED_{lung}\ (\text{mSv.Y}^{-1}) = \text{AED} \times \text{WR} \times \text{WT} \quad (8)$$

Where, WR is the radiation weighting factor, 20 for α particles, and WT is the tissue weighing factor, 0.12 for lung.

4.5Lung cancer cases per million people per year (LCC)

Lung cancer cases per million people per year can be calculated from the following equation(Azhdarpoor et al., 2021).

$$\text{LCC} = 18\times10^{-6} \times AED_{\ lung} \quad (9)$$

Where, 18×10^{-6} is the risk factor for lung cancer induction, mSv^{-1}.

The obtained results are shown in table 4.

4.6Estimation of the lung cancer risk

Equations (7) to (9) were applied to estimate the number of lung cancer cases per million people per year (LCC)

4.7 Annual effective radon dose from drinking water

The annual effective dose due to ingestion of radon can be calculated by the following equation (Fakhri et al., 2016, El-Taher et al., 2020, Saman K. E, 2014)

$$AED_{ing} = C_{RnW} \times C_w \times DCF \quad (10)$$

C_{RnW} is the concentration of radon in water. C_w is the annual water intake equal to (0.6, 0.8, 1.3) × 365L.y^{-1} for infant, children, and adults respectively. DCF is the dose convection factor equals to (7×10^{-8},2×10^{-8}, and 1×10^{-8}) Sv.Bq^{-1} for infant, children, and adult. The doses reserved by radon released from water to the indoor air from daily activities at home (showering, washing dishes, etc) can be measured by using the following equation(Saman K. E, 2014);

$$AED_{iha} = C_{Rnw} \times R \times F \times D \times Q \times 8760 \quad (11)$$

$C_{Rnw}$is the radon concentration in water. R: is the ratio of radon in air to water=10^{-4}. F, D, Q, and 8760 have the same meaning and value in equation (7). The results were reported in Table (7, and 8) .

5 Results and Discussion

The characteristics of the investigated dwellings (the stale of the houses, the materials used for the building construction, and the year of construction) are listed in Table 1, and demonstrates radon activity concentrations in 28 dwelling rooms in Barserin village, including living rooms and kitchens listed in Table 2. Indoor radon concentration was variation for the dwelling room regarded to the ventilation rate as shown in Fig. (4). The maximum indoor radon concentrations in living and kitchen rooms were measured for house (H12) which was constructed from rocks and soil in 1991(oldest house), and were found to be 262.84±16.21$Bq.m^{-3}$ and 233.6±15.28 Bq.m^{-3}, respectively. While the minimum average radon concentrations in living and kitchen rooms reported for houses (H2 and H8), were found to be 54.12±7.36 Bq.m^{-3} and 33.44±5.78 Bq.m^{-3}, respectively. The results indicated that the average activity concentrations of radon in home (H12) were the maximum compared with the other homes in Barserin Village. On the other hand, the average radon activity concentration in living rooms was higher than in kitchens by factor 1.36. This is due to the cold weather in winter in the village. The living rooms are normally closed tightly to keep the room's heat; hence, the ventilation is reduced and the radon gas is accumulated, showing high concentration. On the other hand, the average indoor radon concentration in dwellings of western style (built by concrete) was found to be 95.64±8.63$Bq.m^{-3}$, while the radon activity concentration in dwellings of eastern style (built by rocks and soil) was found to be 88.01±8.99 Bq.m^{-3}. The results agree that less ventilated places have more radon concentration, regardless of building material type and the age of house construction (Ismail and Jaafar, 2010B). The investigation results show that the indoor radon level at two houses (H3 and H12) exceeds the EPAs intervention of 148Bq.m^{-3} (EPA). However, in general, the average indoor radon gas concentration was (91±09 Bq.m^{-3}) in Barserin village, which is below the world average indoor radon gas concentration level. The house construction materials, soil beneath, drinking water resources and the rate of ventilation contribute to increase the rate of entering radon gas concentrations indoors.

Table (3) represents the calculated values of potential alpha energy concentration (PACE), annual effective dose equivalent (AEDE), and estimation of excess of lifetime cancer risk (ELCR), of radon progenies in indoor rooms' air in Barserin Village. The values varied from (5.24±0.75 to 26.83±1.7) mWL, (0.216±0.03 to 1.106±0.07) WLM, and (0.008±0.001 to 0.039±0.002) respectively. To estimate the lung cancer risk, the annual effective dose (AED), annual effective dose for lung (AEDL), and lung cancer cases per million per year were calculated and presented in table (4). Their values varied from (1.22±0.18 to 6.26±0.4) mSv.Y^{-1}, (2.93±0.42 to 15.03±0.95) mSv.Y^{-1}, and (52.82±7.57 to 270.53±17.6) per million person per year, respectively. The lowest values were observed in house H2, while the highest were found in the house (H12). The average value of radon doses and risks in the present study are below and within the range limit of the recommended action levels of (53mWL, (1-2) WLM.Y^{-1}, (1.3%), (3-10) mSv.Y^{-1}, and (170-230) per million person as given by (UNSCEAR-1993, NCRP-1989 and ICRP-1993). (Hadeel G. I, 2015, ICRP, 1993, Ismail and Jaafar, 2010A, Ref, Radiation, 1986).

The results of radon concentration in the studied building material and soil samples using the RAD7 detector have been listed in Table 5 and Table 6, respectively. The radon Activity concentration in building materials and soil samples reported a minimum value for limestone (3) (21±06) Bq.m^{-3} and for soil sample (S7SO) (21.8±1.65) Bq.m^{-3}, while it reported the maximum values for black shale (127±08) Bq.m^{-3}and soil sample (S6SO) (115±20) Bq.m^{-3}, with an average of (45±08) Bq.m^{-3} and (57±12) Bq.m^{-3} respectively. It is clear that the average radon activity concentration in the soil samples was higher than in the building materials by factor 1.26. This may be due to the geological settings of the study area, which is made of dolomitic limestone and black shale as mentioned in the text.

The RAD H_2O solid state detector was used to measure radon concentration in drinking water samples used by people living in Barserin village. The results are shown in table 7(colum3). The values of radon concentrations varied from (0.06±0.11) to (62±05)$Bq.l^{-1}$. This variation may be due to the type of water, depth of water source, and the geological environment of areas under the study. The minimum and maximum values were reported to the river water and "Zhnan" spring water samples, respectively. It is clear from table (7) that the average radon activity concentration in spring "Zhnan" was about six times higher than the well drinking water samples, and both their values were found to be higher than the accepted level (11.1) $Bq.l^{-1}$. reported by US-EPA.

Table 7 (columns 4,5,6) shows the calculated values of annual effective dose due to ingestion of radon in four drinking water samples (well water, spring man (Piawan) water, spring women(Zhnan) water and river water) for three different age groups: infants, children and adults, using equation (10). Maximum value was found for infant, children and adults at the spring women (Zhnan) water sample, while the minimum reported for the river water sample. Table (8, col. 2) represents the results of the annual effective dose due to inhalation of radon emanated from drinking water samples using equation (11). It is found that the values are the same for all age groups, but are different per sources. The maximum was reported from spring women

(Zhnan) water samples (156.39±11.54)μSv.Y^{-1}, and the minimum was recorded form river water sample (0.15±0.28μSv.Y^{-1}). Table (8, columns 3,4,5) and Fig. (5) show the total annual effective doses due to ingestion and inhalation of radon from drinking water resources for infants, children and adults. It is clear that infants show increased vulnerability due to a combination of changes of dose conversion factor. The present results show that about 75% of drinking water samples analyzed with RAD H_2O had their total annual effective doses exceeding the annual effective doses limit of 0.1mSv.Y^{-1} proposed by WHO for intake of radionuclide in drinking water. From the values of total radon activity concentrations studied in the environment of Barserin (indoor, building materials, soil and drinking water resources), drinking water samples has been reported the highest value as shown in Fig. (6).

In comparison to the radon measurement values reported by other researches for the same village, we found that the radon concentrations in well water and building materials (13.062±0.15, 209±43) $Bq.l^{-1}$ reported by (Saman K. E, 2014, Azeez, 2010) using RAD7 solid state detector and LR-115 nuclear track detector, in general, agree with the present results. Among past research's study samples in Erbil Governorate, high radon concentration was recorded in Barserin samples. The comparison with the other (local and foreign) studies is demonstrated in table (9).

6 Conclusion

About 14% of the dwellings in Barserin Village recorded radon activity concentrations above the limited value of 148Bq.m^{-3}recommended by EPA, while 29% recorded above limited 100Bq.m^{-3} suggested by WHO. Nonetheless, the average radon activities in Barserin village (91±09)$Bq.m^{-3}$are below the recommended levels. Moreover, the average radon activity concentration in living rooms was higher than in kitchens by factor 1.36. The results of average annual effective doses due to radon in indoor rooms were lower and within average of the action level of (3-10)mSv.Y^{-1} (ICRP), while it was quite higher than the worldwide annual effective dose value of 1.2mSv.Y^{-1} (UNSCEAR) . About 75% of the drinking water samples had their annual effective doses exceeding the annual effective dose limit of 0.1mSv.Y^{-1} of WHO. In addition, the results proved that infants are more exposed to the risks of the total annual effective dose than the other age groups of the village residents. The radon concentration in Barserin Village is relatively high in some of its dwellings, building materials, soil and drinking water samples. Therefore, it is necessary to take care of the issue of the danger of cancerous diseases, especially the lung cancer, which is left by radon progenies in the lungs of the exposed residents of the village. So, is necessary to increase the level of public awareness concerning the hazards of radon gas.

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We extend our sincere thanks and appreciation to the Geological Department of College of Science /Salahaddin University- Erbil staff for their cooperation with us in grinding and diagnosing rock models.

Table 1. Characteristics of the investigated dwelling.

House	House stale	Building construction	Year of construction
H1	In eastern style	Rock and soil	2003
H2	In eastern style	Rock and soil	2003
H3	In western style	Concrete	2010
H4	In western style	Concrete	2014
H5	In eastern style	Rock and soil	2008
H6	In eastern style	Rock and soil	1992
H7	In western style	Concrete	2018
H8	In western style	Concrete	2016
H9	In eastern style	Rock and soil	1993
H10	In eastern style	Rock and soil	1991
H11	In eastern style	Rock and soil	2008

H12	In eastern style	Rock and soil	1991
H13	In eastern style	Rock and soil	1998
H14	In eastern style	Rock and soil	1999

Table 2. Radon activity concentration (C_{Rn})in the living room and kitchen and the average radon activity concentration were measured in investigated dwelling.

Symbol	Place in the house	C_{Rn}(Bq.m^{-3})	Average radon concentration C_{Rn}(Bq.m^{-3})
H1	living room	104.68±10.23	107.75±10.38
	Kitchen	110.82±10.53	
H2	Living room	54.12±7.36	48.465±6.95
	Kitchen	42.81±6.54	
H3	living room	235.05±15.33	169.785±9.615
	Kitchen	104.52±10.22	
H4	living room	109.21±10.45	106.865±10.335
	Kitchen	104.52±10.22	
H5	living room	56.22±7.5	54.85±7.405
	Kitchen	53.48±7.31	
H6	living room	79.32±8.91	55.33±7.255
	Kitchen	31.34±5.6	
H7	living room	73.67±8.58	66.56±8.145
	Kitchen	59.45±7.71	
H8	living room	72.7±8.53	53.07±7.155
	Kitchen	33.44±5.78	
H9	living room	91.76±9.58	68.335±8.14
	Kitchen	44.91±6.7	
H10	living room	79.97±8.94	66.32±8.1
	Kitchen	52.67±7.26	
H11	living room	Broken	85.14±9.23
	Kitchen	85.14±9.23	
H12	living room	262.84±16.21	248.22±15.745
	Kitchen	233.6±15.28	
H13	living room	81.1±9.01	55.335±7.225
	Kitchen	29.57±5.44	
H14	living room	79.16±8.9	90.39±9.49
	Kitchen	101.62±10.08	
Average	Living room	106.14±9.96	91.4±9.16
	Kitchen	77.71±8.42	

Table 3. Radon Activity concentration (C_{Rn}**)** in Barselin village dwellings, potential alpha energy concentration (PAEC), Annual effective dose equivalent (AEDE), Estimation of excess of lifetime cancer risk (ELCR).

House	C_{Rn} Bq.m^{-3}	PAEC(WL)× 10^{-3}	AEDE(WLM)	(ELCR)
H1	107.75±10.38	11.65±1.12	0.48±0.05	0.017±0.002
H2	48.465±6.95	5.24±0.75	0.216±0.03	0.008±0.001
H3	169.785±9.615	18.36±1.04	0.757±0.04	0.026±0.001
H4	106.86±10.335	11.55±1.12	0.476±0.05	0.017±0.002

H5	54.85±7.405	5.93±0.8	0.244±0.03	0.009±0.001
H6	55.33±7.255	5.98±0.78	0.247±0.03	0.009±0.001
H7	66.56±8.145	7.2±0.88	0.297±0.04	0.01±0.001
H8	53.07±7.155	5.74±0.77	0.237±0.03	0.008±0.001
H9	68.335±8.14	7.39±0.88	0.305±0.04	0.011±0.001
H10	66.32±8.1	7.17±0.88	0.296±0.04	0.01±0.001
H11	85.14±9.23	9.2±1	0.379±0.04	0.013±0.001
H12	248.22±15.745	26.83±1.7	1.106±0.07	0.039±0.002
H13	55.335±7.225	5.98±0.78	0.247±0.03	0.009±0.001
H14	90.39±9.49	9.77±1.03	0.403±0.04	0.014±0.001
Average	91.17±9.16	9.86±0.99	0.406±0.04	0.014±0.001

Table 4. Annual effective dose (AED), Annual effective dose for lung (AEDL), and Lung cancer cases per million per year.

House	AED ($mSv.Y^{-1}$)	AEDL($mSv.Y^{-1}$)	Lung cancer cases
H1	2.72±0.26	6.52±0.63	117.44±11.31
H2	1.22±0.18	2.93±0.42	52.82±7.57
H3	4.28±0.24	10.28±0.58	185.05±10.48
H4	2.7±0.26	6.47±0.63	116.47±11.26
H5	1.38±0.19	3.32±0.45	59.78±8.07
H6	1.4±0.18	3.35±0.44	60.3±7.91
H7	1.68±0.21	4.03±0.49	72.54±8.88
H8	1.34±0.18	3.21±0.43	57.84±7.8
H9	1.72±0.21	4.14±0.49	74.48±8.87
H10	1.67±0.2	4.02±0.49	72.28±8.83
H11	2.15±0.23	5.16±0.56	92.79±10.06
H12	6.26±0.4	15.03±0.95	270.53±17.16
H13	1.4±0.18	3.35±0.44	60.31±7.87
H14	2.28±0.24	5.47±0.57	98.51±10.34
Average	2.3±0.23	5.52±0.55	99.37±9.98

Table 5. The activity concentration of radon **(C_{Rn})** in some type building materials from Barsilen Village using RAD7 solid state detectors.

Building material samples	Color	Mass(gm)	C_{Rn} (Bq.m^{-3})
limestone 1	White	137.75	38±04
limestone 2	Blue	135.74	27±14
limestone 3	Black	138.1	21±06
Sand	Blue	167.79	24±07
black shale	Black	139.62	127±08
Sandstone	Black shiny	150.6	32±9
Average		144.43	45±08

Table 6. The activity concentration of radon (C_{Rn}) in soil samples from Barsilen village using RAD7 solid state detectors

.Soil sample	Mass(gm)	C_{Rn} (Bq.m^{-3})
S1SO	117.83	75.77±22.01
S2SO	108.01	80.33±24.34
S3SO	111.36	53.97±8.55
S4SO	116.85	29.37±9.15
S5SO	106.39	30.3±9.98
S6SO	112.9	115±20
S7SO	130.15	21.8±1.65
S8SO	124.83	54.07±12.43
S9SO	128.33	54.87±4.33
Average	117.41	57±12

Table 7. Radon activity concentration (C_{Rn}) in water samples and the annual effective doses due to ingestion for infants, children and adults.

Water source	**(C_{Rn})** $(Bq.l^{-1})$	Average radon concentration× $1000(Bq.m^{-3})$	annual effective dose due to ingestion of radon by water ($\mu Sv.y^{-1}$)		
			Infants	Children	Adult
well water	12.33±0.96	16±1.27	245.28±19.47	93.44±7.42	75.92±6.03
	19.66±1.58				
Spring man water	58.87±3.78	57.16±3.63	876.26±55.65	333.81±21.2	271.22±17.22
	55.44±3.47				
Spring women water	61.2±4.92	62.06±4.58	951.38±70.21	362.43±26.75	294.47±21.73
	62.92±4.24				
river water	0.06±0.11	0.06±0.11	0.92±1.69	0.35±0.64	0.28±0.52
Average	----------	33.82±2.4			

Table 8. Total annual effective dose due to ingestion and inhalation from water sources in the Bareilen village.

Water source	annual effective dose due to inhalation for all ages (µSv.Y^{-1}) ± S.D	Total annual effective dose taking due to ingestion and inhalation for all ages (µSv.Y^{-1})		
		Infant	children	Adults
well water	40.32±3.2	285.6±22.67	133.76±10.62	116.24±9.23
Spring man water	144.04±9.15	1020.31±64.8	477.86±30.35	415.27±26.37
Spring women water	156.39±11.54	1107.77±81.75	518.82±38.29	450.87±33.27
River water	0.15±0.28	1.07±1.96	0.5±0.92	0.44±0.8

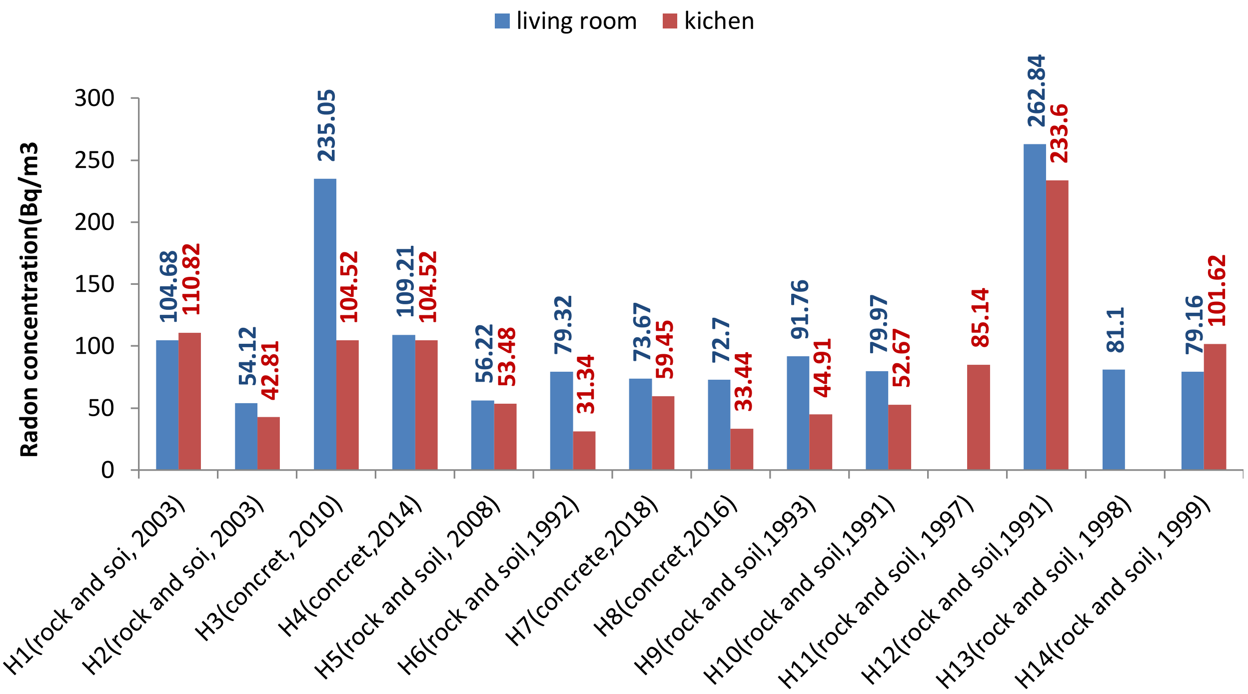

Figure (4). Radon activity concentration in living and kitchen rooms in Bareslin village houses.

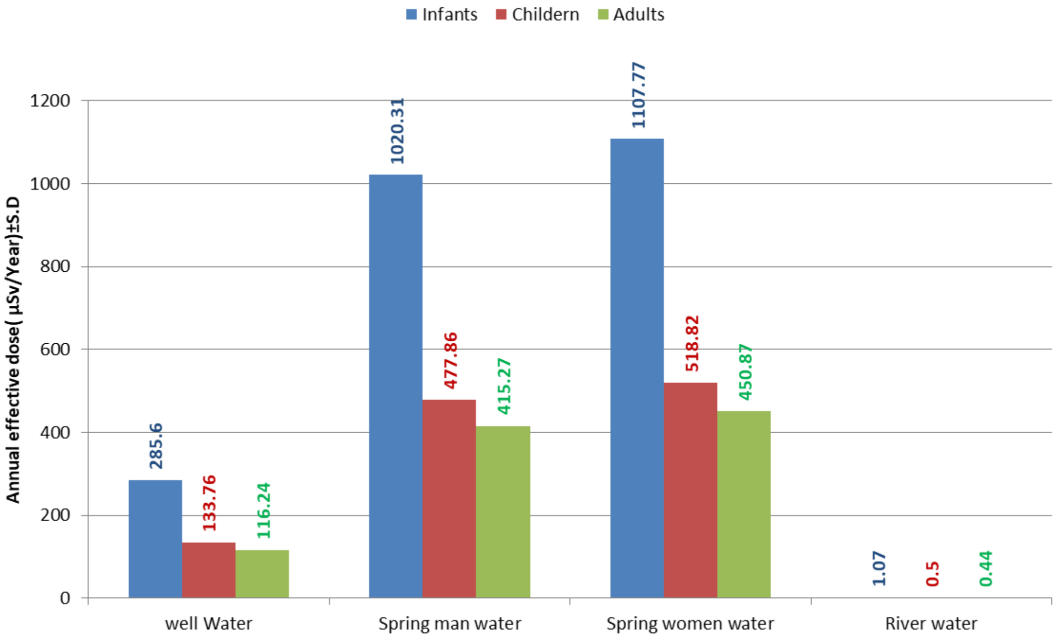

Figure (5). Histogram of the total annual effective dose due to ingestion and inhalation from Drinking water sources in the Barserin village.

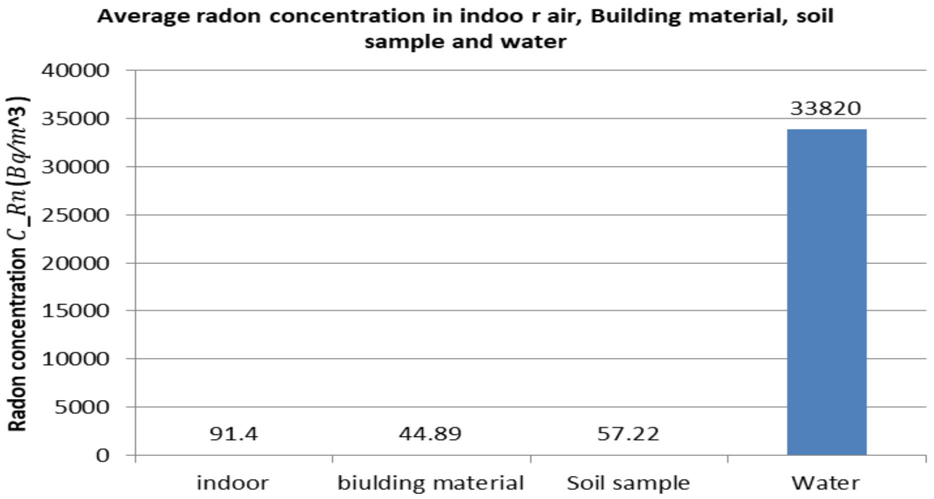

Figure (6) Average radon concentration in indoor air, building material, soil and drinking water samples from Barserin village.

Table 9. Comparison of radon concentration (Bq.m^{-3}) in present study with the other cities of Iraq and countries around Kurdistan and Iraq.

	Country	Minimum value	Maximum value	Average	Detectors type	Ref.
Indoor Radon Bq.m^{-3}	Iraq-Erbil	10.33	90.34	44±23	CR-39	(Mansour et al., 2005)
	Iraq-Mosul	53±5	75±5	62±07	CR-39	(Y Hasan, 2018)
	Iraq-Erbil	951±34	239±77	144±04	CR-39	(Ismail and Jaafar, 2010)
	Iran		2386(winter season)	--------	CR-39	(Kamal Hadad a et al., 2007)
	Turkey		1400±0.0		CR-39	(G. ESPINOSA, 1999)
	Saudi Arabia		195±0.0	24.68	Electretion chamber	(Alghamdi and Aleissa, 2014)
	Pakistan	11	78		CR-39	(Rahman and Anwar, 2008)
	Iraq-Erbil (Barserin village) Winter season	54.12±7.36 for living room 33.44±5.78 for kitchen room	262.84±6.21 for living room 233.6±15.28 For kitchen room	91±09	CR-39 Radon dosimeter	Present Work
Radon in Building material Bq.m^{-3}	Iraqi Kurdistan	154±05	481±5		CR-39	(Hussein et al., 2013)
		139±07	435.72±11.38		RAD7	
	Iraqi Kurdistan	122	383		CR-39	(Najam et al., 2013)

	Iraq	261± 48	762± 29	528± 50	CR-39	(Amin, 2015)
	Iraq-Erbil (Barserin village) Winter season	21±06 for limestone rocks	127±08 for black shale rocks	45±08	RAD 7	Present work
Radon in Soil Bq.m^{-3}	Iraq-Sulaimani	154±3	2242±143	742±27	CR-39	(Abdullah et al., 2015)
	Iraq(Al-Qadisiyah	0.12	13	6± 0.77	CR-39	(Kadhim et al., 2020)
	Iraq(Najaf)	32±02	171	99±0.24	CR-39	(Kadim and Hady, 2018)
	Iraq-Erbil (Barserin village) Winter season	21.8±1.65	115±20	57±12	RAD 7	Present Work
Radon in Water Bq.L^{-1}	Iraq-Kurdistan	19	30	------------	HPGe	(Ahmad et al., 2021)
	Iraq-Kurdistan	0.1±0.04	13±0.2(Barserin well water)	-----------	RAD H_2O	(Ezzulddin and Mansour, 2020)
	India	1.4	22.6	------------	RAD H_2O	(Duggal et al., 2017)
	Iraq-Kurdistan (Barserin Village)	0.1±0.01	13±0.2 (Barserin well water)	--------------	NaI(Tl)	(Ezzulddin and Mansour, 2020)
	Iraq-Erbil (Barserin village) Winter season	0.06±0.11 (River water)	62.06±4.58 (Woman spring water)	33.82±2.06	RAD7-H_2O	Present Work

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