Radon Concentration And Dose Assessment In Well Water Samples From Karbala Governorate Of Iraq

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Abstract. There are numerous studies around the world about radon concentrations and their risks to the health of human beings. One of the most important social characteristics is the use of water wells for irrigation, which is a major source of water pollution with radon gas. In the present study, six well water samples have been collected from different locations in Karbala governorate to investigate radon concentration level using CR-39 technique. The maximum value $4.112\pm2.0\text{Bq/L}$ was in Al-Hurr (Al-Qarih Al-Easariah) region, and the lowest concentration of radon was in Hay Ramadan region which is $2.156\pm1.4\text{Bq/L}$, with an average value $2.84\pm1.65\text{Bq/L}$. The highest result of annual effective dose (AED) was in Al-Hurr (Al-Qarih Al-Easariah) region which is equal to $15.00\pm3.9\mu\text{Sv/y}$, while the minimum was recorded in Hay Ramadan $7.86\pm2.8\mu\text{Sv/y}$, with an average value $10.35\pm3.1\mu\text{Sv/y}$. The current results have shown that the radon concentrations in well water samples are lower than the recommended limit $11.1\text{Bq/L}$ and the annual effective dose in these samples are lower than the permissible international limit $1\text{mSv/y}$.

Keywords: Radon, well water, CR-39 detector, Karbala, Iraq.

1. Introduction

The radon is produced by radium decay and by recoil emanating of the material into the air or water. When underground well are opened, the radon is transported, by diffusion and convection, from the rocks to the environment through water or air circulation. The importance of each process depends on the geological nature of formation. Radon exhalation rate varies due to alterations in the differential air pressure, the uranium and radium levels, the working conditions, and the degree of ventilation. The underground well environment is complex and variable. Radon, after being exhaled, migrates along ventilation currents while it generates the solid decay products: $^{218}\text{Po}$, $^{214}\text{Pb}$, $^{214}\text{Bi}$ and $^{214}\text{Po}$ [1].

Radon is a radiant gas with a half-life 3.82days, odorless, tasteless, and colorless. Its density is 7.5 times that of air [2]. It dissolves in water easily and can spread through gases and water vapor [3]. It produced by naturally decay occurring Radium $^{226}\text{Ra}$, which is a decay product of Uranium $^{238}\text{U}$ chain. Thoron $^{220}\text{Rn}$ with a half-life 56.6s is the result of the decay product of the $^{232}\text{Th}$ Thorium chain. Because of this short half-life, its emergence and emigration are limited to a few centimeters. Radon is inhaled in lung tissues. Its degradation by alpha emission causes ionization damage that causes lung cancer [4]. The second most important contributor to outdoor radon is emanation from well water sources. The radon in the water supply poses an inhalation and an ingestion risk. Radon can then be transported by well water to far large distances than by the diffusion process in a short time [5]. However, radon and its progeny can enter into human’s body through ingestion and inhalation [6].
Therefore, human exposure to high concentrations of radon and its progeny for a long period of time leads to the growth of lung cancer [7]. Radon can dissolve and build up in water from underground sources. Radon in the water dissolves and escapes into the air throughout household water use, especially when it is heated. Radon levels in the air will increase for a short period of time when one uses his dishwasher, cooking, washing clothes, shower and bath. However, research has shown that the risk of lung cancer from respiration radon in the air is much greater than the risk of developing stomach cancer from drinking water containing radon [8, 9]. The objective of this study is to measure radon concentration and dose assessment in well water samples from selected areas in Karbala governorate using the CR-39 nuclear track detector, and assessment of the situation.

2. Materials and Methods

2.1. Description of the Studied Area

Karbala is a well-known Islamic city. It is famous by its holy and it's historical which gall in huge accidents, its dust witnessed on the most Nobel feature of martyrdom in the history. Karbala governorate situated about 108km in southwest of Baghdad, on the edge of desert in west of Euphrates River and on the east side of the Al-Husseiniya River. Its location at latitude (32°36′52″N), and longitude (44°1′27″E), and its elevation above sea level is (32m=104ft), with a total area of (52.856 km²) and with population 1,378,000 at (2013). It is bordered by Anbar to the north and northwest, Al-Najaf to the south, and Al-Hillah and department of the Baghdad to the east [10], see Figure 1. This figure also explains the code and location of the underground areas in Karbala Governorate.

2.2. The Detector

CR-39 solid-state nuclear track detector (SSNTD) with thickness (500μm) is a C_{12}H_{18}O_{7} polymer with density 1.36 gm/cm³ and area of about (1×1cm²) has been used in the current work. It is sensitive to alpha particles of energy up to 40MeV. It was used as complement to detect alpha particles from ^{222}\text{Rn} and its daughter's nuclei. The concentrations of alpha particles which emitted from the radioactive element ^{222}\text{Rn} in selected samples were determined by using the nuclear track detector CR-39. The damage caused by alpha particles when penetrating the detector along its path can be observed by chemical etching and optical microscopy [11].
2.3. Collection and Preparation of Samples
Six samples have been collected from well water at different regions within the boundaries of the administrative Karbala governorate. They are Al-Wand, Alhurr (Alqarih Aleasariah), Hay Al-Hussein, Hay Ramadan, Ain Al-Tamur, and Hay-Al- Muathain. Table 1 shows the symbol of these regions respectively. The water samples were collected from the well water in the plastic containers after washing them with diluted hydrochloride. The acid works to reduce the absorption of radionuclides by the walls of the container and prevent algae growth. The water filtration using filter paper before the container is full to get rid of lingering in the water minutes.

2.4. The Exposure
A capacity of 0.250L of well water is kept in plastic container for 30days before measurements in order to achieve the secular equilibrium as shown in Figure 2.

Square piece of (1×1cm²) has been installed inside the upper lid of the can facing the water surface sample. The detector was exposed for a period of 60days during exposed period from 17-9-2016 to 15-11-2016, to be able to register alpha particles for 90 days after which samples were collected and chemically etching with 6.25 normality of sodium hydroxide (NaOH) at 60°C for 5h. It was then washed, dried, read the tracks and calculated their number in the unit area using an optical microscope with a magnification of 400X to identify and determine radon concentrations. These reagents were calibrated by exposing them to known concentrations of radon and its offspring in the designated chamber.

3. Theoretical Concentrations

3.1. Radon Concentration Measurements
The density of the tracks ($\rho$) in the samples was calculated according to the following Equation [12]:

$$\text{Tracks density (}\rho) = \frac{\text{Average number of total pits (track)}}{\text{Area of the field view}}$$

Radon concentrations in water samples were obtained by comparing the track densities recorded on the detectors of the samples and that of the standard water samples, which are shown in Figure 3, using the following relationship [13]:

$$C_x(\text{sample})/\rho_x(\text{sample}) = C_x(\text{standard})/\rho_x(\text{standard})$$
\[ C_x = \frac{\rho_x}{\rho_s} \cdot (C_s/\rho_s) \]  

(3)  

Where \( C_x \) and \( C_s \) are the radon concentration in the unknown and standard samples respectively. \( \rho_x \) and \( \rho_s \) are the density of the track of unknown and standard samples respectively. This relationship has been explained in Figure 3.

3.2. Annual Effective Dose in Water
This parameter was calculated for the individual popular due to intake consumption of radon according to the following Equation [14]:

\[ AED (\mu Sv/\gamma) = C_{R_i} C_{Rw} D_{Cw} \]  

(4)  

Where \( C_{R_i} \) is the radon-concentration for ingestion, \( C_{Rw} \) is the consumption-rate 730L/y and \( D_{Cw} \) is the dose-conversion factor \( (5 \times 10^{-9} \text{Sv/Bq}) \) according to UNSCEAR [15].

![Figure 3. Relation between track density and radon gas concentration](image)

3.3. Determination of Some Radon Parameters

3.3.1. Radon Exhalation Rate. The radon exhalation rate \( (E_A) \) in any sample is defined as the flux of radon released from the surface of the material. The radon exhalation rate (surface exhalation rate) in units of \( (Bq.m^{-2}.h^{-1}) \) was calculated according to the following Equation [16]:

\[ E_A = \frac{CV_{\lambda}}{A(T+1/\lambda(\exp^{-\lambda T}-1))} \]  

(5)  

Where \( C \) is the integrated-Radon exposure \( (Bq.h.L^{-1}) \); \( A \) is the surface area of the sample; \( V \) is the occupation of air volume in the can; \( \lambda \) is the decay constant of \( ^{222}\text{Rn} \) \((0.1812 \text{ day}^{-1}) \); and \( T \) is the exposure time \( (h) \).

3.3.2. Dissolved Radon Concentration. This parameter was calculated according to the following Equation [17]:

\[ C_d (Bq/L) = C_{R_i} \lambda h T/L \]  

(6)
Where \( C_{\text{Rn}} \) is the radon concentration for ingestion (Bq/L); \( \lambda \) is the decay constant of \(^{222}\text{Rn}\) (0.1812 day\(^{-1}\)); \( \delta \) is the distance between the surface of the water sample and the detector; \( T \) is the exposure-time (h); and \( L \) is the depth of the sample (m).

4. Results and Discussion

Table(1) presented the results of radon concentrations in regions under study. Figure 4 shows the maximum concentration in Al-Hurr (Al-Qarih Al-Easariah) (K2) which was equal to 4.112±2.0Bq/L, while the minimum value of radon concentration was found in Hay-Ramadan (K4) which was equal to 2.156±1.4Bq/L. Al-Hurr (Al-Qarih Al-Easariah) (K2) was characterized by maximum annual effective dose 15.00±3.9μSv/y, and the minimum was found in Hay-Ramadan (K4) to be 7.86±2.8μSv/y, with an average value 10.35±3.1μSv/y, see 'Figure(5)'.

In addition, the average rate of radon exhalation \( (E_A) \) in well water samples was 3.778±0.6Bq/m\(^2\).h. The maximum value 3.761±1.9Bq/m\(^2\).h was in Al-Hurr (Al-Qarih Al-Easariah) (K2) and the minimum value was in Hay-Ramadan (K4) with a value 1.972±1.4Bq/m\(^2\).h, as shown in 'Figure(6)'.

Figure 7 shows the variation of dissolved radon concentration \( (C_{\text{d}}) \) in well water samples. The highest value 122.941±11Bq/L was in Al-Hurr (Al-Qarih Al-Easariah) (K2), while the lowest concentration was in Hay-Ramadan (K4) which was equal to 64.46±8.0Bq/L, with mean value 84.895±9.1Bq/L.

The current results for Karbala governorate showed that all concentrations was less than the recommended upper limit 300pCi/L which amount to 11.1Bq/L according to (USEPA, 2012)\([\text{18}]\). The annual effective dose in all studied samples was lower than the recommended limit 1mSv/y as recorded by (EPA, 2000)\([\text{19}]\). Therefore, all studied areas in Karbala are safe with respect to radon concentration.

Differences in the values of radon concentrations were observed among well water samples. These differences can arise because of the difference in the nature of the samples and the nuclei content of these samples. But the extremes values still found in the same regions that are Al-Hurr (Al-Qarih Al-Easariah) and Hay-Ramadan. The total annual effective dose of radon in well water of Karbala governorate were significantly lower than that of United Nations Scientific Committee on the Effects of Radiation (UNSCEAR, 2012)\([\text{20}]\), World Health Organization (WHO, 2012)\([\text{21}]\) which recommended limit for persons of 1mSv/y.

In Table (2), a summary of the information gathered by other authors in different governorates of Iraq on the well water have been tabulated. The present dialogues showed that the radon concentration in some of the well water samples from the studied areas was either less or higher than the maximum value of the level of contaminant. The current results showed a close concentration of radon in the Sulaymaniyyah governorate.

![Figure 4. Radon concentration in well water](image)
Figure 5. Annual effective dose in well water samples

Figure 6. Surface exhalation rates in well water samples at different regions in Karbala

Figure 7. Dissolved radon concentration in well water
5. Conclusions
The results of the present study provide well water level of radon concentration in province of Karbala. The highest value was found in well (K2) Al-Hurr (Al-Qarib Al-Easariah) region which was equal to 4.112±2.0Bq/L, while the lowest value was recorded in (K4) Hay-Ramadan to be 2.946±1.7Bq/L.

Table 1. Radon concentration ($C_{Rn}$), annual effective dose ($AED$), surface exhalation rate ($E_a$), and dissolved radon concentration in water ($C_d$), of well water samples for different regions in Karbala governorate.

| Sample No. | Location Name / well depth(m) | Track density (track/mm²) | $C_{Rn}$ (Bq/L) | $AED$ (μSv/y) | $E_a$ (Bq/m² h) | $C_d$ (Bq/L) |
|------------|-------------------------------|---------------------------|----------------|--------------|----------------|----------------|
| K1         | Al-wand/7                     | 392.9±2.9                 | 2.896±1.7      | 10.57±3.2    | 2.649±1.6      | 86.585±9.3     |
| K2         | Al-Qarib Al-Esariah/240       | 399.7±2.8                 | 2.946±1.7      | 10.75±3.3    | 2.695±1.7      | 88.08±9.4      |
| K3         | Hay Al-Hussein/12             | 292.5±2.6                 | 2.156±1.4      | 7.86±2.8     | 1.972±1.4      | 64.46±8.0      |
| K4         | Hay Ramadan/12                | 335±3.5                   | 2.47±1.5       | 9.01±3.0     | 2.259±1.5      | 73.848±8.6     |
| K5         | Ain Al-Tumair/100             | 333.3±2.0                 | 2.457±1.6      | 8.96±2.9     | 2.248±1.4      | 73.459±8.5     |
| K6         | Hay Al-Muathafin/12           | 385.2±3.0                 | 2.84±1.66      | 10.35±3.1    | 2.597±1.5      | 84.895±9.1     |
| Average    |                               |                           | 355.8±4.5      | 4.112±2.0    | 2.946±1.7      | 64.46±8.0      |
| Maximum    |                               |                           | 399.7±2.8      | 10.75±3.3    | 2.695±1.7      | 88.08±9.4      |
| Minimum    |                               |                           | 292.5±2.6      | 7.86±2.8     | 1.972±1.4      | 64.46±8.0      |
| Global limit|                             |                           | 355.8±4.5      | 10.35±3.1    | 2.597±1.5      | 84.895±9.1     |

Table 2. Radon concentrations and annual effective dose in well water worldwide, using CR-39 technique, compared with the present work.

| Location (Date of measurement) | $C_{Rn}$ (Bq/L) | $AED$ (μSv/y) | Ref. | Location (Date of measurement) | $C_{Rn}$ (Bq/L) | $AED$ (μSv/y) | Ref. |
|-------------------------------|----------------|--------------|------|-------------------------------|----------------|--------------|------|
| Iraq/Akashat (2004)           | 0.11-0.158     | -----        | Tawfiq et al. [22]           | Iraq/Sulaimany (2013) | 2.756         | ------        | Yousuf and Abdullah [23] |
| Iraq/Sulaimany (2013)         | 0.549±0.041    | ------        | Abdalsattar [24]             | Jordan/Irbid (1997) | 0.979-1.320 | 9.44         | Mohammed et al. [25] |
| Iraq/Karbala Al-Hindiyah city (2014) | 2.156±1.4 | 1.972±1.4     | 64.46±8.0                   | Scotland/Aberdeen Area (1993) | 3.35 to 40-76 | 20-400       | Al Doorie et al. [27] |
| Iraq/Sulaymaniyah (2016)      | 0.549±0.041    | ------        | Abdalsattar [24]             | Present work (2016) | 2.84±3.06 | 10.365±1.7   | Present work |
| Jordan/Irbid (1997)           | 3.1±5.7        | 4.5±0.8      | AL-Bataina et al. [26]       |                  |              |              |      |
2.156±1.4 Bq/L, with mean value of 2.84±1.65 Bq/L. The results were less than the permissible limit 11.1 Bq/L given by USEPA, 2012. Therefore, all studied wells in Karbala governorate are safe as far as radon concentration is concerned. Even the annual effective dose values varied with respect to the increase in radon concentration and were significantly below the recommended limit given by UNSCEAR and WHO for members of the public of 1 mSv/y. Therefore, the consumption of this well water does not cause any health risk to the population of Karbala governorate.

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