Health Risk Assessment of Radon Concentrations in Water Samples of Selected Areas North of Al-Najaf Governorates

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Abstract: - Studies on radon concentrations and the risks they pose to people's health are widely available. Groundwater is one of the most common sources of Rn that the populace consumes directly. Rn gas, occurring naturally in rocks, soil, and water, poses a significant health risk for lung cancer, stomach illnesses, leukemia, and juvenile cancer. This study aimed to measure the content of Rn in groundwater sources and assess the health risk for children and adults in Najaf Governorate, Iraq. Ten samples of well water from various locations in the Najaf governorate have been collected to evaluate the radon concentration level using the RAD7 technology. The concentrations of Radon varied from a maximum of 2.42 Bq/L in the Al-Melad region to a minimum of 0.712 Bq/L in the Al-Naser region, with a mean of 1.6690.194 Bq/L. The estimated annual effective dose in ingestion (stomach) for children varied between 1.470 μSv/y and 4.997 μSv/y. The mean value was 3.447±0.4008 μSv/y, and the total annual effective dosage for adults varied from 1.819 μSv/y to 6.183 μSv/y with a mean of 4.265±0.4958 μSv/year. Each individual's estimated yearly effective dose inhalation (lungs) ranged from 9.959 μSv/year to 33.850 μSv/y for children and adults. With an average of (23.3508±2.7146) μSv/year, while in adults, the annual effective dose varied between 0.0017942 μSv/year and 0.0060984 μSv/year. The average value was 004206888±0.00048907 μSv/year. According to the findings, The Radon concentration in the groundwater specimens was below the global limit of 11.1 Bq/L. Additionally, the yearly effective dosage for the analyzed samples was below the internationally approved threshold of 1mSv/year.

Key-Words: - Radon, health risk, water, well water, RAD-7, Najaf.

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1 Introduction

Radiation is energy emitted through a material medium, and it is the formation of waves or particles. It has a substantial impact on life in the fields of sciences and medicine, [1]. Radiation sources can be divided into two types: natural and artificial. Natural radiation is divided into three main groups based on its origin: cosmic and terrestrial. Cosmic rays separate atoms in the atmosphere, producing cosmic nuclides. There are two groups of primordial radionuclides, with the first being led by chains ^{238}U, ^{235}U, and ^{232}Th in the radionuclide. Second, some radionuclides decay directly into stable nuclides, such as ^{40}K, [2]. Radon is a radioactive gas that lacks color and odor and dissolves in water. It decays into other elements because it is radioactive. The half-life, or how long it takes for half of an element to decay, determines how quickly Radon decays radioactively. Radon-222 undergoes radioactive decay with a half-life of 3.8 days, [3]. Radon-222 was produced by radioactive decay inside the ^{238}U- chain. As a result, sites underlain by granite and other rocks with high uranium contents often have higher radon levels than areas covered by different rock types, [4]. Radioactivity occurs in all natural waters, including mineral water, surface water, and groundwater. Since rocks and soil contain radium, surface and groundwater must also contain dissolved radon, [5], [6]. Radon gas travels from its origin in rocks and soils via cracks and gaps. Exploiting foundation fissures can penetrate structures as a gas. It can also blend with groundwater and be transported to water supply wells. Because the concentrations of aquifer materials, aquifer porosity, permeability, and emanation rates from mineral sources all differ, so do the amounts of Radon-222 in groundwater. In 2017, Inacio et al. conducted a study in Portugal to assess the Radon concentrations in 33 water specimens collected nationwide. Out of the twenty-three collected water samples, all had levels above the maximum allowable threshold. The maximum value achieved was 1690 Bq.L^{-1}. The findings also indicated a yearly effective dosage that was ingested beyond the World Health Organization's advised limit of 0.1 mSv/year, [7]. In Saudi Arabia, adjacent to Iraq, ^{222}Rn levels in tap water vary between 9.2 ± 0.02 and 0.10 ± 0.02 Bq/L. The results were substantially less than the standards set by the EPA. The effective dosages for adults and children varied between 0.51 µSv/year and 46.69 µSv/year, [8]. In Iran, a neighboring nation, research was conducted to calculate the ^{222}Rn content of 44 drinking water sources. Specific samples exhibited an elevated ^{222}Rn concentration, above the EPA level in which the Radon range levels were 26.88 BqL^{-1} and 0.74 BqL^{-1}, respectively. The upper and lower limits of the annual effective dosage for adults were calculated to be 52.7 µSv/year and 2.29 µSv /year, [9]. A study in Iraq analyzed the Radon levels in 100 water samples. This study revealed that the AED resulting from radon intake was 0.236+0.020 µSv/year, whereas the AED resulting from radon inhalation was 0.015+0.0001 nSv/year. The total AED varied between 0.015 µSv and 1.171 µSv, with a mean of 0.236±0.020 µSv/year. The ^{222}Rn levels in this study for most water samples adhered to the internationally accepted standards of the WHO and ICRP, which can be considered safe, [10]. The current research aimed to assess the Radon concentration and related adverse effects in 10 groundwater wells in Al-Najaf province. The study employed a Rad-7 detector to quantify the quantity of Radon and determine the annual effective Radon in the study region. The findings are thought to be crucial for public health. Additionally, this study presents a picture of how the Rn concentration is detected and how it affects both adult's and children's health.

2 Materials and Methods

2.1 The Study Area

Southwest Iraq is where the Najaf governorate is on the western desert plateau's edge, southwest of Baghdad, a distance of approximately 160 km. It is located at latitudes 31059 and longitudes 44019. It rises 70 m above sea level, [11]. Iraq's Najaf is a sacred city. Near the ancient city of Kufa, Najaf is situated in southern Iraq—about 80 km separate Najaf from Karbala in the northwest direction. The Al-Melad, Al-Naser, Al-Nuda, and Al-Faw neighborhoods are located north of Al-Najaf. Figure 1. shows the study area chosen in the area under study, [12]. The measurement locations in northern Najaf are listed in Table 1.

Fig. 1: Study area groundwater locations on a map

Table 1. Code, place, and coordinate of groundwater in the current research

No.	Code	Place	Coordinates	
			North	East
1	Well1	Al-Melad	32.0480	44.3139
2	Well2		32.0534	44.3121
3	Well3		32.0712	44.3060
4	Well4		32.0466	44.3097
5	Well5	Al-Nuda	32.0679	44.3094
6	Well6		32.0537	44.3112
7	Well7		32.0720	44.3037
8	Well8	Al-Naser	32.0421	44.3084
9	Well9		32.0405	44.3088
10	Well10	Al-Faw	32.0583	44.3115

2.2 Measurement System

The RAD-7 detector is a multifunctional device designed explicitly for detecting radon gas. The distinct characteristics set it apart from other detectors, [11]. RAD7's interior cell is a hemisphere with a size of 0.7 litters. In the center of the hemisphere is a flat silicon alpha detector implanted with ions. By introducing the inner conducting to a potential of about (2000–2500 V) to a detector, the high-voltage electrical circuit creates an electric field within the cell volume. Radon and thoron progeny on the detector surface can directly input the solid-state detector with characteristically energetic alpha particles. The signal is picked up by the RAD7 microprocessor and stored, depending on the particle energy, [13]. Durridge Company Inc., USA manufactures a RAD/H2O adapter that can be linked to a RAD 7 device to determine Rn levels in water specimens. This device is battery-powered and portable. After 30 minutes of testing, the sensitivity of the method was on par with or higher than liquid scintillation methods, [14]. RAD 7 was attached to vials containing either 40 ml or 250 ml vials. By recirculating a closed air cycle into the sample water, the Radon monitor's internal air pump removed Radon from the water and transferred it to the air loop. Air is continuously pumped over water to eliminate radioactive Radon until the RAD/H_2O system reaches equilibrium, [14]. It keeps track of the gas in water at various concentrations. Sixty minutes after collecting the sample, the results must be obtained, and sterilization (i.e., a moisture content of less than 60%) must occur. A pump was added to the Grab system to calculate the amount of Radon in the water, [15]. During each session, the pump was operated for 5 min to extract Radon from the sample, which was subsequently delivered to the RAD7 detector for measurement. Following a 5-minute break to reach equilibrium, the remaining four sessions were repeated for a 30-minute examination in total (i.e., monitoring the amount of Radon, the amount of moisture, the temperature, and the normal deviation), [16], [17]. The operational numbers were a 4-circuit diagram, cumulative spectrum, and number of turns, [18]. The radon removal ratio from water in the air ring of a 250 mL sample was 95%, indicating a significantly high value, [16], [19].

2.3 Evaluate the Annual Effective Dose

The annual effective dose (Ed) for children and adults resulting from the ingestion of water containing Radon can be calculated using equation (1), [20]:

$$E_d = A_c\, A_i\, C_f \quad (1)$$

Ac represents the concentration of ^{222}Rn, A_i represents the annual water intake, and C_f represents the dose conversion factor. The coefficients of effective dose conversion, C_f, are 5.9 nSv/Bq for children and 3.5 nSv/Bq for adults, [21]. The formula used for determining the annual effective dose for inhalation ($E_{inhalation}$) resulting from radon gas dissolved in water depends on several variables, including the radon concentration (Ac), AWR (Air-Water Ratio), which equals 0.0001, OCF represents the occupation factor, E.F. Here, represents the equilibrium factor, and DCF is the dose conversion factor for radon gas inhalation at 9 nSv m3/Bq h, as illustrated in equation (2), [10], [22]:

$$E_{\text{inhalation}} = A_c \times AWR \times OCF \times EF \times DCF(\text{inhalation}) \quad (2)$$

2.4 Statistical Analysis

This research employed statistical analysis, specifically descriptive statistics, which included minimum, maximum, average, and standard deviation values calculations. The Shapiro-Wilk and Kolmogorov-Smirnov tests evaluated the distribution's normality, which was considered to have a P- value > 0.05. The statistical software SPSS version 26 was used for the analysis.

3 Results and Discussion

Groundwater samples from 10 locations north of Najaf City are listed in Table 2. The highest value obtained for Well2 (Al-Melad) was 2.42 Bq/L, whereas the sample from Well8 (Al-Nasr) had a minimum value of 0.712 Bq/L. The average value was determined to be 1.669±0.194 Bq/L. Figure 2. displays the radiological map of Radon results for the ten wells drawn using the GIS program used in this study.

Table 2. The results of ^{222}Rn concentration for selected samples of groundwater

Sample code	Radon concentrations (Bq/L)
Well1	2.41±0.19
Well2	2.42±0.19
Well3	1.14±0.13
Well4	2.14±0.18
Well5	2.03±0.18
Well6	1.57±0.16
Well7	1.28±0.14
Well8	0.712±0.11
Well9	0.992±0.12
Well10	2±0.18
Max	2.42±0.19
Min	0.712±0.11
Average±S.E.	1.669±0.194

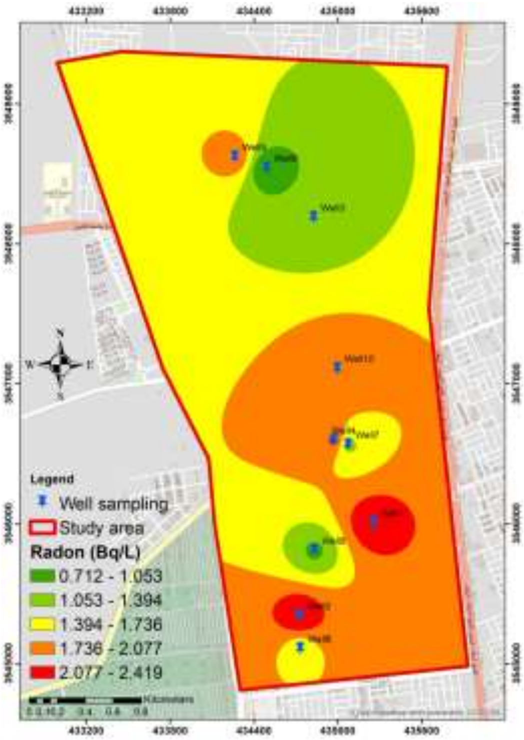


Fig. 2: Map of the current study's groundwater radon concentrations

The current research evaluated "the annual effective ingestion dose" (stomach)(E_d) in children and adults per individual. Table 3 presents each person's E_d values associated with different groundwater samples in the Anajaf governorate. E_d results for children ranged between 4.997 μSv/y for sample coded Well2 and 1.470 μSv/y for sample Well8. The average value was determined to be 3.447±0.4008 μSv/y, whereas the total annual effective dosage for adults varied from 6.183 μSv/y in sample coded Well2 to 1.819 μSv/y in sample Well8, with an average of 4.265±0.4958 μSv/y.

Table 3. The annual effective ingestion dose in current work

No.	code	Annual effective dose (μSv/y)	
		Children	Adult
1	Well1	4.977	6.158
2	Well2	4.997	6.183
3	Well3	2.354	2.913
4	Well4	4.419	5.468
5	Well5	4.192	5.187
6	Well6	3.242	4.011
7	Well7	2.643	3.270
8	Well8	1.470	1.819
9	Well9	2.048	2.535
10	Well10	4.130	5.110
Max		4.997	6.183
Min		1.470	1.819
Average±S.E.		3.447±0.4008	4.265±0.4958

This study estimated the effective inhalation dose ($E_{\text{inhalation}}$)per person for children and adults. Table 4 presents each person's annual effective dose for several groundwater samples for children and adults. The estimated $E_{\text{inhalation}}$for children varied from 9.959 μSv/year in sample Well8 and 33.850 μSv/y in sample Well2 with a mean of 23.3508±2.7146 μSv/year.

Table 4. Results of ′the annual effective dose "for inhalation in current research

No.	Sample code	Annual effective dose (μSv/year)	
		Children	Adult
1	Well1	33.710	0.0060732
2	Well2	33.850	0.0060984
3	Well3	15.946	0.0028728
4	Well4	29.933	0.0053928
5	Well5	28.395	0.0051156
6	Well6	21.960	0.0039564
7	Well7	17.904	0.0032256
8	Well8	9.959	0.00179424
9	Well9	13.876	0.00249984
10	Well10	27.975	0.00504
Max		33.850	0.0060984
Min		9.959	0.0017942
Average±S.E.		23.3508±2.7146	.004206888±.00048907

4 Discussion

Water is vital to living organisms on Earth because it is a necessary component of human existence and all other life forms, including food and beverages. Consequently, it is crucial to examine ^{222}Rn concentrations for water to evaluate the extent of radiation exposure. Radioactive pollution can harm the environment and human health because nuclei can infiltrate the human body via water consumption.

In comparison, $E_{\text{inhalation}}$ for adults ranged between 0.0017942 μSv/year in Well8 as well as 0.0060984 μSv/year in Well2. The average value was determined to be 0.004206888±0.00048907 μSv/year. Results from each site in the research area showed that the total $E_{\text{inhalation}}$ was below the permissible level for WHO, and the Council of the European Union recommended 0.1 mSv/y, [20], [21].

Moreover, upon comparing the mean Radon levels acquired in the current work with those documented in prior investigations conducted in Iraq and other countries (as illustrated in Table 5), it is evident that the present study recorded lower average Radon concentrations than any of the preceding studies, except the investigations conducted in Hela, Iraq, and the Najaf/Haidariya district of Iraq.

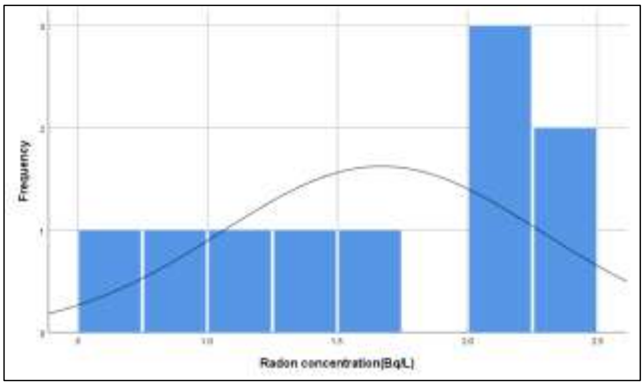
Table 5. Compare with the literature review

Country (year)	Methodology employed	222Rn (Bq/L)	Reference
Turkey/ Anatolia (2013)	GEO-RTM 2128	1.6 - 230	[23]
Scotland/Aberdeen Area (1993	RDU-200	3-35 to 40-76 well water	[24]
Jordan/Irbid (1997)	CR-39	4.5±0.8 well water	[25]
Babyl-Al-Qasim City, Iraq (2015)	RAD-7	0.793-8.005 Groundwater	[26]
Iraq /Karbala- Al-Hindiyah City (2014)	CR-39	11.790 Groundwater	[27]
Al- Hella, Iraq (2013)	RAD-7	0.036 -0.941	[28]
Najaf ,Iraq (2014)	RAD-7	0.569-5.010 Groundwater	[29]
Najaf/Haidariya district, Iraq (2015)	RAD-7	0.487±0.121 Groundwater	[30]
Present work (2023)	RAD-7	1.669±0.194 well water	-----

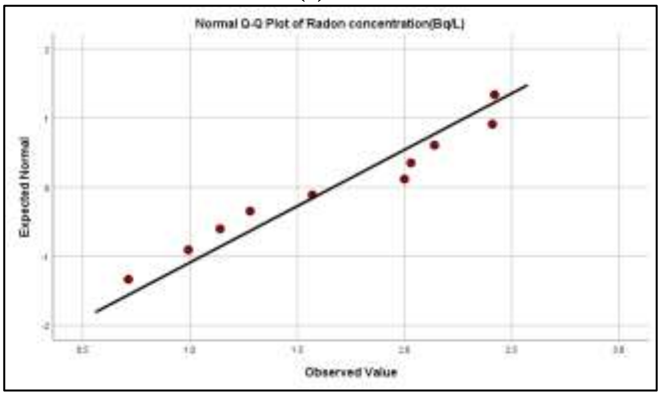
Table 6. The statistical summary of the Radon results and "Annual effective dose" in the water samples

Mean	1.6694	3.4472	4.2654	23.3508	0.004207
Std. Error of Mean	0.19408	0.40081	0.49589	2.71466	0.000489
Median	1.785	3.686	4.5605	24.9675	0.004498
Mode	0.71a	1.47a	1.82a	9.96a	0.00179a
Std. Deviation	0.61373	1.26748	1.56815	8.58451	0.001547
Variance	0.377	1.607	2.459	73.694	0
Skewness	-0.229	-0.229	-0.228	-0.229	-0.229
Kurtosis	-1.496	-1.496	-1.496	-1.495	-1.496
Minimum	0.71	1.47	1.82	9.96	0.00179
Maximum	2.42	5	6.18	33.85	0.0061

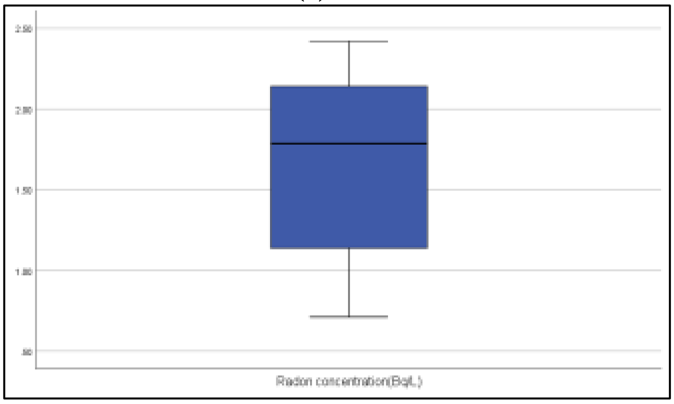
Table 6 shows the descriptive statistics of the Radon concentrations for groundwater and E_d for the cases of ingestion and inhalation associated with the level of Radon. The Radon data displayed in Figure 3(a) show the Radon concentration distribution for the studied wells, which tended to be approximately normal, and the Shapiro-Wilk test with Kolmogorov-Smirnov test was successful in assessing normality (p-value > 0.05), as illustrated in Figure 3(b) and Figure 3(c).



(a)



(b)



(c)

Fig. 3: (a) The Histogram of the Radon distribution, (b) The Q-Q plot of the Radon results, (C) The bpxplot of Radon distribution in the water samples

5 Conclusion

Based on the current study results, the total annual effective dose and radon concentrations for the groundwater samples remained below the acceptable limits of 1 mSv/year and 11.1 Bq/L set by the USEPA in 2012, as well as UNSCEAR and WHO for members of the public. The assessed risk from the total annual effective dose in Al-Najaf province was found to be minimal when compared to the projected risk recommended by the ICRP. Consequently, residents can be regarded as safe in terms of radon exposure risk. As a result, no health risks are linked to the use of Najaf water.

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