Kirkuk Journal of Science Vol. 19, Iss. 2, p 17-26, 2024. doi:10.32894/kujss.2024.145296.1129

Radon concentrations in the Groundwater of Kirkuk city /Iraq.

Jinan Nassir Haws [1,*], Ahmed Abed Ibrahim [2], Omer S. Ibrahim Al-Tamimi [3]

[1,2] Department of Physics, College of Science, University of Kirkuk, Kirkuk, Iraq.
[3] Department of Applied Geology, College of Science, University of Kirkuk, Kirkuk, Iraq.
*Corresponding author : : scph20m020@uokirkuk.edu.iq.

Article Information

Article Type:
Research Article

Keywords:
Radon gas; Groundwater; Annual effective dose; radioactive pollution; RAD7 detector.

History:
Received: 12 December 2023.
Revised: 27 March 2024.
Accepted: 28 March 2024.
Published Online: 9 June 2024.
Published: 30 June 2024.

Citation: Jinan Nassir Haws, Ahmed Abed Ibrahim, Omer S. Ibrahim Al-Tamimi, Radon concentrations in the Groundwater of Kirkuk city /Iraq, Kirkuk Journal of Science, 19(2), 17-26, 2024, https://doi.org/10.32894/kujss.2024.145296.1129

Abstract

Groundwater is becoming more and more recognized as a crucial and indispensable water supply on a worldwide basis. The previous few decades witnessed a high increase in its demand due to the overpopulation and improving living standards. Natural radioactivity in water has garnered a lot of attention in recent years. Twenty-two groundwater samples from Kirkuk region in Iraq were tested for radon using RAD7, an electronic radon detector coupled to a RAD-H_2O accessory (Durridge Co., USA) with an average value of 10.31 BqL^{-1}, the observed radon concentration ranged from 0.18 BqL^{-1} to 23.005 BqL^{-1}. The radon concentration readings that were measured fall well within the range of the maximum contamination limit (MCL) of 11.1 BqL^{-1} set by the EPA. The annual effective dose for individual consumer was 0.039 $mSvy^{-1}$ within the public exposure limit of 1 $mSvy^{-1}$ set by the WHO and UNSCEAR. Farmers can feel secure here, and the population is not particularly at risk from radon concentrations, based on the measured values for subterranean water in the study location. This study ended without considering how radon concentration is impacted by the physics of groundwater and chemical properties like PH and EC. After the sample is kept for a month, the radon concentration is recalculated.

1. Introduction:

Radon ^{222}Rn, a radioactive gas with 3.82 days half-life, is a well-known byproduct of the dissolution of uranium that is used to convey a dose. Radon is common in soil and water, and its concentration in the planet crust depends upon the soil composition. As such, all life on the earth is confronted with radon both internally and externally [1]. Being gaseous, it is very portable and may travel across the ground to water and air. When radon is inhaled or consumed, it typically decompose and releases energy that can negatively affect multiple biological tissues. For instance, the generation of free radicals may cause an anomalous cell division and increased probability of cancer. According to a study, radon inhaled into the mouth or through water meant for human consumption contributes 89% of an individual's estimated cancer risk [2]. As such, radon detection is crucial to the evaluation of the community health, and the knowledge of radon concentrations in domestic water supplies is crucial to preventing people from the negative effects of exposure. Reviews of the distribution of radon gas and its descendants are of global importance, this is because the World Health Organization (WHO) officially recognized the practice in 1988, when the organization recognized that in many countries, radon was the second most common cause of cancerous growth following tobacco smoke [3]. As such, as a result, the International Agency for Research on Cancer (IARC), which is part of the (WHO), has considered radon to be a type 1 carcinogen [4] [5]. As of right now, the increased radon concentrations in drinking water have been connected to radiation doses that are harmful to stomach lining [6], raising the possibility of serious stomach and gastrointestinal cancer [7].

When groundwater is a building's main supply of water, the risk goes up considerably. These closed systems pump water straight to the customer without allowing radon to dissipate or escape [8].

The radioactivity of natural water has drawn a lot of attention lately [9], [10], [11]. The liquid scintillation method was used to measure the radionuclide ^{222}Rn content in water samples from the Wielko region in southern Poland. The measured values ranged from 0.42 to 10.52 BqL^{-1}, with an average of 1.92 BqL^{-1}. Reference [12] evaluated the activity of ^{222}Rn near the coast of Xiangshan, Zhejiang, China, and noted its presence in both surface seawater and all-tidal groundwater. Radon levels on the Xiangshan coast range from 2.4×104 to 1.7×105 Bqm^{-3}. 9.6×104 Bqm^{-3} with an average of 9.6 × 104 Bqm^{-3} for groundwater; the surface seawater is 0.2 × 102 to 2.8 × 102 Bqm^{-3} and the average is 1.1 × 102 Bqm^{-3}.

In Reference [13] analyzed concentration activity of ^{222}Rn activity concentration in well water. Approximately 70 % of water samples from monitoring wells had ^{222}Rn concentrations above the United States Environmental Protection Agency(EPA) recommended limit of the 11.1 BqL^{-1}. In Reference [14] estimated the Radon monitoring in groundwater samples from some areas of northern Rajasthan, India, using a RAD7 detector. Radon concentration in groundwater ranges from 0.5 ± 0.3 BqL^{-1} (Chimanpura) to 85.7±4.9 BqL^{-1} (Khandela) with an average value of 9.03±1.03 BqL^{-1}. The aim of this research is to study the concentrations of radon gas in groundwater samples. These measurements were used to compute the annual effective dose from ingesting and inhaling ^{222}Rn in water.

2. Materials and Method:

2.1 Sampling Area:

Kirkuk Province is located in the northern part of Iraq Figure1, within the semi-mountain region between longitudes (43 18" - 44 47") to the east, and two latitudes (34 50" – 35 52") to the north. It shares borders with Erbil Province to the north and northwest, Mosul Province to the west, Sulaymaniyah Province to the east, and Salah al-Din Province to the south and southwest. Due to its oil reserves, Kirkuk is considered one of the richest cities in the world. In addition to its oil wealth, the area also contains deposits of sulfur and natural gas. These resources are obtained through the primary processing of petroleum. Regarding the geological features, the geological structure plays a major role in distributing and spreading groundwater, and determining its qualitative and quantitative characteristics. The places where that water is stored, its depths, its spatial extension, the flow of water through it, and its qualitative characteristics—that is, its chemical and physical properties—are all determined by the kind and depth of the rocky layers. It is the carrying vessel of that water. The creation of groundwater is also significantly influenced by the porosity and permeability of the crust rocks, which allow surface water to find a way into the rocks to build water tanks.

3. Sample Collection Preparation:

The majority of people in Kirkuk City use groundwater for everyday household purposes and other uses, so groundwater was taken into consideration. To ensure that a precise amount of radon was gathered from water sources, water was permitted to flow for approximately 10 minutes, and the bottles were sealed tightly to prevent radon leakage. The samples were analyzed in University of Kirkuk/ College of Science/ Health Physics Laboratory, and a decay correction was employed to accurately calculate the radon content if the sample was studied for more than 24 hours following the sampling.

This is due to the complexity of obtaining and measuring radon due to its volatility and short half-life. Long-distance locations from the laboratory were avoided in the sampling process because of these occurrences. Twenty-two water samples from groundwater total were gathered in multiple locations in Kirkuk City. Instead of using 40 ml of water, for each measurement in this investigation, 250 ml was used. Since a higher sample size will increase precision and sensitivity at low radon doses, it was decided to employ one. Radon gas concentrations were monitored and samples were gathered between the months of November 2021 to early March 2022.

4. Experimental Technique:

22 water samples were collected for the current study from various locations of Kirkuk Province. Every water sample is collected in unique bottles made specifically for measuring radon activity in water. This lessens the amount of radon lost as a result of exposure and air contact, [15]. Examine samples right away; do not wait more than 24 hours between sample collection and analysis.

The Solid-State Detector RAD7 is beneficial. Figure 2 shows a semiconductor-based solid-state detector that is made of Si. This detector converts the energy of the alpha particles that are produced by the breakup of a molecule (^{218}Po or ^{214}Po), and can differentiate these particles if RAD7 is capable of filtering the electronic energy associated with the particles, this electrical signal is directly related to the alpha particles. The alpha energy is achieved (6MeV) ^{214}Po or (7.97) MeV by isotopes of radon [16].

The RAD H_2O is accurate in its estimation of the volume of radon in the water sample because it follows the pre-established, standard protocol for RAD7. Because of the consistent magnitude of scale, if the radon concentration in the air is increased by 100%, the water concentration can be

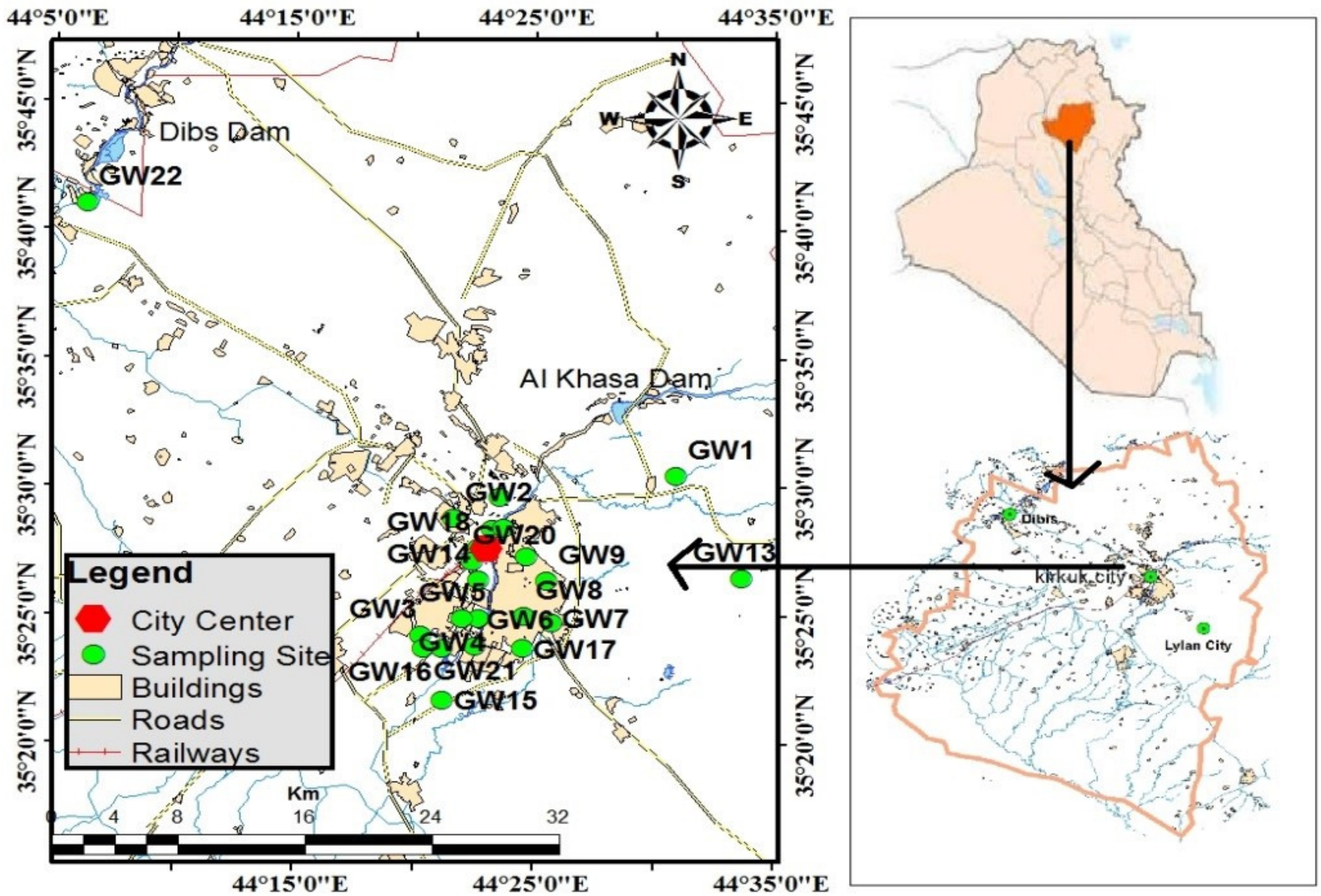


Figure 1. locations of Kirkuk City's study area.

Table 1. Clarify the symbols of the map and the coordinates of each region.

Sample ID	Name	Coordinates	
		Latitude	Longitude
GW-1	Rahimawa	35°30′20″N	44°23′56″E
GW-2	Al-failaq	35°28′48″N	44°21′44″E
GW-3	Huzairan Garden	35°24′21″N	44°20′23″E
GW-4	Hay Adan	35°24′48″N	44°22′36″E
GW-5	Al-saraf Mosque	35°24′54″N	44°22′01″E
GW-6	Nidaa	35°23′46″N	44°22′31″E
GW-7	Banja Ali Apartments	35°24′33″N	44°25′45″E
GW-8	Qadisiyah (Al-Salam Garden)	35°25′01″N	44°24′30″E
GW-9	Ashti Mosque	35°26′20″N	44°25′31″E
GW-10	Qishla	35°28′19″N	44°23′20″E
GW-11	Castle	35°28′19″N	44°23′38″E
GW-12	Shorja Park	35°27′13″N	44°24′46″E
GW-13	Ashti Park	35°26′24″N	44°24′37″E
GW-14	Al-mansor Mosque	35°26′21″N	44°22′39″E
GW-15	Ras Domiz	35°24′12″N	44°21′30″E
GW-16	Al-khasa River	35°23′17″N	44°21′44″E
GW-17	Hay Al-Askari (Al-hijra Mosque)	35°23′38″N	44°24′34″E
GW-18	Al-Baho	35°27′31″N	44°22′40″E
GW-19	Ali Bin Abi Talib Mosque	35°29′36″N	44°23′35″E
GW-20	Tisen Park	35°27′10″N	44°22′30″E
GW-21	Kirkuk University	35°23′41″N	44°20′33″E
GW-22	Al-Zab River	35°41′06″N	44°06′06″E

deduced by measuring the volume. For a 250-mL water sample, a 4-scale factor is calculated using the air flow volume, the sample volume, and the equilibrium radon distribution coefficient at room temperature. In this method, a closed-loop system is employed to ventilate. A procedure that has the flow rate is as its sole variable and the volume of water and air is as its sole adjustment. Water test for the Wet 250 procedure is approximately 30 minutes.

The RAD7's internal pump will start before the test begins in order to agitate the sample and spread the degassed radon to the measurement chamber of the RAD7. Throughout all of the available radon, 95% is removed from water during the course of 5 minute airing out cycle. After the fifth minute of operation, the pump will automatically turn off, and the system will wait for another five minutes. After that, the device will begin to count. Every five minutes, the system produces a concise report for a five-minute period. The same event occurs after five minutes, with a second occurrence after an additional five minutes. As demonstrated in Figure 2a, the RAD7 results a rundown 30 minutes after the race starts that includes the cumulative spectrum, a bar map of the four measurements, and the average radon concentration across four counting intervals of five minutes each. Water concentration of radon, as documented in Figure 2b and the automatically assigned number are displayed. A water quality meter is the device employed to measure EC and PH.

The RAD H_2O is accurate in its estimation of the volume of radon in the water sample because it follows the pre-established, standard protocol for RAD7. Because of the constant conversion factor, the volume of radon in the water sample is estimated by taking the product of the radon concentration in the air channel and the volume of the container. The factor 4 for a water sample 250 mL in a flask is derived from the air flow volume, the sample volume, and the equilibrium distribution of radon at a room temperature. In this method, a closed system with a loop is used.

A method in which the flow rate is constant and both water and air are maintained at a constant volume. Water test for the wet 250 procedure is approximately three hours. The integrated pump of the RAD7 automatically begins functioning five minutes before the test begins in order to agitate the sample and move the degassed radon into the measurement chamber of the RAD7.

During a 5-minute aeration, more than 94% of the available radon gas was removed, most of it from the water. After five minutes of operation, the pump automatically shuts off, and the system waits five more minutes. After that, the device starts counting. The device creates a concise report every five minutes. Five minutes later, the same thing happened twice more within five minutes, RAD7 generates a 30-minute profile containing the average radon concentration within each 5-minute interval, a plot of the 4 measurements, and the overall spectrum.

5. Annual Effective Dose:

The following formula is employed to calculate the individual's annual effective dose of ^{222}Rn derived from water consumption [19], [20]

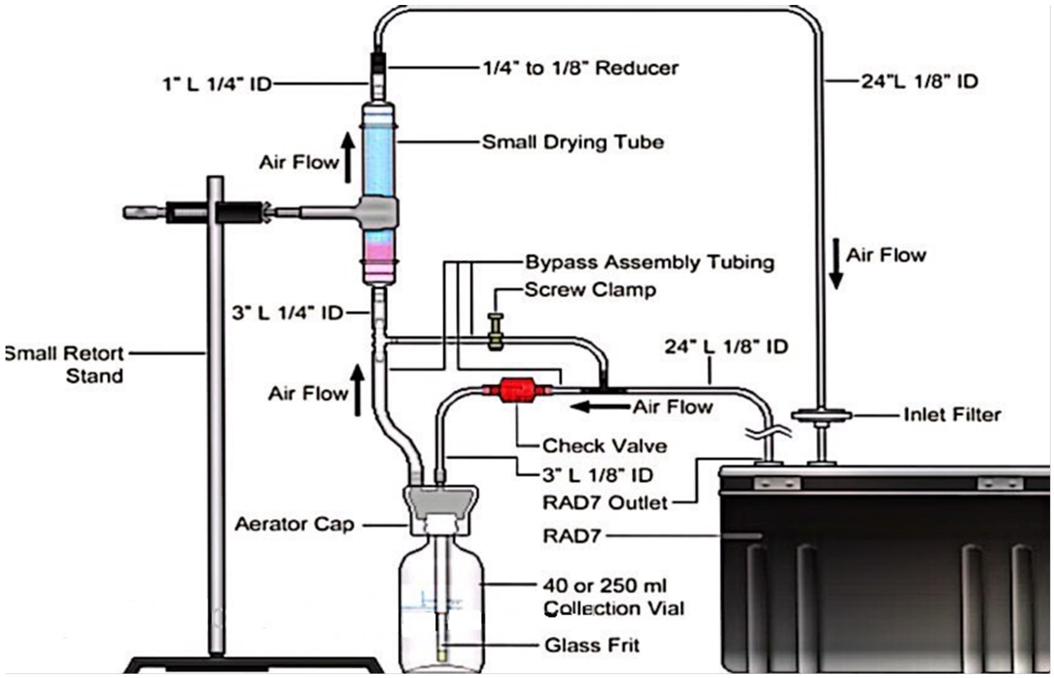
$$Dw = CwCrwDcw \tag{1}$$

The annual effective dose (y^{-1}) from the radioactive consumption of water intended for human consumption is.

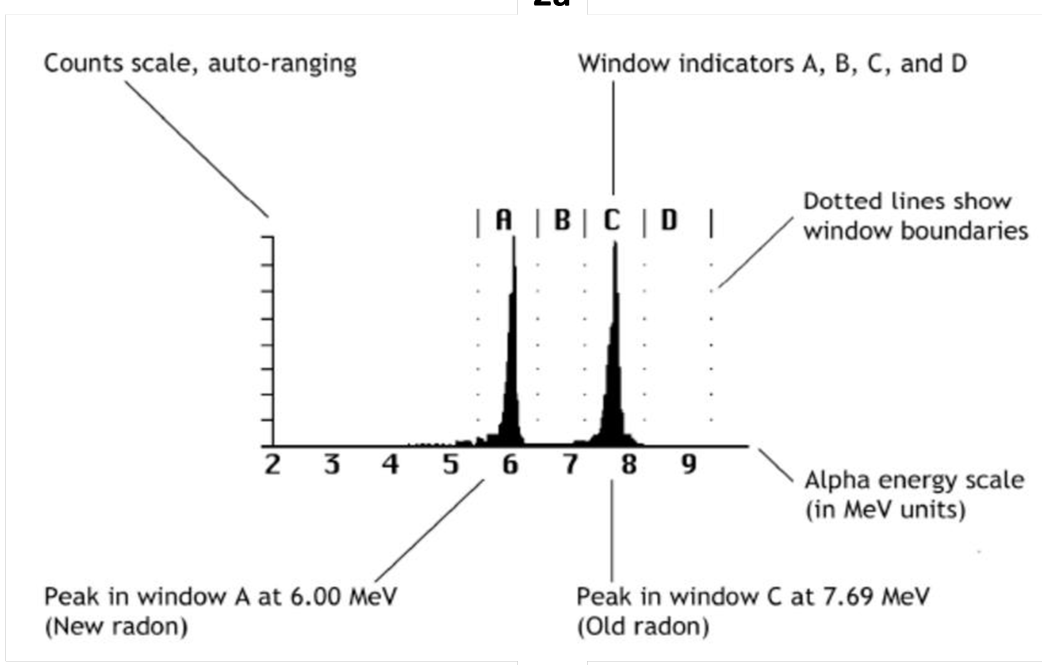
Cw is the amount of ^{222}Rn in the consumed water (BqL^{-1})

Crw is the annual volume of water consumed ($Ly\text{-}1^{-1}$)

Dcw is the estimated percentage of ^{222}Rn that is converted to dosage ($SvBq^{-1}$)



2a



2b

Figure 2. Two pictures displaying the water's measurement utilizing RAD7 accessories and the cumulative operational spectrum.

2a. A picture displaying the elements 218 Po and 214 Po in channels A and C, respectively, as well as the alpha spectrum [17].

2b. An illustration demonstrating the use of RAD7 and its RADH_2O derivatives to assess a water sample [18].

One factor that converts doses into units of 5×10^{-9} $SvBq^{-1}$ has been employed, in accordance with the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1993), an adult (over the age of 18) annually consumes, on average, 730 L of water [21], [22].

6. Results and Discussion:

Table 2 illustrates the concentration of radon in groundwater samples from the Kirkuk region (the medium concentration is average, the low concentration is the lowest, and the high concentration is the highest). Additionally, the annual effective dose for each sample was determined. The lowest concentration of ^{222}Rn was in the Zab River sample 0.18 BqL^{-1}, the maximum concentration was in the Falak sample 23.005 BqL^{-1}, and the average concentration in BqL^{-1} was 10.31. We believe the primary cause of this discrepancy is the different lengths of the source grids.

We believe that the primary cause of this discrepancy is the different lengths of the grids involved. One of our findings is that the volume of the variable depends upon the humidity level if the humidity level increases the activity and thus the error will increase as well.

The relative humidity should be 10 percent or less during the duration of the measurement. However, during testing, the humidity is typically greater than 10 percent. High humidity adversely affects the efficacy of corn harvesting. In this context, a low level of radioactivity is apparent. The RAD7 detector has a remarkable capacity to differentiate between the new ^{222}Rn isotope of radon and the old counterpart. The high concentration of radon and the long time the sample was in the cell increased the number of active offspring nuclei. To eliminate the background, the chemical was purged and the remaining chemical activity in the cell remaining after the chemical removal [23].

The amount of radon gas in the container was measured before and after a month of storage. The outcomes are listed in Table 2. We discovered that the concentration of groundwater samples from different areas (Aden Quarter, the Khassa River) before storage was 13.003, 0.921 BqL^{-1}. The radon concentration in the same region decreased to 0.397, 0.0361 BqL^{-1} following storage. After storage, the average concentration dropped to 9.84% of the original concentration of the sample. This is due to the short half-life of ^{222}Rn relative to the storage period 3.8 days.

The results of the average activity of radon concentration of groundwater in Kirkuk city were less than the accordable limit as reported in USEPA [24]. The maximum tolerable concentration of ^{222}Rn in water that can be achieved is 11 $kBqm^{-3}$. The concentration of activity in BqL^{-1} of the groundwater samples in this investigation was contrasted with other investigations that were conducted in different areas and listed in Table 3.

Some of the values in this investigation were less than the international values. The variations in radon concentration are primarily caused by the geological composition of the area, water depth, and also differences in the climate. Others have reported that the geological structure of an area is a predominant factor for high radon concentration and climate is also an important factor [25]. From throughout the globe in Table 3, groundwater radon concentrations are subject to change over time due to several variables, such as groundwater source relocation or recharge area growth. The seasonal average number of cases may vary depending on what caused the increase in radon in the groundwater. Deionized water can lower radon levels, according to the study [26] on the concentration of radon in tube wells. Additionally, a direct relationship was observed between the pH of the water sample and the radon levels. Numerous studies on the volume of radon in groundwater that have been conducted in different environments have demonstrated a strong relationship between the increase in radon and the presence of uranium and thorium in the stone parent. Because of the high concentration of

Table 2. Clarify the symbols of the map and the coordinates of each region.

Study Area	Radon Concentration C_{R_N} (BqL^{-1})		Mean of C_{R_N} (BqL^{-1}) before storage	ADE ($mSvy^{-1}$)	Mean of C_{R_N} (BqL^{-1}) after storage
	Low	High			
GW1	10.009	12.002	11.003	0.040	0.324
GW2	22.001	26.002	23.005	0.084	0.218
GW3	9.300	13.003	11.00	0.040	0.288
GW4	12.005	14.007	13.003	0.047	0.397
GW5	12.00	16.004	14.002	0.051	0.215
GW6	14.009	18.001	16.007	0.058	0.181
GW7	11.008	15.008	13.001	0.047	0.252
GW8	14.006	18.005	17.004	0.062	0.325
GW9	21.002	24.00	23.00	0.083	0.252
GW10	1.17	2.35	1.87	0.0068	0.253
GW11	4.19	5.87	4.64	0.017	0.18
GW12	15.005	17.002	16.005	0.058	0.15
GW13	9.845	13.00	10.00	0.037	0.217
GW14	10.005	14.006	12.00	0.044	0.256
GW15	13.001	14.006	14.001	0.051	0.19
GW16	0.297	1.91	0.921	0.0034	0.0361
GW17	13.007	17.004	15.001	0.055	0.288
GW18	14.007	15.007	15.00	0.054	0.359
GW19	4.18	7.54	5.55	0.020	0.0722
GW20	6.6	7.92	7.34	0.027	0.216
GW21	3.8	5.98	5.2	0.019	0.219
GW22	0.143	0.289	0.18	6.57E-7	0.0286
Rain water	0	0.871	0.398	0.0015	0.287
	Average		10.31	0.039	0.226

radon in groundwater, the concentration is typically high in areas with significant tectonic stress. Changes in soil composition, structural issues, and geology are associated with the spatial variation of ^{222}Rn concentrations. Elevated levels of radon have been found in soil and groundwater above folds, fractures, faults, and lineaments. It is employed in numerous hydrogeological studies as a natural tracer and to measure submarine discharge along sea coats.

These investigations show a clear correlation between groundwater radon enrichment and the amount of uranium and thorium in source rocks. Because of the influence of other elements, groundwater radon concentrations rise in places with significant tectonic activity. The quantity of layers, changes in soil type, structural characteristics, and geology are frequently responsible for spatial variance.

Table 3. Clarify the symbols of the map and the coordinates of each region.

Water type	Country	Average radon concentration (BqL^{-1})	Reference
Groundwater	Iraq-Kirkuk	10.31	Current study
Tap water	Iraq-Al-shomaly	0.29	[27]
Khassa water	Iraq-kirkuk	0.1575	[28]
Groundwater	Iraq-Kufa city	0.267-5.662	[29]
Groundwater	Iraq-Nenava	1.133	[30]
Groundwater	Khartoum	59.2	[31]
Groundwater	Algeria	7	[32]
Groundwater	Italy	1.80-52.70	[33]
Groundwater	Jordan	3.9	[34]
Groundwater	China	110-36.00	[12]
Groundwater	Saudi Arabia	0.76-9.15	[35]
Tap water	Iran	0.21-3.89	[36]
Well	Turkey	0.70-31.70	[37]
Well	Mexico	1.78-39.75	[38]
Drinking water	Kirkuk	0.97	[39]

7. Conclusions:

Health hazard from exposure to radon is not an acute problem, if considered globally. But a looming danger of health complications cannot be ignored due to the health risks involved in areas where radon concentration assumes dangerous proportions. The present study showed that the radon concentration of the groundwater samples from the study areas were close than the maximum contaminant level (MCL) value. Even the annual effective dose values were significantly lower than the UNSCEAR and WHO recommended limit for members of the public of 1 mSv y^{-1}. These data must be regarded as preliminary and further extensive studies should be done on large scale by initiating further detailed investigation of whole command area completely for radon contamination, to increase awareness and mitigate possible hazards. With some exceptions related to a known radioactive anomaly and other closer results, they do not present a danger for the public, will bring a definite additional radiological risk to indoor air. In household water usage, showers, baths, dishwashers, laundries, and toilets all provide adequate aeration to release a high percentage of the water's radon content into household air. Hence, mitigation process of reducing radon gas related exposure in the home or workplace such as increasing indoor ventilation (open windows, air-to-air heat exchangers), removing radon progeny from the air (filters, fans), or ventilating the soil surrounding the building should be promoted.

Funding: None.

Data Availability Statement: All of the data supporting the findings of the presented study are available from corresponding author on request.

Declarations:

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: The manuscript has not been published or submitted to another journal, nor is it under review.

References

[1] C. Sabbarese, F. Ambrosino, A. D'Onofrio, M. Pugliese, G. La Verde, V. D'Avino, and V. Roca. The first radon potential map of the Campania region (Southern italy). *Applied Geochemistry*, 126: 104890, 2021, doi:10.1016/j.apgeochem.2021.104890.

[2] Cong H. Le, Nguyen P. Th. Huynh, Van Th. Nguyen, and Quoc B. Le. Radon and Radium Concentrations in Drinkable Water Supplies of the Thu Duc Region in Ho Chi Minh City, Vietnam. *Applied Radiation Isotopes*, 105: 219–224, 2015, doi:10.1016/j.apradiso.2015.08.033.

[3] K. Joaquim, B. Yoenls, I. Margarida, P. Luis, and S. Sandra. Radon concentration potential in Bibala municipality water: Consequences for public consumption. *Radiation Physics Chemistry*, 126, 2021, doi:10.1016/j.radphyschem.2020.108951.

[4] M. Rohit and B. Pankaj. Estimation of annual effective dose due to Radon level in indoor air and soil gas in Hamirpur district of Himachal Pradesh. *Geochemical Exploration*, 142: 16–20, 2014, doi:10.1016/j.gexplo.2013.07.005.

[5] Sh. Sumit, M. Kamini, N. Saurabh, and K. Ajay. Dose estimation from the exposure to radon, thoron and their progeny concentrations in the environs of

Kangra area, Himachal Himalayas, India. *Groundwater Sustainable Development*, 11: 100409, 2020, doi:10.1016/j.gsd.2020.100409.

[6] WHO. WHO Handbook on Indoor Radon: Public Health Perspective. *World Health Organization*, 2009.

[7] Daryoush Sh. Gahrouei and S. Mohsen. Dose assessment and radioactivity of the mineral water resources of Dimeh springs in the Chahar-mahal and Bakhtiari Province, Iran. *Nukleonika*, 53(1): 31–34, 2008.

[8] J. K. Otton, L. C. S. Gundersen, and R. Schumann. Geology of Radon, U.S. Department of Interior. *U.S. Geology survey*, 1995.

[9] M.C. Schwartz. Significant groundwater input to a coastal plain estuary: Assessment from excess radon. *Estuarine, Coastal and Shelf Science*, 56(1): 31–42, 2009, doi:10.1016/S0272-7714(02)00118-X.

[10] Daniel D. Snow and Roy F. Spalding. Short-term aquifer residence times estimated from ^{222}rn disequilibrium in artificially-recharged ground water. *Environmental Radioactivity*, 37(3): 307–325, 1997, doi:10.1016/S0265-931X(97)00001-5.

[11] B. Henryk, P. Urszula, S. Marta, Ewa M. Bem, and M. Daria. Radon (^{222}rn) in underground drinking water supplies of the Southern Greater Poland Region. *Radioanalytical Nuclear Chemistry*, 299(3): 1307–1312, 2014, doi:10.1007/s10967-013-2912-1.

[12] W. Tingyu D. Jinzhou, J. Tao, and W. Xilong. Use of ^{222}rn to trace submarine groundwater discharge in a tidal period along the coast of Xiangshan, Zhejiang, China. *Radioanalytical Nuclear Chemistry*, 299: 53–60, 2014, doi:10.1007/s10967-013-2786-2.

[13] Janine N. Correa, P. Sergei, K. Jaqueline, and P. Allan. Measurements of ^{222}rn activity in well water of the Curitiba metropolitan area (Brazil). *Radiation Physics and Chemistry*, 104: 108–111, 2014, doi:10.1016/j.radphyschem.2014.01.006.

[14] R. Asha, M. Rohit, and D. Vikas. Radon monitoring in groundwater samples from some areas of northern rajasthan, india, using a rad7 detector. *Radiation Protection Dosimetry*, 153(4): 496–501, 2013, doi:10.1093/rpd/ncs130.

[15] Christina E. Stringer and William C. Burnett. Sample bottle design improvements for radon emanation analysis of natural waters. *Health Physics*, 87(6): 642–646, 2004.

[16] User Manual. Rad7 Radon Detector, 2011.

[17] Ref. Manual. (Rad7) Electronic Radon Detector, 2017.

[18] Reference Manual version 6.0.1. Rad7 Electronic Radon Detector, 2010.

[19] R. K. Somashekarand and P. Ravikumar. Radon concentration in groundwater of Varahi and Markandeya river basins, Karnataka State, India. *Radioanalytical Nuclear Chemistry*, 285(2): 343–351, 2010, doi:10.1007/s10967-010-0573-x.

[20] M.N. Alam, M.I. Chowdhry, M. Kamal, S. Ghose, M. N. Islam, and M. Awaruddin. Radiological assessment of drinking water of the Chittagong region of Bangladesh. *Radiation Protection Dosimetry*, 82: 207–214, 1999, doi:10.1093/oxfordjournals.rpd.a032626.

[21] United Nation Scientific Committee on the Effect of Atomic Radiation. Sources and Effects of Ionizing Radiation, 1993.

[22] C. Ugur, D. Nevzat, K. Gursel, C. Nilgum, and A. I. Kobya. Natural radioactivity in tap waters of eastern black sea region of turkey. *Radiation Protection Dosimetry*, 118(1): 88–92, 2006, doi:10.1093/rpd/nci325.

[23] H. M. Diab. Measurement of Radon Levels in Water in Arar City, Saudi Arabia. *Romanian Journal of Biophysics*, 27: 129–136, 2017.

[24] The CT DPH Radon Program. Connecticut Department of Public Health Environmental Health Section Radon Program, 2010.

[25] J. Vaupotic, I. Kobal, and J. Planinic. Long-term radon investigation in four selected kindergartens in different geological and climate regions of Slovenia. *Radioanalytical Nuclear Chemistry*, 238(1-2): 61–66, 1998, doi:10.1007/bf02385356.

[26] R.G. Sonkawade, R. Rewa, K. Dinakar, and Rakesh C. Ramola. Radon in tubewelz drinking water and indoor air. *Indoor Built Environment*, 13: 383–386, 2004, doi:10.1177/1420326X04046464.

[27] H. k. Inam. Measurement of radon concentration and their annual effective dose exposure in water from al-shomaly district of babylon iraq. *Arabian Journal of Science and EngineeringHealth and Medical Sciences*, 1(2): 34–37, 2014.

[28] Dunya O. Kareem, Ahmed A. Ibrahim, and Omer S. Ibrahiem. Heavy metal and radon gas concentration levels in Khasa River in Kirkuk City (NE Iraq) and the associated health effects. *Arabian Journal of Geoscience*, 13(1023): 1–11, 1996, doi:10.1007/s12517-020-06037-8.

[29] Ali A. Al-Hamadwi, Abdulhussan A. Al-Bayati, and Asia H. Al-Mashhadani. Radon and Thoron Concentration measurement of Ground Water in Kufa City by

using RAD7 detector. *Journal of Kufa-Physics*, 4(2): 44–49, 2012.

[30] S.Y. H. Ukla. Determination of radon Uranium and other radioactive isotopes concentration in different types of natural water in nenava governorate. Master's thesis, University of Mosul, 2004.

[31] I. Hajo S. Isam and A. K. Sam. Study of radon in ground water and physicochemical parameters in Khartoum state. *Radioanalytical and Nuclear Chemistry*, 290(2): 333–338, 2011, doi:10.1007/s10967-011-1295-4.

[32] D. Amrani. Natural radioactivity in Algerian bottled mineral waters. *Radioanalytical and Nuclear Chemistry*, 252: 597–600, 2002.

[33] D. Walter and F. Vita. Groundwater radon measurements in the Mt. Etna area. *Environmental Radioactivity*, 65(2): 187–201, 2003, doi:10.1016/S0265-931X(02)00096-6.

[34] A. T. Al-Kazwini and M. A. Hasan. Radon concentration in jordanian drinking water and hot springs. *Radiological Protection*, 23(4): 439–448, 2003, doi:10.1088/0952-4746/23/4/007.

[35] Wedad R. Alharbi, Adel G. E. Abbady, and A. El-Taher. Radon Concentrations Measurement for groundwater Using Active Detecting Method. *American Scientific Research Journal for Engineering Technology and Sciences*, 14(1): 1–11, 2015.

[36] A. Jalili-Majareshin, A. Behtash, and D. Rezaei-Ochbelagh. Radon concentration in hot springs of the touristic city of Sarein and methods to reduce radon in water. *Radiation Physics and Chemistry*, 81(7): 749–757, 2012, doi:10.1016/j.radphyschem.2012.03.015.

[37] Huseyin A. Yalim, Ayla S. Gümüş, U. Ridvan, and O. Önder. Measurements of radon concentrations in well waters near the Akşehir fault zone in Afyonkarahisar, Turkey. *Radiation Measurements*, 42(3): 505–508, 2007.

[38] L. Villalba, L. Colmenero S., M. E. Montero Cabrera, A. Cano Jimenez, and E. F. Herrera Peraza. Radon concentrations in ground and drinking water in the state of chihuahua, mexico. *Environmental Radioactivity*, 80(2): 139–151, 2005.

[39] Muaiad T. Ahmed, Mohamed A. Naje malde n, Ali A. Abdulwhab, and Rehab T. Ahmed. Estimation of radon gas concentration in soil and drinking water supply sample of kirkuk governorate, iraq. *Journal of University of Garmian, Iraq*, 6: 26–33, 2019, doi:10.24271/garmian.scpas4.

تراكيز الرادون في المياه الجوفية لمدينة كركوك /العراق

جنان ناصر هواس [1,*] ، احمد عبد ابراهيم [2] ، عمر صباح التميمي [3]

[2,1] قسم الفيزياء، كلية العلوم، جامعة كركوك، كركوك، العراق.

[3] قسم علوم الارض، كلية العلوم، جامعة كركوك، كركوك، العراق.

* **الباحث المسؤول:** *scph20m020@uokirkuk.edu.iq*

الخلاصة

أصبحت المياه الجوفية معترفا بها أكثر فأكثر كإمدادات مياه حاسمة ولا غنى عنها على أساس عالمي. شهدت العقود القليلة الماضية زيادة كبيرة في الطلب بسبب الاكتظاظ السكاني وتحسين مستويات المعيشة. حظي النشاط الإشعاعي الطبيعي في الماء بالكثير من الاهتمام في السنوات الأخيرة. تم اختبار اثنين وعشرين عينة من المياه الجوفية من منطقة كركوك في العراق للرادون باستخدام *RAD7* ، وهو كاشف رادون إلكتروني مقترن بملحق $RAD-H_2O$ ، تراوح تركيز الرادون الملحوظ من BqL^{-1} 10.31 إلى 0.18 BqL^{-1} 23.005 تقع قراءات تركيز الرادون التي تم قياسها بشكل جيد ضمن نطاق الحد الأقصى للتلوث (*MCL*) البالغ BqL^{-1} 11.1 الذي حددته وكالة حماية البيئة. كانت الجرعة الفعالة السنوية للمستهلك الفردي 0.039 $mSvy^{-1}$ ضمن حد التعرض العام البالغ 1 $mSvy^{-1}$ الذي حددته منظمة الصحة العالمية و *UNSCEAR* . يمكن للمزارعين أن يشعروا بالأمان هنا، والسكان ليسوا معرضين بشكل خاص للخطر من تركيزات الرادون، استنادا إلى القيم المقاسة للمياه الجوفية في موقع الدراسة. انتهت هذه الدراسة دون النظر في كيفية تأثر تركيز الرادون بفيزياء المياه الجوفية والخصائص الكيميائية مثل *PH* و *EC* . بعد الاحتفاظ بالعينة لمدة شهر، يتم إعادة حساب تراكيز الرادون.

الكلمات الدالة: غاز الرادون؛ المياه الجوفية؛ الجرعة السنوية الفعالة؛ التلوث الاشعاعي؛ كاشف *RAD7* .

التمويل: لايوجد.

بيان توفر البيانات: جميع البيانات الداعمة لنتائج الدراسة المقدمة يمكن طلبها من المؤلف المسؤول.

اقرارات:

تضارب المصالح: يقر المؤلفون أنه ليس لديهم تضارب في المصالح.

الموافقة الأخلاقية: لم يتم نشر المخطوطة أو تقديمها لمجلة أخرى، كما أنها ليست قيد المراجعة.