# Assessment of $^{222}$Radon Concentration and Annual Effective Dose in Drinking Water in Bardarash, Kurdistan Region of Iraq

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## ABSTRACT

**The study aims to determine the concentration of radon to assess the radioactive risk in groundwater in Bardarash, Kurdistan region, Iraq, which relies on groundwater as its primary source of water. Fifty samples were collected from wells for water use and were evaluated with RAD7-active Durridge Electronic Detector. Radon concentrations ranged from 0.93±0.43 Bq/l to 11.39±1.86 Bq/l, with a mean of 7.22 Bq/l and a standard deviation of 2.5. The results were used to estimate the annual effective doses of three categories. The annual effective doses of ingestion of groundwater ranged from 14.26 to 174.61 µSv/y with an average value of 110.73 µSv/y, 19.02 to 232.81 µSv/y with an average value of 147.67 µSv/y, and 4.41 to 54.05 µSv/y with an average value of 34.27 µSv/y, for infants, children, and adults, respectively. Furthermore, the annual effective dosage obtained in inhalation ranged from 2.34 to 28.70 µSv/y, with an average of 18.20 µSv/y. The total annual effective dose ranged from 16.60 to 203.31 µSv/y with an average value of 128.93 µSv/y, 21.35 to 261.51 µSv/y with an average value of 165.84 µSv/y, and 6.76 to 82.75 µSv/y with an average value of 52.48 µSv/y for infants, children, and adults, respectively. The majority of the samples had radon concentrations and effective dosages that were less than the maximum permissible limit of 11.1 Bq/l. This indicates that the majority of the samples are drinkable and safe to consume.**

***Keywords-cancer; radon; annual effective dose; RAD7***

## I. INTRODUCTION

Cancer is a global serious health issue. [1]. In Iraq, almost 80 instances of cancer are discovered for every 100,000 individuals, according to the officials. Medical professionals frequently warn about the rise in cancer incidences across the nation due to pollution, obesity, and other bad behaviors [2]. Cancer is the multistage process in which healthy cells change into tumor cells, often expanding from a precancerous lesion to a malignant tumor. This process may be brought on by biological carcinogens, the effects of age, and physical carcinogens (such as UV and ionizing radiation) or by exposure to recognized chemical carcinogens (such as smoking tobacco, drinking water contaminants, aflatoxin, etc.). Most chemical carcinogens are consumed by drinking tainted water. Heavy metals like arsenic and lead, asbestos, radionuclides like radon and uranium, agricultural chemicals, and hazardous waste are some of the contaminants found in drinking water [3-5].

Water is significant an all-purpose solvent. Given that water is frequently obtained from natural sources like wells, rivers, etc., large amounts of radionuclides including $^{40}$K, $^{226}$Ra, 2$^{32}$Th, $^{238}$U, and $^{222}$Rn have been discovered to have traces in water. Human activities like mining might increase the activity of these radionuclides [6, 7]. The primary theme of this collection is radon, a naturally occurring radioactive gas produced by the decay of $^{238}$U. The uranium present in soil progressively degrades to other radionuclides like radium, which over time transforms into radon [8-10]. A small portion of the radium enters the groundwater and remains below the surface. When radon is present in surface or ground waters, it can enter the body by ingestion (drinking contaminated water) or breathing. This radon breaks down into its daughter nuclides during either procedure (ingestion or inhalation), releasing alpha particles that irradiate the cells in the lungs or the stomach, causing them to mutate and ultimately trigger cancer [11, 12].

Iraq is witnessing its greatest water scarcity in a century, according to the Ministry of Water Resources, and 7 million people have less access to the resource, so we must utilize alternative methods to acquire sufficient water. Every community in the nation has a significant number of wells among these resources [3, 13, 14].

Radon has been linked to lung cancer, and, according to previous studies, is the main cause of lung cancer among non-smokers and the second greatest cause among smokers. The World Health Organization (WHO) and the International Agency for Research on Cancer (IARC) have classified radon as a human lung carcinogenic [15, 16]. The ICRP also recommends that all countries should conduct radon surveys to identify radon-prone locations. The current study aims to measure radon concentration and dose assessment in well water in Bardarash and compare it with international standards for drinking water use [16].

## II. STUDY AREA

The Bardarash region, which is located southeast of Duhok in northern Iraq, has been chosen as the research location for the current investigation. The latitudes 36°30' - 36°55' N and longitudes 43°20' - 43°60' E describe the area's boundaries. Bardarash has a population of about 36,356 people and is divided into three subdistricts: Rovya, Darto, and Kalak.

The GIS techniques are effectively used in assessing and mapping the spatial distribution of chemical parameters and groundwater quality in the selected area. There are many wells in this region, and these wells are the most common source of water in the region and are used for all needs, including drinking (Figure 1).

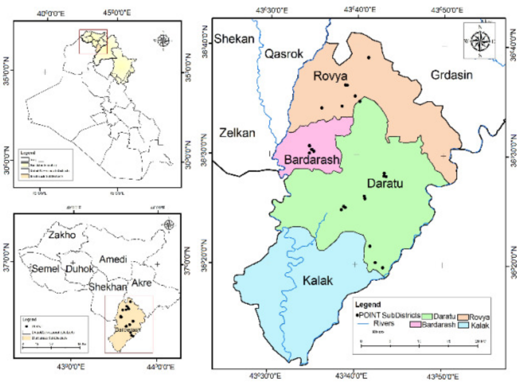


Fig. 1. Map of Bardarash district, displaying the study area.

## III. MATERIALS AND METHODS

The location chosen in this study is one of the most suitable areas in the country due to the frequent use of wells as a main source of water. As mentioned above, the Bardarash area is rich in groundwater, mostly in wells. We chose fifty wells in Bardarash district, each well separated from the others, to find out the total percentage of radon gas in the district. Taking samples from the fifty wells was accurate and according to the requirements and guidelines of the device that was used. The water samples were taken at a distance below the surface of the water, in order not to minimize the effect of external factors such as air that would change the proportion of radon gas in the water [17, 18]. The bottles were placed inside a fetcher and were covered in the water as they were filled to the brim, collecting the water samples. The sampling time was recorded. The samples were immediately taken to the lab in order to improve the radon analysis accuracy and prevent a change in the composition of the samples [19]. The RAD7 is an advanced measurement device that is often used in labs and for research projects. Researchers who investigate groundwater, mines, deserts, the ocean, and volcanoes at high temperatures utilize it in addition to certified radon testers. Water samples taken from the mining site were analyzed using a calibrated RAD7-Active Electronic detector connected to a Durridge RAD-H2O attachment [19, 20]. By connecting it to an effervescing kit that enables the degassing of radon from the water into the air in a closed loop, this detector was set up to measure the concentration of radon in water samples as shown in Figure 2.

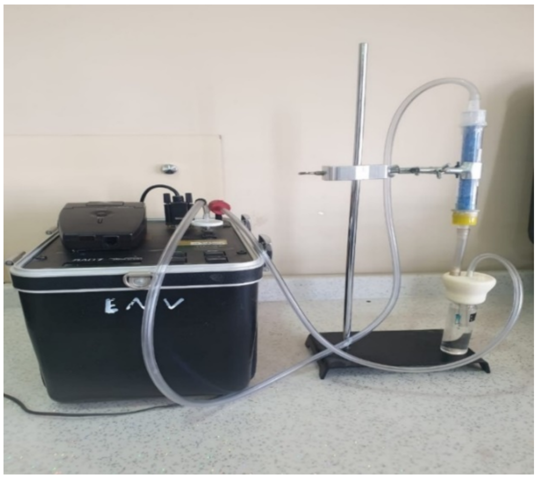

Fig. 2. Setup of the RAD7-Active Electronic Detector for measuring radon in water.

The alpha spectrometry technique was used by the RAD7-Active Electronic detector. In roughly 20 minutes, this electronic detector can accurately determine the radon content in a given water sample. This measuring period is brief when compared to the radon's 3.8-day half-life. As a result, the Durridge RAD7-Active Electronic detector is appropriate for measuring radon in water [21, 22]. Radon in drinking water has drawn attention due to its potential to have additional serious radiological health impacts outside the well-known lung cancer. Equation (1) was used to calculate the Annual Effective Dose (Sv/year) for ingestion (AEDing) [22, 23].

$$AEDinh = CRnw \times Rnw \times F \times O \times DCFinh \quad (1)$$

where AEDinh indicates the annual effective dose from radon inhalation (Sv/y) and F = 0.4 denotes the equilibrium factor between radon and its offspring. Rnw = $10^{-4}$ is the radon in air/water percentage, O = 7,000 h. y-1 is the average indoor occupancy time per individual. The dosage conversion factor for radon exposure in the air is DCFinh (9 $nSvh^{-1}$ ($Bqm^{-3}$) [22, 24, 25]. The total Annual Effective Dose (total) generated from the sum of ingested and inhaled doses as a result of surface and groundwater use in this mining area is calculated by.

$$AEDtotal = AEDing + AEDinh \quad (3)$$

where AEDtotal denotes the total annual effective dosage (μSv/y). AEDing denotes the annual effective dose from radon consumption (μSv/y). AEDinh denotes the annual effective dose from radon inhalation (μSv/y).

## IV. RESULTS AND DISCUSSION

The result of $^{222}$Rn concentration and effective dose absorbed due to groundwater consumption of the fifty sampled wells located in Bardarash are shown in Table I.

TABLE I. $^{222}$RN CONCENTRATION AND ANNUAL EFFECTIVE DOSE OF GROUNDWATER IN BARDARASH, KURDISTAN, IRAQ

| **Location Name** | **$^{222}$Ra (Bq/L)** | **AEDing infants (μSv/y)** | **AEDing children (μSv/y)** | **AEDing adults (μSv/y)** | **AEDinh (μSv/y)** | **AEDtotal infants (μSv/y)** | **Total children (μSv/y)** | **Total adults (μSv/y)** |
|---|---|---|---|---|---|---|---|---|
| GW1 | 7.7 ± 0.61 | 118.04 | 157.39 | 36.54 | 19.40 | 137.45 | 176.79 | 55.94 |
| GW2 | 7.22 ± 0.66 | 110.68 | 147.58 | 34.26 | 18.19 | 128.88 | 165.77 | 52.45 |
| GW3 | 4.67 ± 0.8 | 71.59 | 95.45 | 22.16 | 11.77 | 83.36 | 107.22 | 33.93 |
| GW4 | 5.83 ± 0.66 | 89.37 | 119.17 | 27.66 | 14.69 | 104.07 | 133.86 | 42.35 |
| GW5 | 4.67 ± 0.47 | 71.59 | 95.45 | 22.16 | 11.77 | 83.36 | 107.22 | 33.93 |
| GW6 | 3.27 ± 0.54 | 50.13 | 66.84 | 15.52 | 8.24 | 58.37 | 75.08 | 23.76 |
| GW7 | 6.3 ± 0.75 | 96.58 | 128.77 | 29.89 | 15.88 | 112.46 | 144.65 | 45.77 |
| GW8 | 9.08 ± 1.6 | 139.20 | 185.60 | 43.08 | 22.88 | 162.08 | 208.48 | 65.97 |
| GW9 | 9.06 ± 1.69 | 138.89 | 185.19 | 42.99 | 22.83 | 161.72 | 208.02 | 65.82 |
| GW10 | 11.24 ± 1.17 | 172.31 | 229.75 | 53.33 | 28.32 | 200.63 | 258.07 | 81.66 |
| GW11 | 4.41 ± 2.44 | 67.61 | 90.14 | 20.93 | 11.11 | 78.72 | 101.25 | 32.04 |
| GW12 | 8.22 ± 0.62 | 126.01 | 168.02 | 39.00 | 20.71 | 146.73 | 188.73 | 59.72 |
| GW13 | 10.03 ± 1.69 | 153.76 | 205.01 | 47.59 | 25.28 | 179.04 | 230.29 | 72.87 |
| GW14 | 8.16 ± 0.93 | 125.09 | 166.79 | 38.72 | 20.56 | 145.66 | 187.35 | 59.28 |
| GW15 | 5.6 ± 0.67 | 85.85 | 114.46 | 26.57 | 14.11 | 99.96 | 128.58 | 40.68 |
| GW16 | 7.9 ± 1.28 | 121.11 | 161.48 | 37.49 | 19.91 | 141.02 | 181.38 | 57.39 |
| GW17 | 6.74 ± 1.19 | 103.32 | 137.77 | 31.98 | 16.98 | 120.31 | 154.75 | 48.97 |
| GW18 | 9.53 ± 1.11 | 146.09 | 194.79 | 45.22 | 24.02 | 170.11 | 218.81 | 69.24 |
| GW19 | 5.58 ± 0.52 | 85.54 | 114.06 | 26.48 | 14.06 | 99.60 | 128.12 | 40.54 |
| GW20 | 7.44 ± 0.62 | 114.06 | 152.07 | 35.30 | 18.75 | 132.80 | 170.82 | 54.05 |
| GW21 | 10.22±1.17 | 156.67 | 208.90 | 48.49 | 25.75 | 182.43 | 234.65 | 74.25 |
| GW22 | 11.39 ± .86 | 174.61 | 232.81 | 54.05 | 28.70 | 203.31 | 261.51 | 82.75 |
| GW23 | 6.97 ± 0.54 | 106.85 | 142.47 | 33.07 | 17.56 | 124.41 | 160.03 | 50.64 |
| GW24 | 9.76 ± 0.8 | 149.62 | 199.49 | 46.31 | 24.60 | 174.22 | 224.09 | 70.91 |
| GW25 | 7.44 ± 0.63 | 114.06 | 152.07 | 35.30 | 18.75 | 132.80 | 170.82 | 54.05 |
| GW26 | 6.74 ± 0.49 | 103.32 | 137.77 | 31.98 | 16.98 | 120.31 | 154.75 | 48.97 |
| GW27 | 6.27 ± 1.15 | 96.12 | 128.16 | 29.75 | 15.80 | 111.92 | 143.96 | 45.55 |
| GW28 | 8.83 ± 0.68 | 135.36 | 180.49 | 41.90 | 22.25 | 157.62 | 202.74 | 64.15 |
| GW29 | 9.29 ± 0.64 | 142.42 | 189.89 | 44.08 | 23.41 | 165.83 | 213.30 | 67.49 |
| GW30 | 6.97 ± 0.53 | 106.85 | 142.47 | 33.07 | 17.56 | 124.41 | 160.03 | 50.64 |
| GW31 | 9.31 ± 0.65 | 142.72 | 190.30 | 44.18 | 23.46 | 166.18 | 213.76 | 67.64 |
| GW32 | 6.74 ± 0.77 | 103.32 | 137.77 | 31.98 | 16.98 | 120.31 | 154.75 | 48.97 |
| GW33 | 1.86 ± 0.39 | 28.51 | 38.02 | 8.83 | 4.69 | 33.20 | 42.71 | 13.51 |
| GW34 | 6.74 ± 0.8 | 103.32 | 137.77 | 31.98 | 16.98 | 120.31 | 154.75 | 48.97 |
| GW35 | 4.41 ± 0.57 | 67.61 | 90.14 | 20.93 | 11.11 | 78.72 | 101.25 | 32.04 |
| GW36 | 10.46±0.64 | 160.35 | 213.80 | 49.63 | 26.36 | 186.71 | 240.16 | 75.99 |
| GW37 | 7.15 ± 0.59 | 109.61 | 146.15 | 33.93 | 18.02 | 127.63 | 164.16 | 51.94 |
| GW38 | 10.72±0.65 | 164.34 | 219.12 | 50.87 | 27.01 | 191.35 | 246.13 | 77.88 |
| GW39 | 9.53 ± 0.76 | 146.09 | 194.79 | 45.22 | 24.02 | 170.11 | 218.81 | 69.24 |
| GW40 | 4.37 ± 1.36 | 66.99 | 89.32 | 20.74 | 11.01 | 78.00 | 100.34 | 31.75 |
| GW41 | 10.33 ± 0.9 | 158.36 | 211.15 | 49.02 | 26.03 | 184.39 | 237.18 | 75.05 |
| GW42 | 9.53 ± 0.74 | 146.09 | 194.79 | 45.22 | 24.02 | 170.11 | 218.81 | 69.24 |
| GW43 | 6.51 ± 0.63 | 99.80 | 133.06 | 30.89 | 16.41 | 116.20 | 149.47 | 47.30 |
| GW44 | 11.39 ± 1.3 | 174.61 | 232.81 | 54.05 | 28.70 | 203.31 | 261.51 | 82.75 |
| GW45 | 0.93 ± 0.43 | 14.26 | 19.01 | 4.41 | 2.34 | 16.60 | 21.35 | 6.76 |
| GW46 | 5.58 ± 0.87 | 85.54 | 114.06 | 26.48 | 14.06 | 99.60 | 128.12 | 40.54 |
| GW47 | 5.81 ± 3.33 | 89.07 | 118.76 | 27.57 | 14.64 | 103.71 | 133.40 | 42.21 |
| GW48 | 3.43 ± 0.54 | 52.58 | 70.11 | 16.28 | 8.64 | 61.23 | 78.75 | 24.92 |
| GW49 | 5.88 ± 3.33 | 90.14 | 120.19 | 27.90 | 14.82 | 104.96 | 135.00 | 42.72 |
| GW50 | 3.95 ± 0.6 | 60.55 | 80.74 | 18.74 | 9.95 | 70.51 | 90.69 | 28.70 |
| MIN | 0.93 | 14.26 | 19.01 | 4.41 | 2.34 | 16.60 | 21.35 | 6.76 |
| MAX | 11.39 | 174.61 | 232.81 | 54.05 | 28.70 | 203.31 | 261.51 | 82.75 |
| MEAN | 7.22 | 110.73 | 147.64 | 34.27 | 18.20 | 128.93 | 165.84 | 52.48 |
| SD | 2.5 | 38.33 | 51.11 | 11.86 | 6.30 | 44.63 | 57.41 | 18.17 |
| CV | 34.63 | 34.62 | 34.62 | 34.62 | 34.62 | 34.62 | 34.62 | 34.62 |

The radon concentration ranged from 0.93 ± 0.43 Bq/l to 11.39 ± 1.86 Bq/l with a mean of 7.22 Bq/l and a standard deviation of 2.5. Groundwater always contains a greater concentration of radon gas than surface water, due to the low temperature in the wells and the low oxygen content in the water on the ground, but in the selected area the temperature is very high most of the year, affecting the concentration of radon in the water. The USEPA proposes a Maximum Contamination Level (MCL) of 11.1 Bq/l for the concentration of $^{222}$Rn in groundwater [26]. So, all the wells sampled in the study are acceptable according to USEPA, except for three, namely GW10, GW22, and GW44. The annual effective doses from $^{222}$Rn ingestion and inhalation by adults, children, and infants in groundwater from the wells are also presented in Table I. Ingestion of groundwater had annual effective doses ranging from 14.26 to 174.61 µSv/y with an average value of 110.73 µSv/y, 19.02 to 232.81 µSv/y with an average value of 147.67 µSv/y, and 4.41 to 54.05 µSv/y with an average value of 34.27 µSv/y for infants, children, and adults, respectively. Moreover, the annual effective dosage for groundwater for the sampled wells caused by inhalation of $^{222}$Rn ranged from 2.34 to 28.70 µSv/y, with an average value of 18.20 µSv/y.

By AEDing and AEDinh, the total annual effective doses of all samples were determined and their ranges are from 16.60 to 203.31 µSv/y with an average value of 128.93 µSv/y, 21.35 to 261.51 µSv/y with an average value of 165.84 µSv/y, and 6.76 to 82.75 µSv/y with an average value of 52.48 µSv/y for infants, children, and adults respectively as shown in Figure 3.

The dose conversion factor for the three considered categories (infants, children, and adults) shows the flow difference between them categories depending on the percentage of water consumption. The majority of the examined wells turned out to be very healthy water sources, and their water can be used by the public. The effective dose values calculated for all categories were less or close to the acceptable limits of 100 µSv/y (WHO, 2004), so the water from the sampled wells does not pose any radiation hazard.

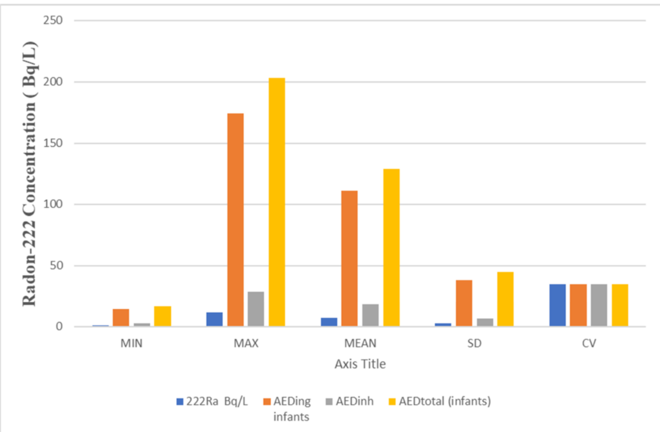


Fig. 3. Total radon concentrations and annual effective doses of the selected water samples.

## V. CONCLUSION

This study aims to shed light on a hitherto unexplored facet about the concentration of radon gas and the associated effective absorbed dose in the Bardarash region. This geographical location is entirely reliant on groundwater sources for its water supply. While prior investigations have delved into the examination of water quantity and quality using chemical tests, it is worth noting that no relevant studies have concentrated on the issue of the radon gas concentration of the officially sanctioned wells within this region. The analysis of groundwater samples from fifty locations in the area revealed a minimum radon concentration of 0.93 ± 0.43 Bq/l. In terms of annual effective dose, which accounts for both ingestion and inhalation exposure, it was found that for surface water samples, infants faced a mean dose of 14.26 µSv/y, children were exposed to 19.01 µSv/y, and adults experienced 4.41 µSv/y. It should be noticed that the radon concentration levels and the corresponding effective doses resulting from ingestion and inhalation were generally found to be below the recommended limits. These limits are set at 11.1 Bq/l for radon concentration (as per UNSCEAR, 2000, and USEPA, 1991) and 100 µSv/y for effective dosage (according to WHO, 2004). This outcome provides a reassuring indication that the majority of the sampled wells in the area supply potable water is safe for consumption. In other words, the levels of radon and the associated health risks in these wells are well within the acceptable and safe parameters. This is essential information for ensuring the well-being of the community and underscores the suitability of these wells as a reliable source of drinking water.

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