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Assessment of ^{222}Rn Activity in Bottled Water from Baghdad and Its Radiological Impact †

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Abstract: This study investigates the radiological impact of ^{222}Rn activity concentrations in bottled drinking water sourced from local markets in Baghdad, Iraq. Utilizing the solid-state nuclear track detector (SSNTD) technique with CR-39 detectors, ^{222}Rn activity concentrations were measured in 25 bottled water samples. Concentrations ranged from 1.5 to 11.12 Bq/L, with an average value of 4.58 Bq/L. To assess the potential health risks, the annual effective dose (AED) due to ^{222}Rn ingestion was calculated. The potential radiation doses ranged from 3.21×10^{-6} Sv/y for infants to 1.17×10^{-5} Sv/y for adults. These values are significantly lower than the established dose limit of 0.1×10^{-3} Sv/y, thereby indicating a negligible radiological risk to consumers. The study also explored the correlation between total dissolved solids (TDS) and ^{222}Rn concentrations, finding a direct relationship between higher TDS values and elevated ^{222}Rn levels. The findings of this research contribute to the understanding of natural radionuclide levels in drinking water and their implications for public health.

Keywords: bottled drinking water; ^{222}Rn; radiological impact; SSNTD; CR-39

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1. Introduction

Drinking water serves as an essential resource for sustaining life but also acts as a matrix that often contains substances detrimental to human health, including radionuclides. Natural radionuclides are frequently detected in drinking water owing to their release from rock formations via processes such as erosion and dissolution [1]. Uranium-238 (^{238}U) is the most abundant element in rocks and serves as a parent element for several progeny radionuclides, notably radon-222 (^{222}Rn). Radon-222 is an odorless, tasteless, and colorless noble gas with a half-life of 3.8 days. The primary health risks associated with ^{222}Rn arise from internal exposure, primarily through inhalation. Once inhaled, ^{222}Rn and its decay products (^{218}Po, ^{214}Po) can reach bronchiolar cells, where emitted alpha particles may induce DNA damage, potentially leading to carcinogenesis [2–6]. The World Health Organization (WHO) acknowledged radon gas as the second leading cause of lung cancer following tobacco smoking in 2009 [7]. Similarly, the International Agency for Research on Cancer (IARC) classified radon as a Group 1 carcinogen in 1998 [8].

In addition to inhalation, ingestion serves as another route for internal exposure to ^{222}Rn. Although ^{222}Rn is the most frequently occurring radionuclide in water, its solubility in water is relatively low and inversely proportional to temperature [9,10]. Water usage liberates radon into indoor air; consequently, nearly 90% of the ^{222}Rn dose from drinking water originates from inhalation rather than ingestion [11]. Ingestion of radon-laden water also poses direct health risks, as ^{222}Rn can irradiate the sensitive cells of the intestinal tract before being rapidly expelled from the body [12–15]. Despite the potential hazards, no studies have definitively established a link between ingested radon and gastrointestinal tumors [16].

The present study aims to quantify the activity concentration of ^{222}Rn in bottled drinking water in Baghdad city and to assess the potential health impacts through the evaluation of the annual effective dose due to radon ingestion.

2. Materials and Methods

2.1. Sample Collection and Analysis

Bottled drinking water samples, with capacities ranging from 0.25 to 20 L, were procured from local markets in the Baghdad governorate in January 2022. These samples were classified based on their trade names, and a total of 25 such samples were analyzed. Each sample was assigned a unique code and stored in a refrigerator until the time of analysis.

2.2. Measurement of Radon Concentration

For assessing cumulative radon concentration, time-integrated passive radon dosimeters equipped with CR-39 solid-state nuclear track detectors (SSNTDs) were utilized. The CR-39 detector employed in this study is composed of polyallyl diglycol carbonate and has a thickness of 1.5 mm and an effective area of 2.38 cm^2. This detector fits into the groove of the dosimeter, which also features slits that permit the diffusion of radon gas while excluding other contaminants. Alpha particles emitted from the decay of ^{222}Rn and its daughter isotopes interact with the CR-39 film, inducing molecular bond damage. This damage manifests as sub-microscopic tracks on the surface of the film. Under specific chemical or electrochemical etching conditions, these latent tracks can be enlarged to become permanent, observable tracks. The number of these tracks is quantified using an optical amplification readout device, and the equilibrium radon concentration is subsequently calculated using an appropriate Equation (1) [17].

$$C_{Rn} = \frac{N_T - N_B}{A \times k \times T} \tag{1}$$

In this equation, C_{Rn} represents the equilibrium radon concentration in Bq/m^3; N_T is the total number of tracks registered in the CR-39 detector; N_B signifies the background tracks in the detector; A is the effective area of the CR-39 detector in cm^2; k is the calibration factor of the CR-39 detector in Tr·cm^{-2}/kBq·m^{-3}·h; and T is the effective exposure time in hours (960 h, 40 days).

2.3. Measurement of Total Dissolved Solids

The concentrations of total dissolved solids (TDS) in the samples were determined using a TDS meter.

2.4. Estimation of ^{222}Rn Annual Effective Dose (AED)

The annual effective dose (AED) serves as the metric for assessing the radiological effects of radon exposure. The calculation of the AED requires consideration of the yearly water consumption rates. Based on reference [12], average water consumption rates were categorized into three age groups: infants, children, and adults. These were further distributed across six subgroups (G1–G6), as listed in Table 1. The AED is computed using the following Equation (2) [12,18]:

$$\mathrm{AED} = A \times C \times \mathrm{DCF} \tag{2}$$

In this equation, A represents the radon activity concentration in water (Bq/L); C denotes the average water consumption rate (L/year); and DCF is the dose coefficient factor, valued at 3.5×10^{-9} Sv/Bq.

Table 1. The average consumption rate of water for each age category, as reported in reference [12].

Age Category	Age Group	Age Range (Years)	Consumption Rate (L/year)
Infants	G1	0–1	200
	G2	1–2	260
Children	G3	2–7	300
	G4	7–12	350
	G5	12–17	600
Adults	G6	>17	730

3. Results and Discussion

The study analyzed ^{222}Rn concentrations in 25 bottled water samples available in local markets in Baghdad, along with their total dissolved solids (TDS) values. As summarized in Table 2, the ^{222}Rn concentrations varied significantly among the samples. The highest concentration of 11.12 Bq/L was observed in a sample from the Royal brand, while the lowest of 1.5 Bq/L was found in an Aquafina-branded sample.

The mean ^{222}Rn concentration across all samples was 4.58 Bq/L. These variations are likely influenced by the distinct geological characteristics of the water sources, affecting the radioactive content in the soil and rocks. Notably, all measured ^{222}Rn concentrations were below the regulatory threshold of 100 Bq/L [12]. Correlation was observed between samples showing high radioactivity and elevated TDS values, indicating a direct relationship between the concentration of dissolved solids and ^{222}Rn radioactivity levels. This observation was further substantiated by data from the Tigris River in Baghdad, which displayed a ^{222}Rn level of 42 Bq/L and a TDS value of 472 ppm. Hence, water purification methods that effectively remove solid materials could potentially reduce ^{222}Rn levels. To evaluate the potential health risks associated with long-term consumption of the analyzed bottled water, annual effective doses (AEDs) were calculated using Equation (2). The AED results, categorized by age and further divided into six groups (G1–G6), are presented in Table 3. The highest dose recorded was 1.17×10^{-5} Sv/y for adults aged over 17 years, and the lowest was 3.21×10^{-6} Sv/y for infants aged 0–1 years. All calculated doses were found to be well below the reference dose level of 0.1×10^{-3} Sv/y [19], thereby indicating negligible health risks under standard conditions. Figure 1 further elucidates these dose assessments, revealing the highest and lowest dose rates to be 2.84×10^{-5} Sv/y and 1.05×10^{-6} Sv/y, attributed to the Royal and Aquafina brands, respectively.

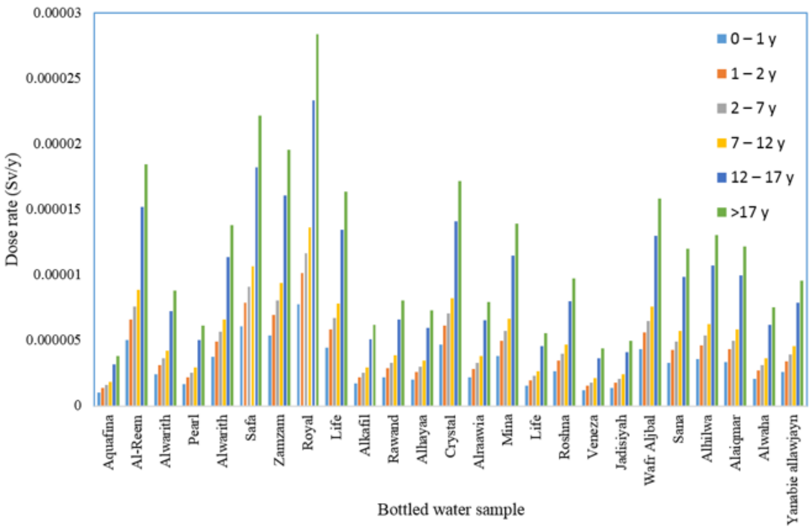

Figure 1. Results of dose assessment for different populations groups and for different bottled water types.

Table 2. ^{222}Rn and TDS concentrations in investigated bottled mineral water samples.

No.	Trade Name	^{222}Rn Concentration (Bq/L)	TDS (ppm)
1	Aquafina	1.5	72
2	Al-Reem	7.23	122
3	Alwarith	3.45	94
4	Pearl	2.4	78
5	Alwarith	5.4	102
6	Safa	8.69	138
7	Zamzam	7.66	137
8	Royal	11.12	145
9	Life	6.4	95
10	Alkafil	2.42	86
11	Rawand	3.15	91
12	Alhayaa	2.85	92
13	Crystal	6.72	115
14	Alraawia	3.11	87
15	Mina	5.46	121
16	Life	2.17	89
17	Roshna	3.82	84
18	Veneza	1.72	76
19	Jadisiyah	1.95	82
20	Wafr Aljbal	6.2	105
21	Sana	4.7	102
22	Alhilwa	5.1	109
23	Alaiqmar	4.76	112
24	Alwaha	2.95	83
25	Yanabie allawjayn	3.74	92
	Average $\pm\, \sigma$:	4.58 ± 2.42	100.36 ± 20.11
	Range:	1.5–11.12	72–145

Table 3. Results of dose assessment for different population groups.

Age Category	Age Group	Age (years)	Consumption Rate (L/year)	Dose Rate (Sv/y)
Infants	G1	0–1	200	3.21×10^{-6}
	G2	1–2	260	4.17×10^{-6}
Children	G3	2–7	300	4.81×10^{-6}
	G4	7–12	350	5.61×10^{-6}
	G5	12–17	600	9.62×10^{-6}
Adults	G6	>17	730	1.17×10^{-5}

4. Conclusions

The present study examined the radiological implications of ^{222}Rn concentrations in bottled drinking water sold in local markets in Baghdad. The ^{222}Rn concentrations in the analyzed samples ranged from 1.5 to 11.12 Bq/L, all of which were below the regulatory reference value of 100 Bq/L [12]. Thus, the sampled bottled waters do not pose a significant radiological hazard to consumers. The annual effective dose (AED) due to ^{222}Rn ingestion was calculated to evaluate its impact on different age groups. For an average activity concentration of 4.58 Bq/L, the potential radiation doses ranged from 3.21×10^{-6} Sv/y for infants (0–1 years) to 1.17×10^{-5} Sv/y for adults (>17 years). These doses are well below the reference dose limit of 0.1×10^{-3} Sv/y [19], indicating a negligible risk to public health. Furthermore, the study evaluated the correlation between ^{222}Rn activity concentrations and total dissolved solids (TDS) values in bottled water samples.

The findings suggest that samples with higher ^{222}Rn concentrations generally also exhibit higher TDS values, implicating the dissolved solids as a contributing factor to elevated ^{222}Rn levels.

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