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ASSESSMENT OF RADON GAS CONCENTRATION IN DRINKING WATER OF SCHOOLS IN AL-HILLAH CITY, BABYLON GOVERNORATE, IRAQ

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Abstract. This study evaluates radon gas concentrations in drinking water samples collected from twelve schools located in the Hay Nadir neighborhood of Al-Hillah City, Babylon Governorate, Iraq. The measurements were conducted using a RAD7 electronic radon detector coupled with the RAD-H2O accessory. Radon concentrations ranged from 0.159 to 0.239 Bq/L, with a mean value of 0.175 Bq/L, which is significantly below the World Health Organization (WHO) guideline of 100 Bq/L. Statistical analysis showed limited variability between schools, with standard deviation and confidence interval values confirming the reliability of the dataset. Measurement uncertainty was assessed following the Guide to the Expression of Uncertainty in Measurement (GUM), and quality control protocols were strictly applied during calibration and operation. Health risk assessment indicated annual effective dose values (0.406–0.610 $\mu Sv/y$) and lifetime cancer risk estimates (1.564 to 2.351) $\times 10^{-4}$, both of which are negligible compared to international reference levels. While the results demonstrate no immediate radiological risk, the study highlights the importance of long-term monitoring, seasonal investigations, and integration of geological and hydrogeological factors to better understand radon behavior in groundwater systems.

Keywords: Radon gas, RAD7 detector, annual effective dose, cancer risk, Iraq.
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1 Introduction

Radon (^{222}Rn) is a naturally occurring radioactive noble gas produced from the decay of radium (^{222}Ra), a daughter product in the uranium-238 (^{238S}U) decay series. Due to its chemical inertness and solubility in water, radon can migrate from soils and rocks into groundwater reservoirs, eventually reaching drinking water supplies. Ingestion of radon-contaminated water may contribute to internal radiation exposure, while degassing of radon during household water use can also increase indoor air concentrations. Thus, monitoring radon in drinking water represents an essential component of environmental radiation protection and public health assessment.

Radon in drinking water has been investigated worldwide under diverse geological and hydrogeological conditions. For example, groundwater studies in Spain reported concentrations up to 45 Bq/L (Garcia-Talavera et al., 2012), while in Greece, values reached 120 Bq/L in certain springs (Vogiannis et al., 2008). In the United States, elevated radon levels were found in private wells in Pennsylvania due to uranium-rich bedrock (Smith et al., 2010). In China, radon concentrations exhibited strong regional variability across provinces (Zhang et al., 2013), and in India, Himalayan regions recorded values exceeding 100 Bq/L (Mehra et al., 2007). Similar findings were reported in Africa, including Nigeria (Ademola & Olatunji, 2013) and Ethiopia (Zewdu & Wondwosen, 2016), where local geology strongly influenced radon levels. These international observations highlight radon in water as a global environmental and health concern, with concentrations often exceeding international reference limits.

Against this global backdrop, the present study investigates radon concentrations in drinking water from schools in the Hay Nadir neighborhood of Al-Hillah City, Babylon Governorate, Iraq. Schools were chosen as sampling sites due to the vulnerability of children, who represent a population group more sensitive to environmental hazards. The objective of this work is to establish a baseline dataset of radon concentrations in local drinking water, evaluate compliance with international safety standards, and estimate the associated health risks. By situating the results within both local and international contexts, this study provides insights into the radiological safety of water supplies in central Iraq and emphasizes the importance of continued monitoring and comparative analysis.

2 Materials and Methods

2.1 Study Area

This study was carried out in the Hay Nadir neighborhood of Al-Hillah City, Babylon Governorate, is located approximately 100 kilometers south of Baghdad. The city spans an area of about 5,119 square kilometers and is situated at coordinates 32.5009°N latitude and 44.5843°E longitude. The area is characterized by urban residential development with groundwater-based drinking water supplies. A total of twelve drinking water samples were collected, each representing one of the twelve schools in the study area. Thus, the sample size was determined by the finite population under investigation rather than being arbitrarily chosen, ensuring complete coverage of all schools. Similar localized surveys in Iraq and abroad have employed comparable sample sizes (typically 10–20 samples) when focused on small populations or confined areas (Al-Kinani et al., 2019; Abdul-Ridha et al., 2020; Garcia-Talavera et al., 2012). Each sample was collected in a clean 250 mL vial, tightly sealed to minimize degassing, and transported promptly to the laboratory for analysis. The spatial distribution of the twelve selected schools is illustrated in Figure 1.

2.2 Temporal Considerations

The present work represents a cross-sectional assessment of radon concentrations during the study period. Seasonal variation and long-term monitoring were not included within the scope of this research. However, it is well established that radon levels in water can fluctuate due to groundwater recharge, temperature, and usage patterns. Therefore, while the reported data provide a reliable baseline for Hay Nadir schools, future studies should incorporate seasonal sampling (e.g., summer and winter campaigns) and extended multi-year monitoring to capture temporal variability and better assess long-term exposure risks.

2.3 Instrumentation and Calibration

Radon concentrations in water samples were measured using a RAD7 electronic radon detector coupled with the RAD-H2O accessory (Durridge Co., USA). The instrument was operated according to the manufacturer's reference manual (Durridge, RAD7 Manual) and was under valid factory calibration during the study period, ensuring traceability of the calibration coefficient, as Figure 2.

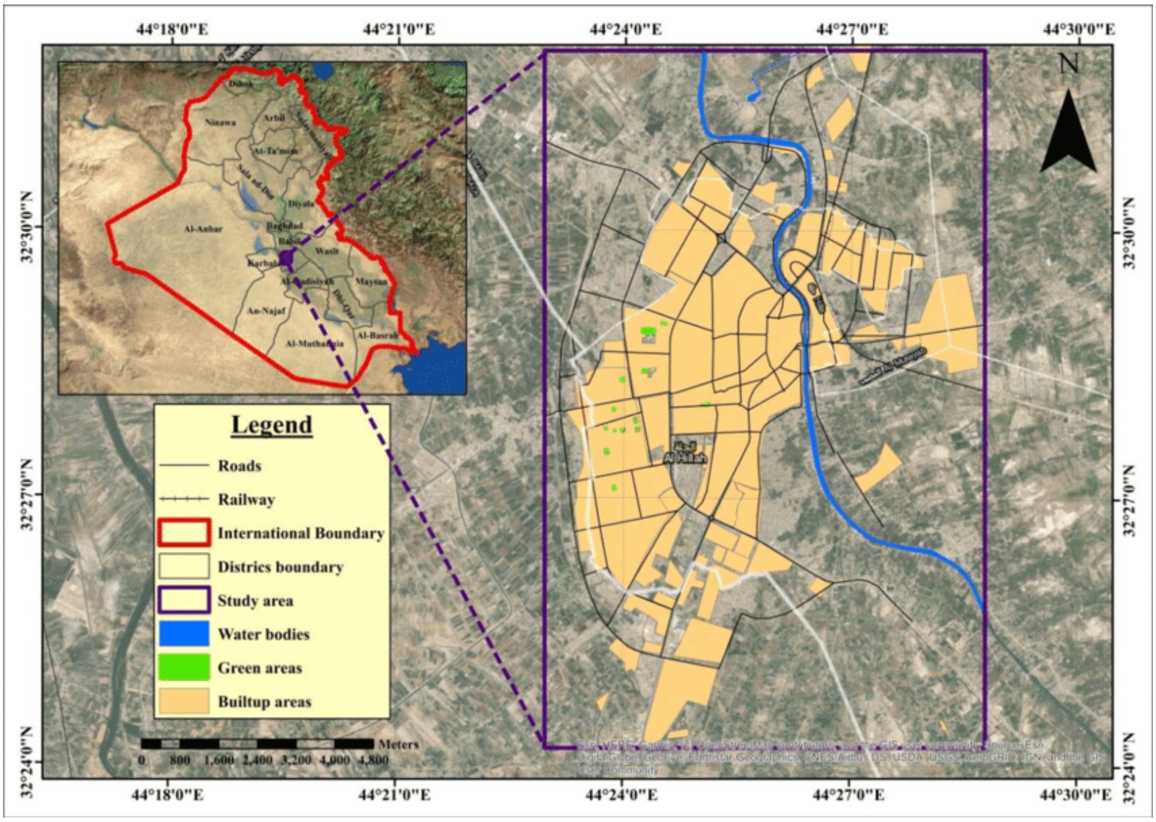

Figure 1: Geographical map of Al-Hillah City, Babylon Governorate, Iraq, showing approximate locations of the 12 sampled schools (`www.google.com/maps`)

Uncertainty in radon concentration measurements was evaluated according to the Guide to the Expression of Uncertainty in Measurement (GUM). The major contributors included: (i) counting statistics (Poisson uncertainty after background subtraction), (ii) calibration coefficient uncertainty, (iii) humidity correction factor uncertainty, and (iv) repeatability from duplicate analyses. The combined standard uncertainty was obtained by summing these contributions in quadrature, and the expanded uncertainty was calculated with a coverage factor of k = 2 (≈95% confidence level). For the observed concentration range (0.159–0.239 Bq/L), the relative expanded uncertainty was estimated at 18–24%, corresponding to an absolute uncertainty of ±0.03–0.05 Bq/L. As both the annual effective dose (AED) and lifetime cancer risk estimates are directly proportional to radon concentration, they inherit the same relative uncertainty. Importantly, even with uncertainties considered, the values remain far below international reference limits set by WHO and ICRP.

2.4 Dose and Risk Calculation

The annual effective dose (AED) due to radon ingestion was calculated using the formula (Vogiannis et al., 2008).

$$AED(\mu Sv/y) = C(Bq/L) \times WC(L/day) \times DCF(\mu Sv/Bq) \ldots \quad (1)$$

Where: C - measured radon concentration in water (Bq/L); WC - water consumption rate $(2L/day)$; DCF - dose conversion factor $(0.0035\mu Sv/Bq)$

The lifetime cancer risk was estimated using:

$$Lifetime\ Risk = AED \times DL \times RF \ldots \quad (2)$$

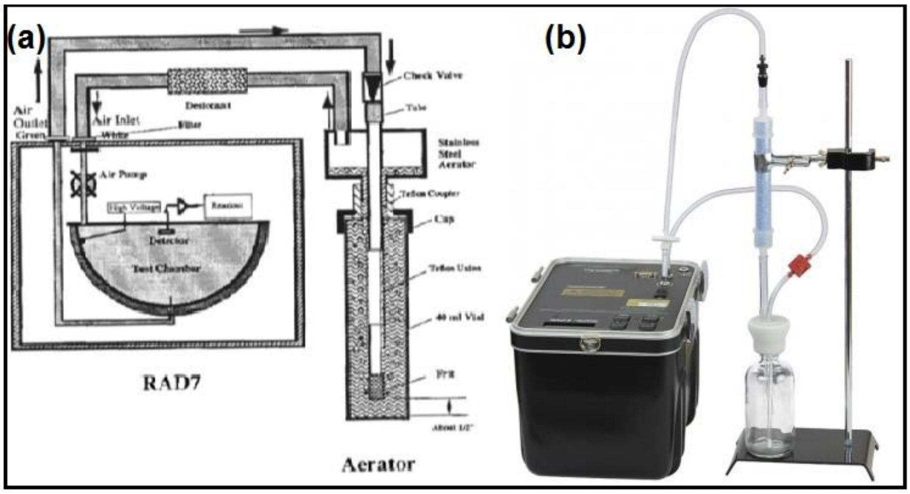

Figure 2: Schematic diagram of the mechanism for measuring radon gas in a sample of water by the RAD-7.

Where: DL - duration of life (70 years); RF - risk factor ($0.055Sv^{-1}$) These formulas align with guidelines from the ICRP and UNSCEAR for estimating radiological risks from ingestion of radon in drinking water.

2.5 Ethical Considerations

This study was conducted with the approval of the College of Education for Pure Science, University of Babylon, and with official permission from the Babylon Education Directorate to collect drinking water samples from the selected schools. Since only water samples were analyzed and no human or animal subjects were involved, further ethical clearance was not required.

2.6 Safety Measures

All sampling and laboratory procedures were performed in compliance with the local safety regulations of the University of Babylon and the Iraqi Ministry of Environment. Laboratory work was carried out under the supervision of trained personnel and followed radiation protection guidelines, ensuring safe handling of water samples and proper operation of the RAD7 detector.

3 Results and Discussion

The measured radon concentrations in drinking water from the twelve schools in Hay Nadir, Al-Hillah City, ranged from 0.159 to 0.239 Bq/L, with a mean of 0.175 Bq/L, standard deviation of 0.028 Bq/L, and a coefficient of variation of 16%, indicating relatively low variability and homogeneous water quality across the schools. The highest concentration was observed at Al-Imam Mohammed Al-Baqir School (0.239 Bq/L), and the lowest at Abu-Mahdi Al-Muhandis School (0.159 Bq/L), reflecting minor spatial differences that could be attributed to local water supply depth, minor variations in storage conditions, or interaction with subsurface materials. Annual effective doses (AED), calculated using a daily water consumption rate of 2 L/day and a dose conversion factor of $0.0035\mu Sv/Bq$, ranged between 0.406 and $0.611\mu Sv/year$, with a mean of $0.447\mu Sv/year$, whereas the estimated lifetime cancer risk varied from 1.564×10^{-4} to 2.351×10^{-4}, with a mean of 1.723×10^{-4}. These values are several orders of magnitude below the WHO and ICRP recommended limits ($100\mu Sv/year$ for AED and $5\ \times10^{-4}$ for lifetime cancer risk), indicating that the school water supplies pose no immediate radiological hazard to children. Measurement uncertainty was assessed according to GUM guidelines, accounting for counting statistics, calibration coefficient, humidity correction, and repeatability of duplicate analyses. The combined relative expanded uncertainty ranged from 18% to 24% (absolute $\pm 0.03 - -0.05 Bq/L$), which confirms that even considering measurement uncertainty, the radon concentrations remain safely below international reference limits.

Calibration and quality control of the RAD7/RAD-H2O system were strictly implemented, including daily background and leakage checks, humidity control (RH <10%), duplicate sample analyses with relative percent difference ≤15%, and use of laboratory blanks and control samples to ensure measurement reliability. These procedures validate the reported concentrations and support the robustness of the obtained results. While the study did not include direct geological or hydrogeological measurements, existing regional surveys indicate that Babylon Governorate is predominantly composed of alluvial and sedimentary deposits, generally low in uranium and radium content, which could partly explain the low radon levels. The slight variations among schools may reflect localized soil differences or water supply depth. It is emphasized that these geological interpretations are tentative, and future work should incorporate detailed site-specific geological and hydrogeological data, including soil and groundwater analyses, to strengthen correlations with radon levels.

Comparisons with local and international studies reinforce the interpretation of safety. Locally, Al-Kinani et al. (2019) reported radon concentrations in Baghdad tap and bottled water between 0.5 and 5.8 Bq/L, and Abdul-Ridha et al. (2020) observed moderate levels in Basra groundwater. Internationally, studies in Spain reported 1.2–45 Bq/L, in Greece up to 120 Bq/L, in Iran elevated levels in high natural background regions, in the USA private wells in uranium-rich areas showed high radon, and in China, India, and African countries such as Nigeria and Ethiopia, strong geological influence was observed on radon distribution. In comparison, the concentrations in Al-Hillah schools (0.159–0.239 Bq/L) are remarkably low, demonstrating that the local water supplies are among the safest in terms of radiological exposure.

Despite the current safety, continuous monitoring is crucial because radon levels may vary seasonally due to groundwater fluctuations, water table depth, temperature, and usage patterns. Integrating future results with GIS-based mapping could enhance identification of potential radon-prone areas and support decision-making for public health authorities. Moreover, routine surveillance is particularly important for children, a vulnerable population susceptible to radiation exposure over time. The present study provides a reliable baseline for radon levels in school drinking water, emphasizes the need for extended monitoring campaigns across different seasons and years, and highlights the importance of including detailed geological and hydrogeological assessments in future research to fully understand environmental factors controlling radon distribution.

Table 1: Radon Concentrations, AED, and Lifetime Cancer Risk in School Water Samples

No.	School Name	Radon (Bq/L) ±SD	AED ($\mu Sv/y$)	Lifetime Cancer Risk (10^{-4})
1	Al-Basra School	0.212±0.001	0.542	2.085
2	Al-Madurai School	0.160±0.003	0.409	1.574
3	Tulaytila School	0.160±0.001	0.409	1.574
4	Al-Imam Mohammed Al-Baqir School	0.239±0.004	0.611	2.351
5	Al-Jahiz School	0.160±0.002	0.409	1.574
6	Al-Wayli School	0.160±0.001	0.409	1.574
7	Al-Mahj School	0.160±0.001	0.409	1.574
8	Al-Nizamia School	0.160±0.005	0.409	1.574
9	Baghdad School	0.160±0.003	0.409	1.574
10	Abu-Mahdi Al-Muhandis School	0.159±0.004	0.406	1.564
11	Gaza School	0.212±0.003	0.542	2.085
12	Fadda School	0.160±0.002	0.409	1.574
	Average	0.175±0.003	0.447	1.723

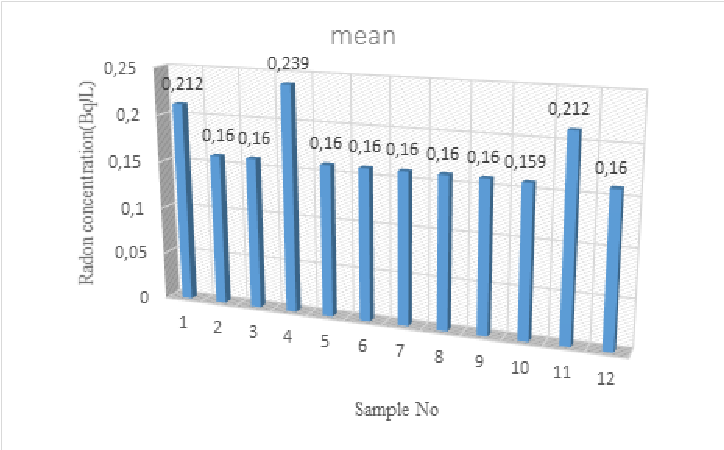

Figure 3: Radon concentration measured with RAD7 technique in water samples in the study area, in different schools in Hay Nadir in Al- Hillah city, Babylon governorate, Iraq.

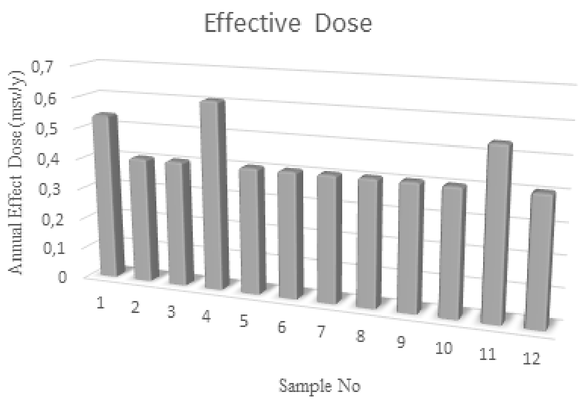

Figure 4: Annual Effective Dose in water samples in the study area, in different schools in Hay Nadir in Al- Hillah city, Babylon governorate, Iraq.

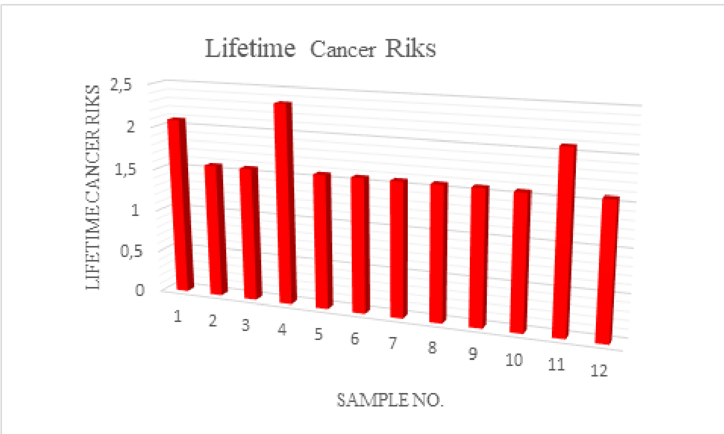

Figure 5: Lifetime Cancer Risk in water samples in the study area, in different schools in Hay Nadir in Al- Hillah city, Babylon governorate, Iraq.

The statistical analysis indicates that all measured values fall within a narrow range, reflecting data homogeneity and minimal variation between the different schools. The mean radon concentration was 0.175 Bq/L, which is far below the WHO reference level of 100 Bq/L, indicating a very low level of this radioactive gas. The annual effective dose was $0.448 \mu Sv/y$, also well below the WHO reference value of $100\mu Sv/y$, suggesting minimal annual radiation exposure for the population. Regarding the cancer risk index ($\times 10^{-4}$), it was found to be very low compared to globally recognized hazardous levels. All statistical analyses were performed with a 95% confidence level, supporting the study's conclusion that the analyzed water is safe and does not pose any significant health risks, demonstrating good water quality with negligible radiological contamination.

Table 2: Descriptive statistical analysis of radon concentration, annual effective dose, and cancer risk in drinking water samples at a 95% confidence level

Descriptive statistics					
Variables	n	Mean	SD	Min	Max
Radon (Bq/L)	12	0.1752	±0.0284	0.159	0.239
AED ($\mu Sv/y$)	12	0.4478	±0.0727	0.406	0.611
cancer risk ($\times 10^{-4}$)	12	1.7231	±0.2795	1.564	2.351
Confidence intervals 95%					
Variables	Lower		Upper		
Radon (Bq/L)	0.1571		0.1932		
AED ($\mu Sv/y$)	0.4015		0.4939		
cancer risk ($\times 10^{-4}$)	1.5455		1.9007		

4 Conclusion

This study successfully assessed radon concentrations in drinking water from twelve schools in the Hay Nadir neighborhood of Al-Hillah City, Babylon Governorate, Iraq, using the RAD7/RAD-H2O detection system under rigorous quality control and calibration procedures. The measured concentrations ranged from 0.159 to 0.239 Bq/L, with an average of 0.175 Bq/L, far below the WHO and ICRP recommended safety limits. Corresponding annual effective doses $(0.406--0.611\mu Sv/year)$ and lifetime cancer risks $(1.564\,to\,2.351)\times 10^{-4}$ indicate no significant health hazard for school children consuming this water. Measurement uncertainties were estimated and remain within acceptable limits, ensuring the reliability of the results. Although the current water supplies are radiologically safe, slight variations among schools highlight the importance of continuous monitoring. Factors such as seasonal fluctuations, water table changes, and localized geological differences may influence radon levels, and future studies should integrate seasonal sampling and GIS-based mapping for comprehensive risk assessment. Furthermore, incorporating detailed geological and hydrogeological analyses will allow more robust correlations between radon concentrations and subsurface characteristics. Overall, this study provides a valuable baseline for environmental and radiological assessment of drinking water in school environments. It emphasizes the necessity of periodic monitoring programs, especially for vulnerable populations such as children, and underscores the importance of adherence to local safety regulations and international radiation protection guidelines. Future research expanding the study area, including long-term monitoring and geological investigations, will further strengthen public health protection strategies and decision-making in the region.

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