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Natural Radioactivity Levels in Tap and Bottled Water Samples for Some Primary Schools of Karbala Governorate, Iraq

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Abstract

Natural radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K were assessed in 10 tap water samples collected from different schools in Karbala govenorate, as well as 5 commercial bottled drinking water samples. The activity concentrations were measured using gamma spectrometry with a NaI(Tl) 3"×3" detector equipped with a specially designed shield. In tap water samples, the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K ranged from <0.063 to 0.817, <0.067 to 0.493, and <0.117 to 9.896 Bq·L^{-1}, respectively. For bottled water, ^{226}Ra and ^{232}Th concentrations were below the Minimum Detectable Actictivity (MDA), while ^{40}K ranged from <0.117 to 8.180 Bq·L^{-1}. Overall, tap water samples exhibited higher concentrations than bottled water. The measured values for tap water were within the ranges reported in the literature for other countries. Health implications were estimated by calculating the annual effective dose received by school-age children due to ingestion of radionuclides. The average values of annual effective dose in tap and bottled water were 85.05 and 36.40 μSv·y^{-1} respectively. All calculated doses were below the global mean level of 100 μSv·y^{-1}, as reported by World Health Organization (WHO). It is therefore concluded that both tap water and bottled water consumed in schools of Karbala Governorate are radiologically safe and pose no significant health hazard to the public.

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1. INTRODUCTION

Both natural and man-made radionuclides can be found in drinking water. Because of natural processes (like soil absorption) or technological activities involving naturally occurring radioactive materials (like mineral sand mining and phosphate fertilizer production), water may contain natural radionuclides like potassium-40 and those from the thorium and uranium decay series. Water from a variety of sources, including those produced and used in industrial or medical settings, may contain anthropogenic radionuclides (WHO, 2008). Radium is known to cause cancer. High levels of radium exposure can raise the risk of breast, liver, and bone cancer. Because of their similar behavior to that of calcium, an element commonly deposited in bones, radium isotopes (^{226}Ra) have a long half-life (~1600 years) and they are the most radiotoxic and dangerous elements when consumed. The natural radioactive decay series of thorium is initiated by ^{232}Th ($T_{1/2} = 1.4 \times 10^{10}$ y), which is found in the Earth's crust. Although they come from different sources, both radionuclides (^{226}Ra and ^{232}Th) are present in terrestrial materials. They are taken out of rocks, soils, and water by leaching or erosion. With a half-life of $1.25{\times}10^9$ y, potassium-40 (^{40}K) is a radioactive isotope of potassium. About 0.012% (120 ppm) of the total potassium found in nature is made up of it. Like other potassium isotopes, the potassium radioisotope ^{40}K has a similar physiological effect. Humans require potassium to sustain biological

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processes, and most of it (including ^{40}K) is absorbed almost completely when consumed, moving quickly from the stomach into the blood. All organs and tissues quickly absorb the ^{40}K that enters the bloodstream after ingestion or inhalation (Brenner et al., 2003) (Tolstykh et al., 2016) (Altıkulaç et al., 2015). Radiation has a long-lasting effect on the environment, possibly changing the genetic makeup of animals and humans, leading to cellular death and genetic defects that appear in subsequent generations. Radiation's most direct effect on cells is especially dangerous when it causes the death of the body's irreplaceable cells. The foundation of radiation protection is the idea that all radiation exposures carry some level of risk. Long-term exposure, such as consuming drinking water contaminated with radionuclides for extended periods of time, has been linked to an increased risk of cancer in humans at doses greater than 100 mSv (Brenner et al., 2003) (ICRP, 1996). Therefore, radioactive material surveillance is essential for human safety and has been studied in various parts of the world (Abbasi & Bashiry, 2016) (Kinahan et al., 2020) (Al-Shammari et al., 2025) (Qwasmeh & Saleh, 2023). The purpose of this study is to assess the levels of natural radioactivity and the corresponding yearly effective dose of tap and bottled drinking water in a few Karbala Governorate schools. The dearth of information on Karbala's drinking water's radioactivity, which is necessary to guarantee that the annual effective dose and specific activity for drinking water stay within advised bounds, makes this study noteworthy.

2. MATERIALS AND METHODS

2.1. STUDY AREA

Approximately 100 kilometers southwest of Baghdad, in central-southern Iraq, the Karbala Governorate borders the Anbar, Najaf, and Babil governorates. It is situated at roughly 32°27′N, 43°48′E, and is around 30 meters above sea level. Three districts—Karbala Center, Al-Hindiyah, and Ain Al-Tamur—make up the administrative division of the Karbala Governorate. The governorate was estimated to have 1,316,750 residents in 2021, with about 880,400 of them residing in urban areas, according to the Iraqi Central Statistical Organization (CSO).

2.2. SAMPLE COLLECTION AND PREPARATION

The study included 10 tap water samples, sourced from local municipal networks, which were collected in May 2023 from schools distributed across the districts of Karbala Governorate, namely the Karbala district center, Ain Al-Tamur, and Al-Hindiya. We also collected five samples of commercially bottled drinking water. The water samples were used in measurement standard (1L) polyethylene Marinelli beakers. Before using them, the containers were washed with dilute hydrochloric acid and rinsed with distilled water. Each drinking water sample was hermetically sealed and stored for a minimum of four weeks to ensure that secular radioactive equilibrium was reached between ^{226}Ra with ^{222}Rn and its progeny (IAEA, 2003) (Sabbarese et al., 2021). Table (1) shows the coordinates of the schools from which tap water samples were collected, while Table (2) presents the locations of the water bottling plants that were chosen.

2.3. EXPERIMENTAL SETUP

Natural radioactivity measurements and sample preparation were carried out at the University of Kerbala's Nuclear Laboratory, Department of Physics, College of Education for Pure Sciences. A gamma-ray spectrometer fitted with a NaI(Tl) 3"×3" detector contained in a specially made lead shield to reduce background radiation was used to analyze each sample. The detector's energy resolution at the 1.33 MeV gamma line of ^{60}Co was 63 keV (FWHM). Lead that was more than 10 cm thick and lined inside with 1.5 mm of cadmium and 2.5 mm of copper made up the shielding system. Standard radionuclides (^{22}Na, ^{152}Eu, ^{137}Cs, and ^{60}Co) were used to calibrate detector efficiency for each photopeak energy. Maestro software (EG&G ORTEC) was used to analyze the spectra. Figure 1 displays the efficiency curve as a function of gamma-ray energy. An exponential fit is represented by the solid line, which has a correlation coefficient of R^2 = 0.972.

Table 1. School name, sample number and coordinate for tap water samples.

School name and location	Sample number	Coordinates	
		Latitude (N)	Longitude (E)
Zahrat Al-Furat, Karbala district center	TW1	32°36'22.9"	43°59'06.8"
Amerli, Karbala district center	TW2	32°33'24.0"	44°04'28.4"
Al-Makasib, Karbala district center	TW3	32°36'42.6"	44°00'39.5"
Al-Riahi, Karbala district center	TW4	32°39'05.0"	43°58'33.9"
Saif Al- Haq, Karbala district center	TW5	32°41'25.9"	44°06'51.8"
Al AJyal, Karbala district center	TW6	32°40'41.5"	44°04'35.1"
AL Waha Algathra, Ain Al-Tamur	TW7	32°45'54.0"	43°23'20.4"
Al-Rashad, Ain Al-Tamur	TW8	32°35'28.0"	43°29'29.9"
Al-Furat, Al-Hindiya	TW9	32°32'52.6"	44°13'08.0"
Almaearif, Al-Hindiya	TW10	32°32'48.7"	44°14'04.8"

Table 2. Plant name, sample number and water bottling plants location.

Plant name	Sample number	Coordinates	
		Latitude (N)	Longitude (E)
Alkafeel	BW1	32°36'15.4"	44°07'16.3"
Nawar	BW2	32°36'31.9"	44°06'59.7"
Loloa	BW3	32°35'31.2"	44°02'47.8"
Seha	BW4	32°32'23.6"	44°30'40.9"
Barakat Alwareth	BW5	32°32'21.3"	44°05'41.5"

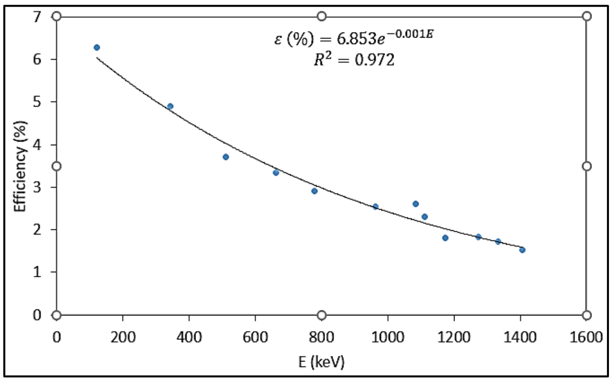

Figure 1. Detection efficiency of NaI(Tl) Gamma spectrometry system.

2.4. THE ACTIVITY CONCENTRATION

The net counts were derived by estimating the photopeak regions in the spectra and adjusting for background counts post-measurement. The subsequent formula was employed to determine the activity concentration (A) of the radionuclides [12,13]:

$$A\left(\frac{Bq}{L}\right) = \frac{\mathrm{C_N}}{\varepsilon(\mathrm{E\gamma})\,.\,\mathrm{I\gamma(E\gamma)}.\,V.\,\mathrm{T_c}} \quad \ldots\ldots\ldots(1)$$

where: C_N is the is the net counts in a given peak area, I_γ (E_γ) is the emission probability of the measuring γ-rays with the given energy; ε (E_γ) is the full-energy peak efficiency; V is the volume of water sample and; T_c is the counting time. Activity concentrations of ^{226}Ra and ^{232}Th were determined using the gamma-ray peak at 1764.49 keV from ^{214}Bi and that at 2614.53 keV from ^{208}Tl, respectively. Direct determination of the activity concentration of ^{40}K was made using the 1460.7 keV gamma emission line (Parhoudeh et al., 2019) (Currie, 1968). Every sample had a counting time of 21,600 seconds.

When measuring low-level activity, the Minimum Detectable Activity (MDA) is a crucial parameter. The following formula (Abdel-Rahman & El-Mongy, 2017) (Currie, 1968) was used to determine the MDA of the gamma-ray measurements:

$$MDA\left(\frac{Bq}{L}\right) = \frac{\mathrm{LLD}}{\varepsilon(\mathrm{E\gamma})\,.\,\mathrm{I\gamma(E\gamma)}.\,V.\,\mathrm{Tc}} \quad \ldots\ldots\ldots(2)$$

where LLD is the lower limit of detection, as defined below (Currie, 1968) (Abdel-Rahman & El-Mongy, 2017):

$$LLD(count) = 2.71 + 4.65\sqrt{B} \quad \ldots\ldots\ldots(3)$$

where B is the number of counts for the background spectrum. Under identical circumstances, including counting time and measurement geometry, the MDA of every radionuclide was computed from the background spectrum. ^{226}Ra, ^{232}Th, and ^{40}K were found to have MDA values of 0.063, 0.067, and 0.117 Bq·L^{-1}, respectively.

2.5. RADIATION DOSE FOR DRINKING WATER

The rate at which food and water are consumed, as well as the concentrations of radionuclides in these media, determine the ingestion dose. To assess the possible radiological risks to the general public, especially children, the Annual Effective Dose from Drinking Water (AED) was calculated. The following formula (ICRP, 1996) (UNSCEAR, 2000)was used to determine the AED (Sv·y^{-1}) using the radionuclide activity concentrations, dose conversion coefficients, and annual water consumption:

$$AED\ (Sv.y^{-1}) = A \times DCF \times CR_W \quad \ldots\ldots\ldots(4)$$

where A (Bq·L^{-1}) is the activity concentration of the radionuclides (^{226}Ra, ^{232}Th and ^{40}K), DCF is the dose conversion factors 2.8 × 10^{-7}, 2.2 ×10^{-7} and 2.1× 10^{-8} Sv·Bq^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively. CR_w is the annual consumption rate of drinking water 350 L·y^{-1} for children aged 10 years.

3. RESULTS AND DISCUSSION

3.1. RADIONUCLIDES ACTIVITY CONCENTRATION

Table 3 displays the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K that were determined in the drinking water samples. It is evident that the MDA value (0.063 Bq·L^{-1}) was exceeded by the concentration of ^{226}Ra in four tap water samples (TW3, TW6, TW9, and TW10). They generally ranged from <0.063 to 0.817 Bq·L^{-1}. While the concentrations of ^{226}Ra in all bottled water samples were below the MDA. The ^{232}Th concentrations in tap water samples were ranged from <0.067 to 0.493 Bq·L^{-1}. In a similar vein, all bottled water samples had ^{232}Th concentrations below the MDA. The ^{40}K concentrations in tap water samples were ranged fom ~0.117 to 9.896 Bq·L^{-1}. While the concentrations of ^{40}K in bottled water were ranged from three samples had of which is below the MDA for ^{40}K. The concentrations of ^{40}K in bottled water were ranged from <0.117 to 8.180 Bq·L⁻¹. Additionally, the BW1 sample (Alkafel bottled water) had activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K that were all below the corresponding MDA values.

Table 3. Activity concentration of natural radionuclides (Bq·L^{-1}) in tap water (TW) samples from schools and commercial bottled water (BW) in Karbala Governorate.

Sample number	Activity Concentration (Bq L^{-1})		
	^{226}Ra	^{232}Th	^{40}K
TW1	0.610	0.493	< MDA
TW2	0.817	0.313	< MDA
TW3	< MDA	< MDA	9.896
TW4	0.729	< MDA	8.643
TW5	0.453	0.253	< MDA
TW6	< MDA	< MDA	7.992
TW7	0.481	0.143	9.194
TW8	0.488	0.387	1.828
TW9	< MDA	0.281	7.545
TW10	< MDA	0.191	1.323
Commercial bottled water(BW)			
BW1	< MDA	< MDA	< MDA
BW2	< MDA	< MDA	7.311
BW3	< MDA	< MDA	1.462
BW4	< MDA	< MDA	8.180
BW5	< MDA	< MDA	7.814

Table 4 summarizes the comparison between the measured activity concentrations of the natural radionuclides and data reported globally. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were significantly lower than the 1, 1 and 10 Bq·L⁻¹ WHO guidance levels, respectively (WHO, 2017). The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in drinking water are generally in line with those reported in Saudi Arabia (Jeddah), Turkey, Kermanshah (Iran), Serbia and Kosovo.

Table 4. Comparison of the activity concentrations and annual effective doses in several countries with our findings in drinking water samples from schools in Karbala Governorate, Iraq.

Countries		Activity Concentration (Bq·L^{-1})			AED (µSv·y^{-1})
		^{226}Ra	^{232}Th	^{40}K	
Saudi Arabia (Jeddah)^{b} (Al-Ghamdi, 2017)		0.77	1.3	11.1	400
Turkey^{b} (Kabadayi & Gümüş, 2012)		0.78	1.05	2.19	---
Serbia^{s} (Tanaskovic et al., 2011)		0.17	---	0.46	
Kermanshah (Iran)^{d} (Parhoudeh et al., 2019)		0.57	0.98	6.42	150
Kosovo (Hodolli et al., 2025)		0.65^{t} 0.98^{w} 0.81^{b}	0.55 0.63 0.56	6.68 7.46 5.40	110
This study	Tap water	0.357	0.206	4.642	85.05
	Bottled water	< MDA	< MDA	4.953	36.40

^{b}bottled, ^{s}spring, ^{w}well, ^{d}drinking, ^{t}tap.

3.2. ANNUAL EFFECTIVE DOSE

The Annual Effective Dose (AED) is the amount that is frequently used to calculate population exposure to terrestrial radionuclides. Table 5 lists the annual effective doses that school-age children in Karbala schools receive from drinking water that contains ^{226}Ra, ^{232}Th, and ^{40}K. The total annual effective doses (AED) caused by ^{226}Ra, ^{232}Th, and ^{40}K in tap water varied from 24.43 to 134.96 µSv·y⁻¹, with an average of 85.05 µSv·y⁻¹. As illustrated in Figure 2, the total AED for bottled water samples varied between 10.74 and 60.12 µSv·y⁻¹, with an average of 36.40 µSv·y⁻¹. Compared to bottled water, tap water had a higher total AED. In bottled drinking water, the AEDs from ^{226}Ra and ^{232}Th were below the lowest levels that could be detected. The average ADE in this study is lower than that reported in some countries (Table 4) and falls below the global average of 100 µSv·y⁻¹ of drinking water consumption as established by (WHO, 2017)

Table 5. Annual effective doses (µSv/y) due to ingestion of natural radionuclides in tap water samples collected from Karbala schools.

Sample number	Annual effective doses (µSv·y^{-1})			
	^{226}Ra	^{232}Th	^{40}K	Total
TW1	59.78	37.96	---	97.44
TW2	80.06	24.10	---	104.12
TW3	---	---	72.74	72.74
TW4	71.44	---	63.53	134.96
TW5	44.39	19.48	---	63.87
TW6	---	---	58.74	58.74
TW7	47.14	11.01	67.58	125.72
TW8	47.82	29.80	13.44	91.06
TW9	---	21.64	55.46	77.09
TW10	---	11.71	9.72	24.43
Average	35.06	15.87	34.12	85.05
Commercial bottled drinking water (BW)				
BW1	---	---	---	---
BW2	---	---	53.73	53.73
BW3	---	---	10.74	10.74
BW4	---	---	60.12	60.12
BW5	---	---	57.43	57.43
Average	---	---	36.40	36.40

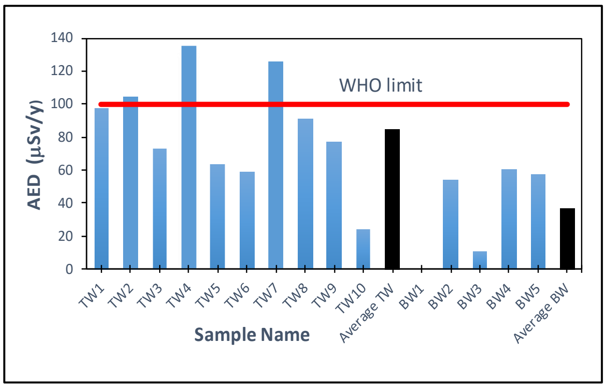

Figure 2. Annual effective doses received by children due to the ingestion of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K in tap water and commercial bottled water samples with standard value reported by WHO.

4. CONCLUSIONS

In Karbala Governorate schools, the levels of radioactivity in drinking water caused by ^{226}Ra, ^{232}Th, and ^{40}K were found to be below WHO guidance levels and within the range of activity concentrations reported globally. Nevertheless, compared to bottled water samples, tap water samples had greater radionuclide concentrations. Additionally, the annual effective doses of these radionuclides received by children in Karbala were lower than the global average level (WHO) 100 µSv·y^{-1} (WHO, 2017). It is determined that there is no substantial risk to the public from either tap or bottled water in Karbala Governorate schools. The baseline radiometric values for tap and bottled drinking water in the Karbala Governorate are provided by the data produced by this study. These values could be used as a guide for future research and help create national standards for natural radionuclides and annual effective doses in drinking water.

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