

# Radioactivity Measurements and Radiation Dose Assessments in Ground Water of Al-Baha Region, Saudi Arabia

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## Abstract

Twenty samples of ground water were collected from different wells in Al-Baha region which is located at south-east of Saudi Arabia. Gamma spectrometer based on HPGe crystal was applied to determine activity concentrations in Bq·L<sup>-1</sup> of the natural radio nuclides: Radium-226 and Thorium-232 series also Potassium-40. The measured results indicate that the average concentrations of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K in the studied samples were 0.85, 0.43, and 2.84 Bq·L<sup>-1</sup>, respectively. The average annual estimated effective dose was found to be 0.058 mSv/y which is lower than the annual limit of the dose allowed by WHO Thus, it has no harmful effects on health.

## Keywords

Drilled Well Water, Natural Radioactivity, Doses, Hpge, Gamma Spectroscopy

## 1. Introduction

Natural radioactivity in groundwater arises from <sup>238</sup>U, <sup>232</sup>Th, <sup>40</sup>K and their decay products which are produced as a result of the interactions between rocks and water (Todorović et al., 2012; Kraemer & Genereux, 1998). Consequently these radionuclides transported in ground water can enter the food chain through irrigation waters and the water source through ground water wells (Malanca et al., 1998). Thus, the ingestion of radionuclides in drinking water causes human internal exposure (Degerlier & Karahan, 2010). The estimated exposure of natural radioactivity sources contributes dose was 2.4 mSv y<sup>-1</sup> (cosmic ray 0.4, terrestrial gamma ray 0.5, radon 1.2, and food and drinking water 0.3) (UNSCEAR, 2000). So, determinations of natural radioactivity concentrations in bedrock wells were important to estimate the dose in the water samples (Salih et al., 2002). In the

south-west of Saudi Arabia (Al-Baha region), there are no rivers, lakes, and springs. Therefore, people depend on the underground water especially those coming from wells. These wells must be safe and of good quality. Concentration levels of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in ground water used in this region and the radiological impacts of the consumed drinking water have not been reported in literature previously. So, the aim of this work is to determine the concentration values of natural radionuclides present in the well water samples collected from different location in Al-Baha region and estimate the corresponding radiation doses for people consuming these waters. This work is necessary due to the demands of having the database available on the waters and is highly required to keep human drinking water standards. The obtained data in this study may afford baseline levels of natural radioactivity in such water and provide background information for future research on drinking water for radiological protection of the human.

## 2. Materials and Method

### 2.1. Study Area

In order to determine the natural radioactivity in ground water, twenty water samples were collected from most frequently used wells spread in different locations of Al-Baha region. It is located in the south-east of Saudi Arabia ( $20^{\circ}0'0''\text{N}$ ,  $41^{\circ}30'0''\text{E}$ ), as shown in **Figure 1**. The sampling locations were chosen mostly based on population density and accessibility. Al-Baha region is an agricultural area, the main agro products, are wheat, vegetables and fruits. This region was chosen based on the active usage of ground water for drinking and for irrigation purposes made by locals of the area which can also be a source of radionuclides in foods.

### 2.2. Samples Collection, Preparation and Measuring

The collected water samples were acidified with nitric acid to avoid the collection of organic materials, then each sample was filled into 500 ml capacity polyethylene Marinelli beakers (IAEA, 1989). Before use the containers were washed



**Figure 1.** The study area (Al-Baha region—Saudi Arabia).

with dilute HCl and rinsed with distilled water. The Marinelli beakers were sealed and stored for more than 4 weeks before counting to reach the secular equilibrium between  $^{226}\text{Ra}$  nuclides and  $^{232}\text{Th}$  nuclides and their daughters for gamma ray measurements (Abbady, 2004). Detection and measurements of the sample concentrations were carried out using a coaxial high-purity germanium (HPGe) detector with relative efficiency of 25% and FWHM 2.0 keV at 1332 keV, of  $^{60}\text{Co}$ . The detector was housed inside a thick lead shield to reduce the background of the system. Genie 2000 basic spectroscopic software was installed in the computer for data acquisition and analysis. The system was calibrated for energy and efficiency on a regular basis in (IAEA, 1989). Each sample after equilibrium was kept on the top of the HPGe detector and counted for 36,000 s. The background was measured every week under the same conditions of sample measurement.

### 2.3. Calculations of the Activity Concentration

The activity of  $^{226}\text{Ra}$  was determined based on the gamma ray energies of 351.9 keV from  $^{214}\text{Pb}$  and 609.3, 1120.3 and 1764.5 keV (from  $^{214}\text{Bi}$ ). The activity concentration of  $^{232}\text{Th}$  was determined based on gamma ray energies of 338.8, 911.2 and 968.97 keV from  $^{228}\text{Ac}$  and 583.0 keV from  $^{208}\text{Tl}$ .  $^{40}\text{K}$  was determined directly by its emission energy of 1461.8 keV gamma-ray line. The activity concentrations  $A_w$  of the natural radionuclides in the measured samples were calculated using the equation (UNSCEAR, 2000):

$$A_w \left( \text{Bq} \cdot \text{L}^{-1} \right) = Ca / \varepsilon P \gamma m \quad (1)$$

where:  $Ca$  is the net gamma counting rate (counts per second),  $\varepsilon$  the detector efficiency of the specific  $\gamma$ -ray,  $P\gamma$  the absolute transition probability of Gamma-decay and  $m$  the mass of the sample (kg).

## 3. Results and Discussion

### 3.1. Activity Concentrations of $^{226}\text{Ra}$ , $^{232}\text{Th}$ and $^{40}\text{K}$

The concentrations in  $\text{Bq} \cdot \text{L}^{-1}$  of radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  measured in the water samples were listed in **Table 1**. As shown, in this table,  $^{226}\text{Ra}$  activities It ranged from  $0.24 \text{ Bq} \cdot \text{L}^{-1}$  ( $w17$ ) to  $1.54 \text{ Bq} \cdot \text{L}^{-1}$  ( $w11$ ). It was not detected in four samples ( $w3$ ,  $w9$ ,  $w18$  and  $w20$ ) and the measured samples ( $w5$ ,  $w6$ ,  $w7$ ,  $w10$  and  $w13$ ) were higher than the recommended limits of  $1.0 \text{ Bq} \cdot \text{L}^{-1}$  (WHO, 2006).  $^{232}\text{Th}$  series were detected in eight samples only, the lowest value was  $0.15 \text{ Bq} \cdot \text{L}^{-1}$  (sample 15) and the highest value was  $0.81 \text{ Bq} \cdot \text{L}^{-1}$  ( $w16$ ). The results show that the concentration values of  $^{226}\text{Ra}$  were higher than those of  $^{232}\text{Th}$ . This may be because of the radium being more soluble in water (Kitto & Kim, 2005).  $^{40}\text{K}$  activities ranged from  $0.66 \text{ Bq} \cdot \text{L}^{-1}$  ( $w7$ ) to  $5.64 \text{ Bq} \cdot \text{L}^{-1}$  ( $w4$ ), all samples concentration were below the recommended limit  $10.0 \text{ Bq} \cdot \text{L}^{-1}$  of  $^{40}\text{K}$  reported by WHO 2006 (WHO, 2006). The obtained average concentrations of the three nuclides ( $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) were 0.85, 0.43 and  $2.84 \text{ Bq} \cdot \text{L}^{-1}$ , respectively. The average values

**Table 1.** Activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  of the ground water samples.

Samples	Concentrations (Bq/L)			Annual effective dose (mSv/y)	Lifetime risk ( $R$ ) $\times 10^{-3}$
	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$		
w1	0.98 $\pm$ 0.25	ND	1.36 $\pm$ 0.07	0.069	0.352
w2	0.65 $\pm$ 0.003	ND	1.60 $\pm$ 0.08	0.047	0.239
w3	ND	ND	2.63 $\pm$ 0.13	0.004	0.02
w4	0.28 $\pm$ 0.10	0.46 $\pm$ 0.21	5.64 $\pm$ 0.96	0.053	0.273
w5	1.52 $\pm$ 0.70	ND	4.70 $\pm$ 1.04	0.111	0.565
w6	3.00 $\pm$ 1.70	0.55 $\pm$ 0.16	1.17 $\pm$ 0.05	0.237	1.211
w7	1.12 $\pm$ 0.24	0.67 $\pm$ 0.30	ND	0.114	0.582
w8	0.29 $\pm$ 0.10	ND	ND	0.019	0.101
w9	ND	ND	2.50 $\pm$ 1.10	0.004	0.001
w10	1.54 $\pm$ 0.36	ND	3.10 $\pm$ 1.10	0.108	0.553
w11	0.59 $\pm$ 0.12	ND	ND	0.040	0.205
w12	0.40 $\pm$ 0.13	ND	4.65 $\pm$ 0.22	0.034	0.175
w13	1.31 $\pm$ 0.25	ND	3.24 $\pm$ 0.17	0.094	0.481
w14	0.53 $\pm$ 0.14	0.81 $\pm$ 0.26	0.92 $\pm$ 0.04	0.083	0.424
w15	0.34 $\pm$ 0.21	0.15 $\pm$ 0.02	3.24 $\pm$ 0.16	0.036	0.186
w16	0.24 $\pm$ 0.09	ND	0.66 $\pm$ 0.04	0.017	0.08
w17	0.42 $\pm$ 0.24	0.17 $\pm$ 0.02	4.28 $\pm$ 0.22	0.016	0.08
w18	ND	ND	3.95 $\pm$ 0.19	0.006	0.03
w19	0.46 $\pm$ 0.14	0.20 $\pm$ 0.12	1.83 $\pm$ 0.019	0.045	0.231
w20	ND	0.42 $\pm$ 0.13	5.38 $\pm$ 0.29	0.032	0.162
Range	0.24 - 1.52	0.15 - 0.81	0.66 - 5.64	0.004 - 0.237	0.001 - 1.211
Average	0.85	0.43	2.84	0.058	0.299
WHO 2006	1	0.1	10	1.0	

ND: not detected.

for  $^{226}\text{Ra}$  and  $^{40}\text{K}$  do not exceed the WHO 2006 recommended limit in drinking water, whereas, slightly higher for  $^{232}\text{Th}$  than the limit. It should be noted that, in the present results,  $^{40}\text{K}$  is the most abundant concentration, about 76% of the total ( $^{226}\text{Ra} + ^{232}\text{Th} + ^{40}\text{K}$ ). Potassium-40 is an isotope of an essential element which is under homeostatic control (Jabir et al., 2007). The activity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the studied ground water samples illustrated in Figure 2.

### 3.2. Radiation Dose Estimation

The annual effective dose equivalents from the consumption of drinking water due to  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were estimated by UNSCEAR (2000) and El-Gamal et al. (2019) as:

$$D_w = A_w \times C_w \times F_w \quad (2)$$

where  $D_w$  is the annual effective dose equivalent from consumption of drinking water (mSv/year),  $A_w$  is the activity concentration of radionuclides in the ingested water (Bq/L),  $C_w$  is the consumption rate of water (L/year). According to WHO (2003), the dose was estimated by considering a consumption rate is 730 L/year for adults. The dose conversion factors  $F_w$  (Sv/Bq) for adults were ( $2.8 \times 10^{-7}$ ,  $2.3 \times 10^{-7}$  and  $6.2 \times 10^{-9}$  Sv Bq<sup>-1</sup>) for <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K, respectively, (WHO, 2006).

The calculated total annual effective doses for adults ingested radionuclides <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K from the ground water samples were tabulated in Table 1. The highest value (0.237 mSv/y) of effective dose was calculated in sample w6 due to the radium high concentration. The range of effective doses due to intake of <sup>226</sup>Ra, <sup>232</sup>Th, and <sup>40</sup>K were from 0.004 to 0.237 mSv/y, with an average value of 0.058 mSv/y which is below the average limit (0.1 mSv/y) reported by WHO (WHO, 2006). Consequently, we recommended that, the investigated waters are acceptable as drinking water for life-long human without any treatment to reduce the concentrations of radioactive contaminants. Figure 3, shows the effective dose for the ingestion of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K by adults.

### 3.3. Lifetime Risk Assessment (R)

Lifetime risk assessment was calculated using the Eq (EPA, 1999):

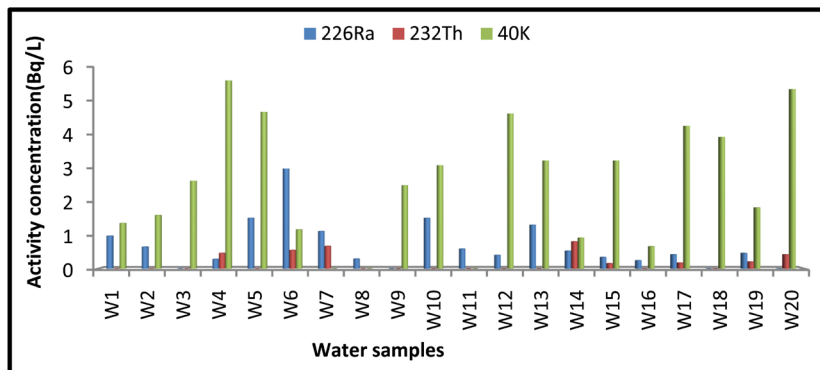


Figure 2. Activity concentration of <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K in ground water samples collected from Al-Baha region, Saudi Arabia.

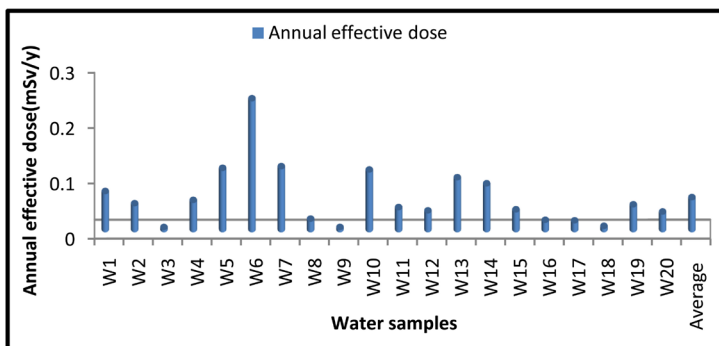


Figure 3. A comparison of total annual effective dose (mSv/y) for adults ingested radionuclides <sup>226</sup>Ra, <sup>232</sup>Th and <sup>40</sup>K from the ground water samples.

$$\text{Lifetime risk } (R) = D_w \times D_L \times R_f \quad (3)$$

where  $D_w$  is annual effective dose equivalent (Sv/y),  $D_L$  is duration of life (70 years) and  $R_f$  is risk factor ( $\text{Sv}^{-1}$ ). For risk assessment, the nominal probability coefficient of  $7.3 \times 10^{-2} \text{ Sv}^{-1}$  was adopted (ICRP, 1996).

The risk levels from the direct ingestion of the natural radionuclides in ground water were estimated as shown in **Table 1**. The cancer risk  $R$  for the adults, i.e. corresponding to the total ingestion dose of 0.058 mSv/y is estimated as  $0.299 \times 10^{-3}$ . This risk is much lower than the limit  $8.4 \times 10^{-3}$ , if the total natural radiation dose of 2.4 mSv/y as given by UNSCEAR 2000 UNSCEAR (2000).

### 3.4. Comparison of Results with Similar in Other Countries

**Table 2** shows a comparison between the measured activity concentration values of the groundwater samples in present work and other samples obtained from different countries. Where, the average concentration of  $^{226}\text{Ra}$  ( $0.56 \text{ Bq}\cdot\text{L}^{-1}$ ) is acceptable with all countries except the maximum values for Yemen and Nigeria.  $^{232}\text{Th}$  average value ( $0.16 \text{ Bq}\cdot\text{L}^{-1}$ ) is almost matched with Saudi Arabia (Alseroury et al., 2018), higher than Jordan (Al-Shboul et al., 2017) and lower than other countries. The present results show that the average of  $^{40}\text{K}$  concentration is nearly matching the value of Nigeria (Ajayi & Owolabi, 2007), higher than Yemen (Abdurabu et al., 2016) and Jordan (Al-Shboul et al., 2017), while it is lower than the other observed values. Therefore, we can indicate that the obtained results are in agreement with the data obtained from various locations in the world, taking into account the data of the countries of different geographical locations differ regarding specific mineral.

## 4. Conclusion

The activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the well water samples collected from Al-Baha region, south-east of Saudi Arabia were investigated in the present study. The obtained average concentrations of the three nuclides ( $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) were 0.85, 0.43 and  $2.84 \text{ Bq}\cdot\text{L}^{-1}$ , respectively. The results indicate that

**Table 2.** Activity concentration of natural radionuclides in ground water from different countries.

Country	Activity concentrations in (Bq/L)			References
	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{K}$	
Saudi Arabia (Al-Baha)	0.65	0.16	2.42	Present work
Saudi Arabia (Jeddah)	0.56	0.21	4.58	(Alseroury et al., 2018)
Jordan	0.131	0.049	0.194	(Al-Shboul et al., 2017)
Nigeria	4.54	0.50	2.94	(Ajayi & Owolabi, 2007)
Yemen	3.31	0.94	0.22	(Abdurabu et al., 2016)
Ghana	0.38	0.54	5.05	(Darko et al., 2015)
WHOO	1	0.1	10	(WHO, 2006)

the natural radioactivity concentrations of these nuclides were below the WHO guidance levels and were within the values reported by the other researchers. The risk assessment data show that the investigated radionuclides in water were below limit values and pose no detrimental health effect.

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### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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