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Measurement of Activity Concentration Levels of Radionuclides and Assessment of Radiation Hazards for Well Water Samples Collected from Baghdad Governorate, Al-Sadr City, Iraq

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ABSTRACT

In this study, Natural radioactivity Levels of water from samples of 10 well and at different depths 7, 3, and 12 meters measured with a gamma-ray spectroscopy device using High-Purity Germanium HPGe detector. The samples were collected from different areas of Sadr City, east of Baghdad Governorate. Al-Sadr city is Considered as one of the important areas in the capital, Baghdad, due to its population density, which constitutes about 45% of the province's population. It is very important to assess the radiation risks in these samples because the population still depends on this water in their daily life. The concentration of naturally occurring radionuclides was determined U-238, Th-232, K-40 as all sample's concentration is higher than the permissible limits according to UNSCEAR 2000. Measurements included the values of natural radioactivity were calculated as the Radium Equivalent Activity Raeq 0.22, External Hazard Index Hex 0.000595, Internal Hazard Index H_in 0.00119, Representative Level were collected The index Iγ 0.001467 and the alpha index I_α 0.0011, the exposure rate Raexp μR/h 0.418, and also calculated the air absorbed dose Dγin nGy/h 0.10164, Dγout nGy/h 0.2024, Dγtotal nGy/h 0.30404, AGED 0.6798, AEDEin 0.000124, AEDE_out 0.000993 and AEDEtotal 0.001117, lifetime cancer risk ELCRout 0.000436, ELCRin 0.003475 and ELCRtotal 0.003911.

KEYWORDS: Ground water radioactivity; radiological hazard indices; cancer risk; Al-Sadr city.

INTRODUCTION

The aim of this study is to measure the activity concentrations of U-238, Th-232 and K-40 in the well water samples in Sadr City. In addition, to measure their radioactivity levels. Exposure rate, absorbed dose rates, radium equivalent activity, radiation risk indices, gonadotropin equivalent annual dose, annual effective dose equivalent, and lifetime cancer risks were calculated for the excess sampling sites. Groundwater contains radioactive materials as a result of its contact with soil, which in turn is naturally radioactive, or some water-dissolved soil material. The radioactivity of groundwater varies from region to region. The presence of brick factories, iron smelting plants, chemical production plants, etc. increases the potential for radioactivity in groundwater to increase. Figures 1 and 2 the area from which the samples were collected [1].

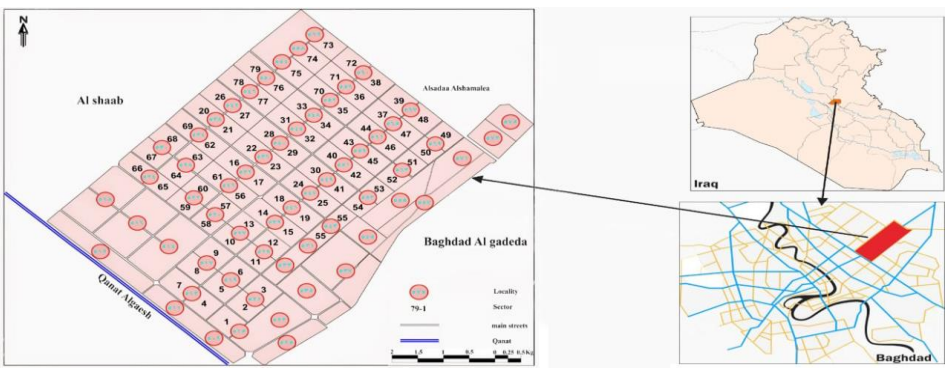

Figure 1. Area of the study [1].

The aim of this study is to measure the activity concentrations of U-238, Th-232 and K-40 in the well water samples in al-Sadr City. In addition, to measure their radioactivity levels. Exposure rate, absorbed dose rates, radium equivalent activity, radiation risk indices, gonadotropin equivalent annual dose, annual effective dose equivalent, and lifetime cancer risks were calculated for the excess sampling sites.
Therefore, the assessment of radiation exposure in these sites is of great importance, and many studies have measured the natural radioactivity of well water in Iraq [2-5].

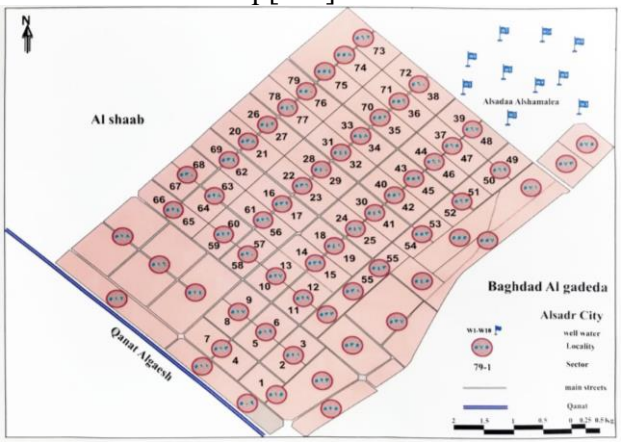

Figure 2. Wells water sampling sites in al-Sadr City.

MATERIAL AND METHOD

Collecting and preparing samples

Ten well water samples were collected from different locations in the east of Baghdad Governorate on the Rusafa side, specifically Sadr City, which is under study during the months of October and November 2020 Well water samples At depths of 3, 7 and 12 meters from the surface of the earth The coordinates were sampled by the Global Positioning System (GPS). Table 1 shows sample codes and dose-measuring sites absorbed by the portable Inspector and their coordinates. To assess the specific activity and radiation risk indicators of U-238, Th-232 and K-40, water samples from wells were transferred to the Radiation Detection and Measurement Laboratory of the Ministry of Science and Technology - Central Laboratories Department.
All samples were filtered in the laboratory by filter paper to remove Traces of sludge. Then they were placed in a Marinelli polyethylene flask, and the respective weights were measured and recorded with an accurate digital weighing scale of 1% ± 0.01%. Then, approximately 1 kg of each sample was filled into a standard Marinelli flask and sealed. Before use, the containers were washed with diluted hydrochloric acid and rinsed with water, knowing that these detergents are tested and do not bear any traces of contamination. The cups are closed completely for 4 weeks for a secular equilibrium where the decay rate of the offspring becomes equal to the rate of decomposition of the parent (Rn-222 and Ra-226) in the uranium chain. This step is necessary to ensure that the radon is confined in volume and that the strain will remain in the sample.

Table 1. Ground water well samples at Al-Sadr city, and their geographical coordinates.

Code	Depth of the Well (m)	Geographical Coordinates	Absorbed Dose (μSv/h)
W1	12	N= 33 41 42 07 E= 44 48 23 69	0.088
W2	10	N= 33 42 14 43 E= 44 49 98 80	0.107
W3	12	N= 33 42 27 99 E= 44 50 13 96	0.111
W4	12	N= 33 41 57 46 E= 44 48 40 74	0.098
W5	7	N= 33 41 51 42 E= 44 47 95 19	0.101
W6	12	N= 33 41 49 15 E= 44 47 91 38	0.099
W7	3	N= 33 41 47 34 E= 44 47 93 59	0.121
W8	12	N= 33 41 63 30 E= 44 48 72 53	0.103
W9	12	N= 33 41 31 91 E= 44 48 08 38	0.105
W10	7	N= 33 41 36 67 E= 44 48 09 66	0.123

Gamma Ray Spectrometer

The pure germanium detector is a closed coaxial p-type (Model GC4018) manufactured by Canberra and contains HPGe crystal as a main part of it. It measures 62 mm in diameter, 60 mm in length and 4.67 mm from the window. Accuracy is <1.8 kV at 1.33 mV and 60 °C capacity. Activity measurements were performed by gamma ray spectrometer, employing a scintillation detector 3×3 inch. It is hermetically sealed assembly, which includes a HPGe crystal, coupled to Personal Computer-Multi Channel Analyzer PC-MCA Canberra Accuses. It is surrounded by a very thick shield of lead, 10 cm

thick, to reduce the background radiation from radiation sources and separate it from other sources in the surrounding areas; it also consists of an electronic system consisting of a (+) 3300V DC depletion voltage detector and a pre-amplifier. The optimal coupling between the detector output and the rest of the counting device is the primary objective of the pre-amplifier. It is also important for the amplifier to reduce any noise sources that could alter the signal. Alongside this is the multi-channel analyzer of the PC Card with integrated computer spectrometer software that is the basis of the MCA. According to their length, it records and stores pulses. Each volume is called a channel. In order to process the information card provided MCA, a personal computer connects an amplifier, rectifier amplifier and high-voltage power supply (DSA 1000) to the detector through which the energies of individual events are converted into a continuum of pulse height. The Genie 2000 software was used to acquire, display, and analyze gamma-ray spectra data to calibrate the efficiency of the detector; a standard multi-gamma power source was used. The energy and efficiency calibration curves of the spectrometer were performed using Marinelli calibration standard source containing those sources are shown in Figures 3 and 4. The lead shield contained an inner concentric cylinder of copper, 0.3 mm thick, in order to absorb X-rays generated in the lead. In order to determine the background distribution in the environment around the detector, an empty sealed beaker was counted in the same manner and in the same geometry as the samples. Every two days, the background radiation is re-measured for one hour before the sample is introduced into the system. The background spectra were used to correct the net peak area of gamma rays of measured isotopes. A dedicated software program Genie 2000 from Canberra has carried out the online analysis of each measured gamma ray spectrum.

SPECIFIC ACTIVITY

To determine the specific activity (activity concentration) of a gamma the following equation can be determined for the emission of radionuclides in the sample [6,7]:

$$A\left(\frac{Bq}{kg}\right) = \frac{N}{I_\gamma \varepsilon M T} \quad (1)$$

N is the net area below the picture peak and M is the estimated sample weight in kg.

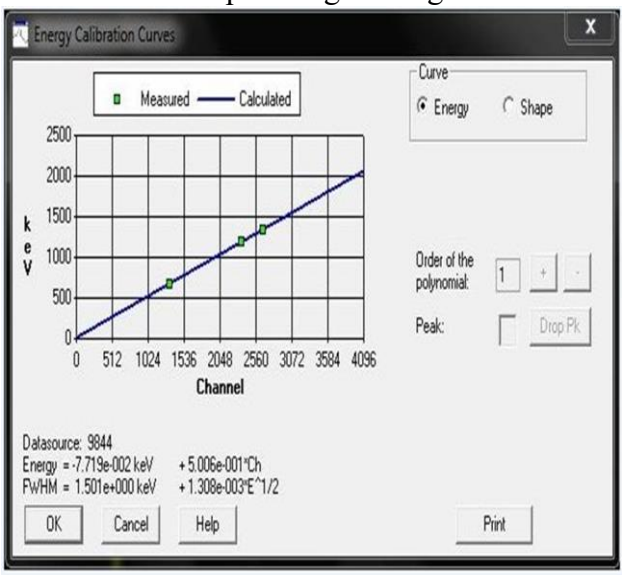

Figure 3. Energy calibration curve of HPGe detector.

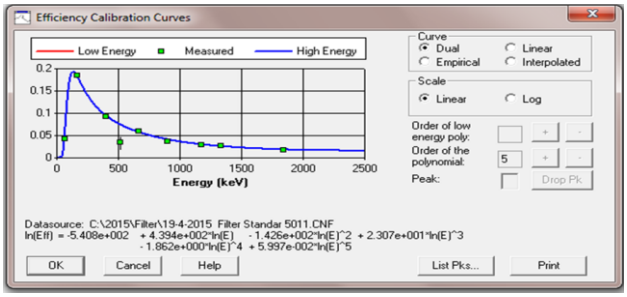

Figure 4. Efficiency calibration curve of HPGe detector.

Radium Equivalent Activity R_{eq}

Radiation hazards related to incoming samples and radionuclides, specifically U-238, Th-232 and K-40 can be found through a radioactive indicator called radium equivalent activity, which can be expressed mathematically [8,9]:

$$R_{eq}\left(\frac{B_q}{K_g}\right) = A_U + 1.43A_{Th} + 0.077A_k \quad (2)$$

$R_{eq=}$ Radium Equivalent Activity

$k_{g=}$kilo gram,

B_q=It is the unit of radioactivity

A_u= uranium activity

A_{Th}= Thorium activity

A_k= Potassium activity

External Hazard Index H_{ex}

For samples under the conditions, the external hazard index is given by the following equation [10]:

$$H_{ex} = \frac{A_u}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (3)$$

where H_{ex} is an indicator for assessing the rate of internal radiation dose due to external gamma exposure.

Internal Hazard Index H

Exposure to Rn-222 and its radioactive progeny is endogenous. The internal hazard indicator is regulated. It can be evaluated according to the equation below [11,12]:

$$H = \frac{A_U}{180} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Representative Level Index Iγr

Representative level index estimates the gamma radiation hazard level that attributable to predetermined natural gamma-emitting radionuclides in the soil or building materials. It is possible to use the following equation to calculate this index [13]:

$$I\gamma r = \frac{A_u}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500} \quad (5)$$

Alpha Index $I\alpha$

Alpha index is used estimate excess alpha radiation due to inhalation of radon gas and its daughters emitted from soil or building materials. The following equation could be used to determine this index with recommended limit 0.5 [18]:

$$I\alpha = A_u/200 \quad (6)$$

Exposure Rate R_{exp}

Since the U-238, Th-232 and K-40 series are uniformly distributed in the material; the average exposure to air from gamma rays at a height of 1 m over a thick and infinitely long slab is given by [14]:

$$R_{exp}\left(\frac{\mu R}{h}\right) = 1.90A_u + 2082A_{Th} + 0.197A_k \quad (7)$$

Where A_U, A_{Th} and A_k are the activity concentrations in (Bq/kg) of uranium, thorium and potassium respectively.

Absorbed Dose Rate $D\gamma$

The limited amounts of terrestrial gamma rays available from the soil mainly contribute to the rate of dose uptake in the air. To convert the activity concentration of the radionuclides U-238, Th-232, and K-40 to a given dose conversion factor, the doses 0.462, 0.604 and 0.041 can be given, respectively, given the amount of dose absorbed one meter above the ground in air given by UNSCEAR, 2008 [15] by:

$$D\gamma_{out}\left(\frac{nGy}{h}\right) = 0.462A_u + 0.604A_{Th} + 0.041A_k \quad (8)$$

The imparted indoor gamma ray dose rate by of U-238, Th-232, and K-40 radionuclides can be estimated by converting the absorbed dose rate to effective dose by using the conversion factors 0.92, 1.1 and 0.081 respectively given by UC European Commission (1999) [16]:

$$D\gamma\left(\frac{nGy}{h}\right) = 0.92A_u + 1.1A_{Th} + 0.081A_k \quad (9)$$

Annual Gonadal Equivalent Dose (AGED)

According to UNSCEAR, 2006 [14], the annual gonadal dose equivalent ($AGDE$) due to the specific activities of U-238, Th-232 and K-40 and conversion factors 3.09, 4.18 and 0.3144 μSv/y per Bq/kg respectively, was calculated using the following equation [10]:

$$AGED\left(\frac{\mu sv}{y}\right) = 3.09A_U + 4.18A_{Th} + 0.31A_K \quad (10)$$

Sv= The Sievert is a unit of radiation equivalent dose.

$AGED$= Annual Gonadal Equivalent Dose.

Annual Effective Dose Equivalent (AEDE)

The annually effective dose equivalent (AEDE) can be calculated by applying a fraction conversion factor of 0.7 Sv/Gy with an external accommodation factor of 0.2 and an internal fraction of 0.8 [15].

$$AEDE_{OUT}(\mu Sv/y) = \left[D\gamma out(nGy/h) \times 8760\left(\frac{h}{y}\right) \times 0.20 \times 0.7\left(\frac{sv}{Gy}\right)\right] \times 10^{-3} \quad (11)$$

$$AEDE\ (\mu sv/y) = [D\gamma in(nG/h) \times 8760(h/y) \times 0.80 \times 0.7(sv/Gy)] \times 10^{-3} \quad (12)$$

Excess Lifetime Cancer Risk ELCR

The lifetime probability of cancer and the risk of developing it depend on the extent of exposure, given that the normal lifespan of a person is 70 years, which can be given by [6]:

$$ELCR_{out} = AEDE_{OUT} \times DL \times RF \quad (13)$$

$$ELCR \quad = AEDE \quad \times DL \times RF \quad (14)$$

Where DL = the normal duration of life.
RF = is the risk factor assigned to be 0.05 given by ICRP, 2012 [19].

RESULTS AND DISCUSSION

The radioactivity of well water samples collected from different locations in Al-Sadr City, Baghdad Governorate, was evaluated, and their radioactive hazards were determined. The specific activity of U-238 ranged from 21.8 ± 1.1 to 9.9 ± 0.7 Bq / kg with a mean value of 15.35 ± 0.82 Bq / kg. However, no activity was found for Th-232 and K-40, Figure 5 and Table 2 shows the comparison of specific activity concentration of U-238 all recorded readings were within permissible limits [20].

Table 2. The Specific Activity for well water samples at Al-Sadr City sectors, using gamma spectroscopy (HPGe) technique.

Sample well Water	Activity Concentration (Bq/kg)
	U-238 (Pb-212)
W1	0.29±0.1
W2	0.16±0.04
W3	No- detect
W4	No- detect
W5	0.32±0.094
W6	No- detect
W7	0.11±0.06
W8	No- detect
W9	No- detect
W10	No- detect
Max.	0.32±0.094
Min.	0.11±0.06
average	0.22±0.0735
Worldwide average [17]	0.001

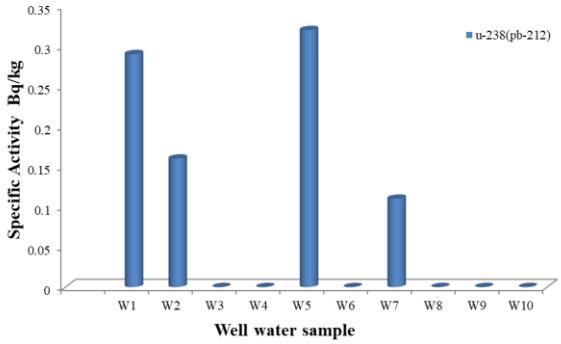

Figure 5. Graph represents values specific activities for well water samples at Al-Sadr city.

The results showed the presence of uranium only, and the absence of thorium and potassium, as it was found through the measured readings that all concentrations of samples were higher than the internationally permissible limits [17].

Radiological Effects

The values of Radium Equivalent Activity (Ra_{eq}), External Hazard Index (H_{ex}), Internal Hazard Index (H), Representative Level were collected the index (I_γ) and the alpha index (I_α) shown in Table 3. As noted in Table 3, the values of radium equivalent activity (Ra_{eq}) of the water samples ranged from (0.11) to (0.32) Bq/kg with a mean of (0.088) Bq/kg, Radiation can cause severe health effects such as skin burning or acute radiation syndrome when radiation doses exceed certain levels or cancer, note Figure 6.

Table 3. Radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (Hin), representative level index (Iγ) and alpha index (Iα).

sample Water	Ra_{eq}	H_{ex}	H	I_γ	I_α
W1	0.29	0.000784	0.001568	0.001933	0.00145
W2	0.16	0.000432	0.000865	0.001067	0.0008
W3	---	---	---	---	---
W4	---	---	---	---	---
W5	0.32	0.000865	0.00173	0.002133	0.0016
W6	---	---	---	---	---
W7	0.11	0.000297	0.000595	0.000733	0.00055
W8	---	---	---	---	---
W9	---	---	---	---	---
W10	---	---	---	---	---
max	0.32	0.000895	0.00173	0.002133	0.0016
min	0.11	0.000297	0.000595	0.1067	0.00055
average	0.22	0.000595	0.00119	0.001467	0.0011

The results for H_{ex}, H , I_γ, and I_α see Table 3 range from (0.000297) to (0.000865) with a mean value of (0.000238), from (0.000595) to (0.00173) with a mean of (0.000476), from (0.000733) to (0.002133) with a mean of

(0.000587) and from (0.00055) to (0.0016) with a mean of (0.00044) respectively, All the results obtained are higher than the permissible limits according to the scientific committee UNSCEAR (2000)[20], so this water is considered dangerous to use ,note Figure 7.

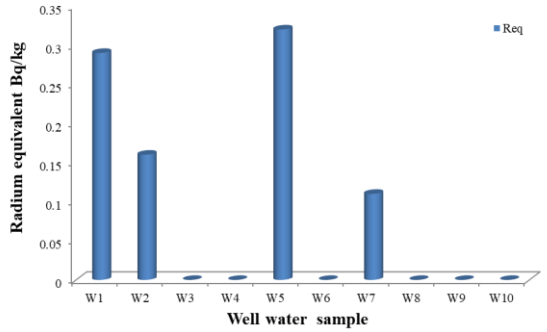

Figure 6. Graph represents values Radium equivalent activity (Ra_{eq}), in Al- Sadr City.

The values were obtained for exposure rate (R_{exp}) µR/h, rate of absorbed dose in air ($D\gamma$, $D\gamma_{out}$, $D\gamma_{total}$) nGy/h, annual gonadotropin equivalent dose ($AGED$), annual equivalent effective dose internally, externally and ($AEDE$, $AEDE_{out}$ and $AEDE_{total}$),increased lifetime cancer risk ($ELCR_{out}$ and $ELCR_{total}$).

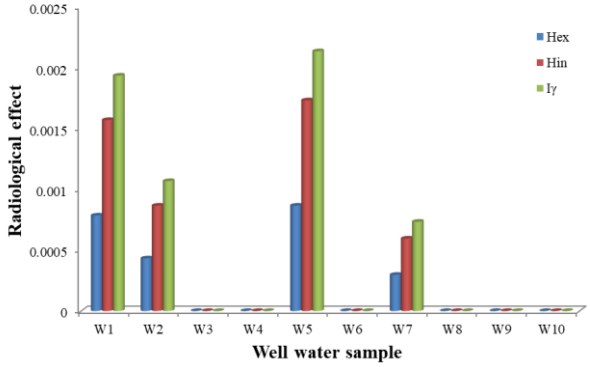

Figure 7. Graph represents values external hazard index (H_{ex}), internal hazard index (H_{in}), representative level index (I_{γ}), and alpha index (I_{α}) well water samples.

Therefore, the results of the highest value of the (R_{exp}) µR/h were recorded to the lowest value, where it was (0.608) to (0.209) µR/h, with an average value of (0.167) µR/h Figure 8, ($D\gamma$) nGy/h results range from (0.294) to (0.101) nGy/h with an average value of (0.080) nGy/h, ($D\gamma_{out}$) nGy/h results range from (0.147) to (0.050) nGy/h with an average value of (0.040) nGy/h and ($D\gamma_{total}$) nGy/h results range from (0.442) to (0.152) nGy/h with an average value of (0.121) nGy/h Figure 9, $AGED$ results as shown in Table 4 range from (0.9888) to (0.3399) mSv /y with an average of (0.271) mSv/y Figure 8. The results of ($AEDE$, $AEDE_{out}$ and $AEDE_{total}$), in this study ranged from (0.00144) to (0.00049), with Average (0.00039), from (0.00016) to (0.00006) with average (0.00004), from (0.0016) to (0.0005) with average (0.0004) respectively. Table 4 shows where the ($ELCR$,$ELCR_{out}$, and $ELCR_{total}$), values range from (0.00063) to (0.00021) with an average (0.00017), from (0.0050) to (0.0017) with an average of (0.0013), from (0.0056) to (0.0019) with an average of (0.0015). Of course, the ELCR out is higher than the ELCR in, because it is more exposed to radiation, so we note the results obtained are higher than the permissible limits according to decisions with the scientific committee UNSCER 2000[20].

Table 4. Exposure rate (R_{exp}), Dose Rate in Air (D_{γ}), Annual gonadal equivalent dose ($AGED$), Annual Effective Dose Equivalent ($AEDE$), and Excess Lifetime Cancer Risk ($ELCR$) in Al-Sadr City.

Water sample code	R_{exp} $(mSv/h$	$D_{\gamma}out$ (nGy/h)	$D_{\gamma} \in$ (nGy/h)	$D_{\gamma}total$ (nGy/h)	$AGED$ (mSv/y)	$AEDE_{out}$ (mSv/y)	$AEDE$ (mSv/y)	$AEDE_{total}$ (mSv/y)	$ELCR_{out}$ $\times 10^{-3}$	$ELCR$ $\times 10^{-3}$	$ELCR_{tatal}$ $\times 10^{-3}$
W1	0.551	0.133	0.266	0.401	0.8961	0.000164	0.001309	0.00147	0.00057	0.00458	0.00515
W2	0.304	0.073	0.147	0.221	0.4944	0.000090	0.000722	0.00081	0.00031	0.00252	0.00284
W3	---	---	---	---	---	---	---	---	---	---	---
W4	---	---	---	---	---	---	---	---	---	---	---
W5	0.608	0.147	0.294	0.442	0.9888	0.00015	0.001444	0.00162	0.00063	0.0050	0.0056
W6	---	---	---	---	---	---	---	---	---	---	---
W7	0.209	0.050	0.101	0.152	0.3399	0.000062	0.000496	0.00055	0.00021	0.00173	0.0019
W8	---	---	---	---	---	---	---	---	---	---	---
W9	---	---	---	---	---	---	---	---	---	---	---
W10	---	---	---	---	---	---	---	---	---	---	---
Average	0.418	0.10164	0.2024	0.30404	0.6798	0.000124	0.000993	0.001117	0.000436	0.003475	0.003911
±SD	±0.246	±0.058	±0.117	±0.176	±0.394	±0.001	±0.001	±0.001	±0.001	±0.002	±0.002

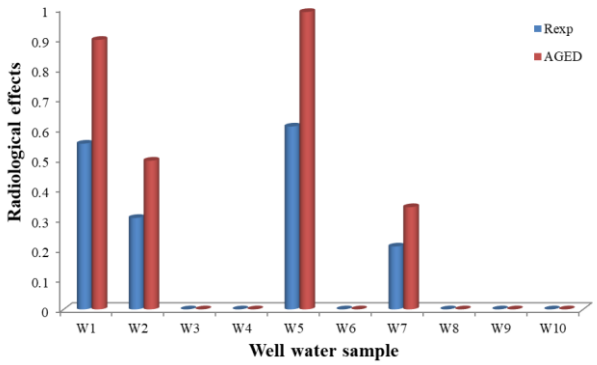

Figure 8. Graph represents values exposure rate (R_{exp}) μR/h and ($AGED$), annual equivalent effective dose internally.

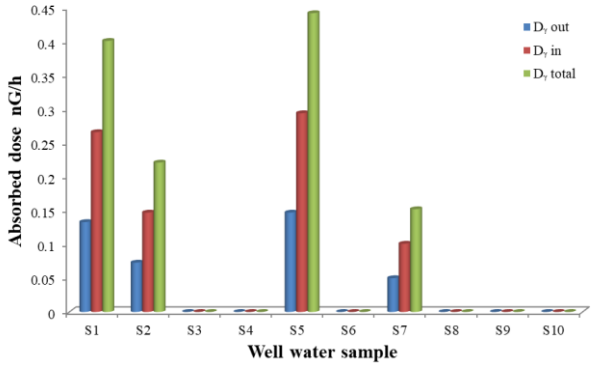

Figure 9. Graph represents values rate of absorbed dose in air ($D_{\gamma}in$, $D_{\gamma}out$, $D_{\gamma}total$) nGy/h.

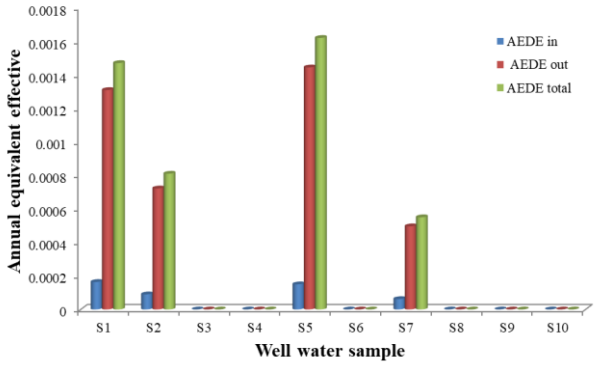

Figure 10. Graph represents values annual equivalent effective dose internally, externally and total ($AEDE_in$, $AEDE_{out}$ and $AEDE_{total}$).

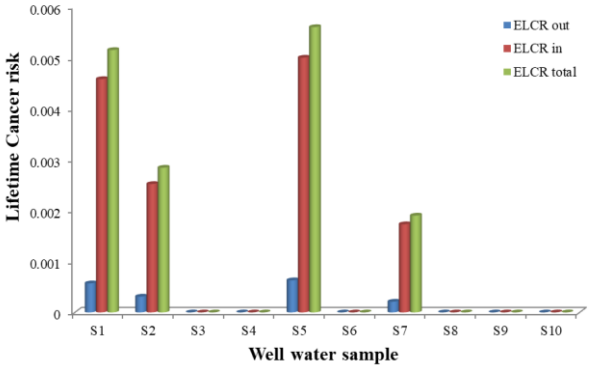

Figure 11. Graph represents values lifetime cancer risk ($ELCR_{in}$, $ELCR_{out}$, and $ELCR_{total}$).

CONCLUSIONS

The activity concentrations and radiological hazard indicators of natural radionuclides U-238, Th-232 and K-40 were examined in well water samples collected from different locations in Sadr City, and it was noted that U-238 was detected where the highest percentage of 0.32 was recorded in a sample. W5, and the lowest percentage was 0.11 in the W7 sample and it was higher than the global average of 0.001 values. It is recommended by UNSCEAR (2000). The overall results indicate that the values were above the permissible limit, but in the long run, the use of well water for various human uses may pose a serious impact on human life.

ACKNOWLEDGMENTS

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