# Measuring the Radioactivity Concentration of 40 K, 226 Ra, 232 Th and Radiological Risk Assessment from Water Tap

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**Research Article**

**Keywords:** Gamm ray, Water, Radionuclide, Radioactivity, Annual effective dose

**Posted Date:** July 28th, 2022

**DOI:** https://doi.org/10.21203/rs.3.rs-1878168/v1

# Abstract

The water has an importance in environmental studies because of its daily usage by human and its ability to transport pollutants, such as radionuclides that can pose a health risk to human. The radiological quality of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in some samples of water tap collected in kirkuk area, Iraq, has been measured by direct gamma ray spectroscopy using high purity germanium detector Result: or radium equivalent activity, internal hazard index (Hin), external hazard index (Hex),representative level index Iγr, Dose rate ($nGyh^{-1}$),indoor and outdoorAnnual effective dose (AEDE) in the air,respectively, due to gamma radiation and the annual gonadal dose equivalent (AGDE) were calculated, it was lowerthe world average value $300\mu Sv.y^{-1}$, recommended by UNSCEAR. Also, the values of radiation hazard expressed by (Raeq) varied from (223.2445 to 369.9037) $mBq.kg^{-1}$ with a mean of 339.9506 $mBq.kg^{-1}$ which is less, lower than the worldwide average. These values are far below the allowable limit (370 $Bq.kg^{-1}$) recommended by the International Atomic Energy Agency (IAEA). And the calculated external hazard indices were found to be less than 1 which shows a low dose. These results can be contributed to the database of this area


# Introduction

Naturally occurring radiation and artificial sources are the important source of environmental radiation. Major sources of natural radioactivity are nuclides with very long half-lives which have persisted since the formation of earth (Anees et al., 2019). Naturally occurring radioactive materials (NORM) consist of uranium, thorium, potassium and any of their decay products such as radium and radon. One of the main determinants of the natural background radiation is radionuclide ($^{238}U$, $^{232}Th$ and $^{40}K$) concentration (Awad et al., 2018). Since water is very important for human life, so measuring their contents of radioactivity is important and must be under control+ In the ground, water fills the spaces between rocks and soils which contains the radioactive elements, that transfers to the water (Malik et al., 2019). These elements can be brought to the surface by human activities.

Although the radioactive elements in the earth's crust are the reasons of presence of radioactivity in water resources, high concentration of radioactive materials in water resources might be accidentally or intentionally. The public can be affected by the environment where is adjacent to the released point of the radioactive materials. If radioactive materials are released into the environment, radionuclides may be moved into the body by inhalation and ingestion, which causes internal exposure (Elham et al., 2014; Fakeha et al., 2011). The most vital sources to the environment are the freightage of radioactive materials, and the residual fallout from nuclear weapon testing, also nuclear accidents that continually spread a huge amount of radioactivity in the environment. Consequently, radionuclides in water have been monitored since their discovery. Most of this 1% drinking water exposure is from inhalation of radon gas released from running water activities, such as bathing, showering, and cleaning. Although the effects of ingested radon are not fully understood, calculations suggest that the great majority of the radiation dose from such exposure is in the stomach (Najeba et al., 2015).

Measurement of naturally occurring radioactive materials in drinking water is an important subject for public health studies (Najeba et al., 2019a). Drinking water contaminated with natural radionuclides is one of the

main causes of the health hazard to the population due to internal exposure of the absorbed radionuclide's decay inside the human body (Nisar et al., 2018). The presence of radonuclide in the drinking water are considered as a potential threat to public health (Ahmad et al. 2018), the annual effective doses in water reported in this study were found lower than recommended levels that contributes by inhalation and ingestion doses (Ahmad et al. 2018). To assess radiation hazards, it is necessary to know the rate at which radiation is received; consequently, it is necessary to study the natural radioactivity to assess the dose to the population in order to know the health risks (Altaf & Nasima, 2015). Many health effects such as chronic lung diseases, acute leucopoenia, anemia, and necrosis of the mouth occur by exposure to uranium ($^{238}U$) and radium ($^{226}Ra$). The bone, cranial, and nasal tumors result from exposure to radium, while the lung, pancreas, hepatic, bone, and kidney cancers and leukemia result from exposure to Thorium (Althoyaib, 2012).

There are a linearly proportional between the damages that occur in the cells and the dosage received, where these damages depend on many factors including radiation type, energy deposited, intensity and period of exposure (Majied & Anees, 2019), therefore, used Hyper-pure germanium (HpGe) detectors are widely used for gamma spectrometry measurements. They have special features over other detectors due to their high characteristic resolution. In a few cases, some of the gamma rays emitted by one isotope are very close in energy to gamma rays emitted by other isotopes in the sample (Salman et al., 2019). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) estimated that exposure to natural radionuclides contributes around 70% of the population radiation dose. The global average human (Elham et al., 2014). In the recent years, there are many studies done on the high background radiation areas in the world to show the risk estimation due to long term low-level whole body exposures to the public, such as Australia, Brazil, China, India, Iran, and Japan. In order to have environmental protection, the monitoring of any release of radioactivity to the environment is important. Fast and accurate methods for examine of radioactivity are necessary for the monitoring (Hamada et al., 2013). Determination of radioactivity concentration in a drinking water is preferred method for monitoring the internal exposure of radiological contaminants (Majied & Anees, 2019), therefore, the objective of this study is to obtain a representative estimate of the concentration levels of natural radionuclides in water resources which might be used as drinking to provide background data on natural radioactive isotopes for the study region

# Methodology

### Sample collection and preparation

In this study, drinking water samples were collected from twenty sites in Kirkuk governorate of north region in Iraq, before collection of drinking water samples, the bottles were washed according to the IAEA standard with 15% nitric acid and with double deionized water three times (Nisar et al. 2018) and before measurement of natural radioactivity. Physicochemical parameters of all water samples such as pH were analyzed by using a pH meter in order to find the impact of these parameters on the concentration of the radionuclides in water (Ahmad et al., 2018; Elham et al., 2014), 99 to 124 gm for each sample was weighed using electronic balance, as shown in Table 1. With each sample of volume 1 litre was sealed separatly, labeled by sample code, with the location, date of collection, weight and sample number, and stored in a Marinelli beaker for four weeks( one month ) to achieve equilibrium between the $^{238}U$ and $^{232}Th$ series and their respective progenies to

prepare for measurements and their respective progenies. About 98% equilibrium level was attained for the duration. The natural $^{226}Ra$, $^{232}Th$, and $^{40}K$ radioactivity levels of the drinking water samples were measured using a gamma multi channel analyzer equipped with a high purity germanium coaxial detector (HPGe) system (Khatun et al., 2013; Majied & Anees, 2019) that shielded with 10 cm thick of lead to reduce the background radiation from various natural radiation sources and to isolate from other radiation sources used in nearby surrounding (Eric et al., 2016; Ahmed et al., 2014). The samples were placed directly on the tap of detector for the gamma analysis attempting to attain minimum counting error (Majied & Anees, 2019; El-Taher et al., 2019; El-Taher & Abdelhalim, 2014), and was counted for 86,400 (Najeba, 2019 b) seconds so as to achieve minimum counting error, also the background measured under the same conditions (Najeba, 2019 b, Ahmad et al., 2018; Altaf & Nasima, 2015). The sampling sits are listed in table 1. The pH and electrical conductivity (EC) of the drinking water samples were also measured using the methods described by (Hanlon, 2009). Prior to carrying out the measurements, the pH equipment (Matiohm model 827 Ph lab) was calibrated with three standard values (4 = acid, 7 = normal, 9 = basic).

**Table 1** The code of drinking water with the mass of samples and (pH and Electrical conductivity (EC)) of the drinking water.

| No. | Code of Samples | Mass of samples gm | PH | EC (mS/cm) |
|---|---|---|---|---|
| 1 | SW01 | 105.53 | 7.98 | 0.26 |
| 2 | SW02 | 111.16 | 6.50 | 0.18 |
| 3 | SW03 | 114.18 | 4.98 | 0.24 |
| 4 | SW04 | 110.37 | 4.67 | 0.23 |
| 5 | SW05 | 104.35 | 7.94 | 0.25 |
| 6 | SW06 | 100.01 | 6.78 | 0.27 |
| 7 | SW07 | 113.51 | 5.73 | 0.31 |
| 8 | SW08 | 104.25 | 6.94 | 0.28 |
| 9 | SW09 | 107.41 | 5.91 | 0.21 |
| 10 | SW10 | 112.56 | 7.88 | 0.28 |
| 11 | SW11 | 119.85 | 6.39 | 0.30 |
| 12 | SW12 | 116.13 | 7.17 | 0.29 |
| 13 | SW13 | 107.49 | 8.47 | 0.37 |
| 14 | SW14 | 108.18 | 5.76 | 0.27 |
| 15 | SW15 | 103.67 | 6.52 | 0.35 |
| 16 | SW16 | 111.07 | 7.11 | 0.19 |
| 17 | SW17 | 106.98 | 7.83 | 0.26 |
| 18 | SW18 | 101.28 | 7.88 | 0.25 |
| 19 | SW19 | 104.71 | 6.27 | 0.31 |
| 20 | SW20 | 106.66 | 6.78 | 0.32 |

### Gamma spectrometry analysis

The natural radioactivity levels were measured with an HPGe detector connected to a multichannel analyser with high voltage (0–1500 V) (Najeba, 2019b). The energy resolution of the detector was set on 1.99 keV at 1332 keV of 60Co source that has the ability to differentiate the gamma ray energies that is agree with (Ahmad et al., 2018). The energy calibration entailed converting channel numbers to gamma ray energy in MeV, while the efficiency calibration was aimed at determining the gamma ray counting efficiencies over the full energy range of measurement (Darwish et al., 2015).

### Energy and efficiency calibrations

In this study, before the analysis of the samples, the calibrations of gamma energy and efficiency calibration for the system were performed by mixed standard gamma sources using standard sources from the

International Energy Agency (IAEA), such as $^{60}Co$, $^{137}Cs$, $^{22}Na$, $^{241}Am$ and $^{226}Ra$, which is in agreement with (Najeba, 2019b). The efficiency and energy resolution were determined as a function of gamma ray energies (Najeba, 2018) as shown in Table 1. Calibration of gamma rays was obtained from the energy range of 26–1332.5 keV. Certified standards of known activities were used to derive the efficiency of the HPGe detector because the efficiency is an important parameter of HPGe detector (Najeba, 2018). The efficiency calibration curve of HPGe detector is shown in Figure 1. Furthermore, the absolute efficiency of the HPGe detector was calculated using the equation presesnted in the (Najeba, 2018; Njinga et al., 2015).

**Table 2** Gama ray standards source for the energy calibration and efficincy calibration of HPGe detector in this study.

| No. | Nuclide | Gama energy (keV) | Activity $Bq.kg^{-1}$ | Abundance pγ(%) | Half-life (T1/2) | Intensity (%) | Source No. |
|---|---|---|---|---|---|---|---|
| 1 | Americium-241 | 26.34 | 35.6 | 36.0 | 432.2 years | ….. | RF 807 |
| 2 | Barium-133 | 276.4, 356, 853 | 38.0 | 7.1, 61.9,8.0 | 10.52 years | 7.16,62.1,18,33 | RF 808 |
| 3 | Cesium-137 | 661.6 | 35.8 | 85.1 | 30.2 years | 85.10 | RF 809 |
| 4 | Cobalt-57 | 129.00 | 42.7 | 87.0 | 273 days | 99.97 | RF 810 |
| 5 | Cobalt-60 | 1332.50 | 40.0 | 100 | 5.26 years | 99.98 | RF 811 |
| 6 | Manganese-54 | 834.8 | 46.7 | | 312.5years | ... | RF 813 |
| 7 | Sodium-22 | 1274 | 39.1 | 100 | 2.6 years | 99.94 | RF 814 |

The analyses of the radionuclides in the water samples were carried out based on the energy peaks of the progenies, as shown in Table 2. The energy of the decay products of the radionuclides $^{214}Pb$ (abundances 295.224 keV, 18.7 % and 351.932 keV, 35.8 %) and $^{214}Bi$ (609.312 keV, 45 %, 1120.287 keV, 14.8 % and 1764.494 keV, 15.65 %) were taken to indicate were taken to indicate the activity concentrations of $^{226}Ra$, and the specific activity of $^{232}Th$ has been calculated based on the energy peaks of $^{212}Pb$ (238.632 keV, 47.3 %), $^{228}Ac$ (911.204, 29 % and 968.971 keV, 17.5 %) and $^{208}Tl$ (583.191, 84.5 %), although the activity concentration of $^{40}K$ was assessed directly from its gamma ray peak of (1460.83 KeV, 10.67 %) (IAEA, 1989) which is in compliance with studies by (Darwish et al., 2015), which is also in agreement with the study by (Njinga et al., 2015; IAEA, 1989).

**Table 3** Radionuclides with the energy of gamma ray.

| Parents | Daughters | Energy(Kev) | Abundance pγ (%) |
|---|---|---|---|
| $^{232}$Th | $^{212}$Bi | 727.33 | 6.6 |
| | $^{212}$Pb | 238.63 | 43.3 |
| | $^{228}$Ac | 911.20 | 25.8 |
| | | 968.97 | 15.8 |
| | $^{208}$Tl | 510.77 | 22.6 |
| | | 583.19 | 84.5 |
| | | 860.56 | 12.4 |
| | | 2614.53 | 99.0 |
| $^{226}$Ra | $^{214}$Bi | 609.31 | 46.1 |
| | | 1120.28 | 15.1 |
| | | 1764.49 | 15.4 |
| | $^{214}$Pb | 295.22 | 19.3 |
| | | 351.93 | 37.6 |
| $^{40}$K | $^{40}$K | 1460.83 | 11.0 |

## Calculation of specific radioactivity and hazard indices

### Determination of Concentration of Radionuclides

The specific activity concentration (As) of the radionuclides of $^{226}$Ra, $^{232}$Th and $^{40}$K in water was calculated from the background subtracted area of prominent gamma-ray energy by using Eq. (1) as given by (Murtadha et al., 2017a).

$$A = \frac{\mathrm{CPS} \times 1000}{\varepsilon_\gamma \times I_\gamma \times W}$$

Where, A is the specific activity in Bq.L$^{-1}$, CPS is is the net count rate under peak per second and subtract the background under this peak of the experimental sample, W is the weight of the sampleing, ε is the absolute efficiency for each gamma-ray energy E, Iγ is the gamma-ray emission probability of the corresponding γ-ray energy (at each energy) (Mayeen et al., 2013, Bhuiyan et al., 2019).

### Assessment of radiological hazard index

#### *Radium equivalent activities (Raeq)*

To assess the radiological hazard of the waeter samples and as a result of non-uniform distribution of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in water uniformity with respect to exposure to radiation has been defined in terms of radium equivalentactivity (Raeq) in $Bq.kg^{-1}$ to compare the specific activity of materials containing different amounts of $^{226}Ra$, $^{232}Th$ and $^{40}K$. This was evaluated using Eq. (2) taken (Eric et al., 2016, Hamada et al., 2013).

**Raeq = ARa + 1.43 ATh + 0.077 AK ……. 2**

Where, ARa, ATh and AK are the specific activity of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in $Bq.Kg^{-1}$, respectively. The acceptable maximum value of the radium equivalent activity is 370 $Bq.kg^{-1}$ (Murtadha et al., 2017b). The Raeq is assumed that 370 $Bq.kg^{-1}$ of $^{226}Ra$, 259 $Bq.kg^{-1}$ of $^{232}Th$ and 4810 $Bq.kg^{-1}$ of $^{40}K$ yield the same gamma dose rate (Abdalrahman & Riyadh, 2019).

**Outdoor hazard index**

***Representative level index (Iγr)**:*

The representative level index, Iγr, used to estimate the level of γ- radiation hazard associated with the natural radionuclides in specific investigated samples,

**The radioactivity level index**; (gamma index **Iγ**) is used to estimate the rate of -radiation hazards linked with natural radionuclide in investigated samples (Saifeldin et al., 2018). The gamma index was calculated by using Equation (3) (Najeba, 2019b).

**Iγ= ARa /300 + ATh /200+AK /3000 ……3**

**The external hazard index (Hex);** was calculated by using Equation (4) in order to assess the equivalent average of dose imposed to the residents of each area under study (Vahid et al., 2013).

**Hex = ARa /370 + ATh /259+AK /4810 ≤1……4**

The outdoor external dose (Dout); is given in Equation (5) (Olga et al., 2019).

**Dout= 0.461A Ra + 0.623 ATh + 0.0414 × AK…….5**

**Indoor hazard index**

**The alpha index**; the excess alpha radiation due to the radon inhalation originating from the grain samples is assessed through alpha index, and it was <1. Alpha index (Iα) was calculated according to the following equation (IAEA, 1989).

**Iα = ARa/200 ……6**

**The internal hazard index (Hin);** the internal hazard index is to locate within the exposure of radon and the descendants with a short half-life and it shows a similar formula with slightly different with external hazard index (Vahid et al., 2013). **Hin** was calculated by using equation(7).

**Hin = ARa /185 + ATh /259+AK /4810 ≤1……..7**

The indoor external dose (Din) was calculated by using Equation (8).

**Din = 0.92ARa + 1.1 ATh + 0.08 AK …….8**

**Annual effective dose equivalent**

The annual effective dose equivalent (AEDE) is determined using the following equation (Olga et al., 2019; Eric et al., 2016).

**AEDE ($mSvy^{-1}$) = D ($nGy\ h^{-1}$) ×8760 (h/y)×0.2×0.7 Sv/G×$10^{-6}$ ……9**

**Excess lifetime cancer risk**

Excess lifetime cancer risk (ELCR); defined as the excess probability of developing cancer at a lifetime due to the radiation exposure levels. The ELCR is calculated using the below equation (Olga et al., 2019).

**ELCR= AEDE × DL x RF …….10**

Where, AEDE, DL and RF are the annual effective dose equivalent, the average duration of human life (70 years) and risk factor respectively. The value of risk factor in the public is 0.05 per Sievert as recommended by ICRP for stochastic effects (Olga et al., 2019; Vahid et al., 2013).

**Annual Gonadal Dose Equivalent, AGDE**

The effect of radio-activity on the bone marrow and its surface cells is interesting that is reported by (UNSCEAR, 2000), therefore, annual dose equivalent applied on endocrine according to the concentra-tions of $^{226}Ra$, $^{232}Th$, $^{40}K$ is calculated in each sample by (Vahid et al., 2013).

**AGDE ($\mu Sv.y^{-1}$) =3.09 ARa +4.18 ATh+ 0.314 AK…11**

**Minimum detectable activity MDA**

The detection limit (minimum detectable activity). The detection limit for each radionuclide was calculated separately for each sample based on the sample weight as reported below.grahm (Alharshana et al., 2017). Minimum Detection Limit (MDA) of gamma ray system at 95 % confidence level calculation modules software based on the equation taken from.This was as followed:

$$MDA(Bq/kg) = \frac{4.66 \times \sqrt{B}}{\varepsilon \times P_\gamma \times T \times M}$$

Where B is the background counts, ε is the absolute efficiency of the detector, Pγ is the gamma emission probability, T is the counting time, and M is the mass of the sample assuming an average mass of all samples equal to 0.12 kg (Eric et al., 2016; Fatimh & El-Taher, 2019).

### Effective doses due to ingestion

Annual effective dose equivalent (AEDE) due to ingestion of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in drinking water was assessed using Equation (13) (Nisar et al., 2018).

$$\mathrm{AEDE} = A_w \times I_A \times E$$

Where Aw (Bq. $l^{-1}$) is natural concentration of radioactivity in water, IA (l. $y^{-1}$) is the annual intake of drinking water and E (Sv $Bq^{-1}$) is ingested effective dose conversion factor for natural radioactivity. The values of dose conversion factor **E** were taken from EC Directive 96/29 ($4.7 \times 10^{-6}$ (infants), $6.2 \times 10^{-7}$ (children) and $2.8 \times 10^{-7}$ mSv $y^{-1}$ (adults) for $^{226}Ra$ and $6.2 \times 10^{-8}$ (infants), $2.1 \times 10^{-8}$ (children) and $6.2 \times 10^{-9}$ mSv $y^{-1}$ (adults) for $^{40}K$. For $^{232}Th$ these values are $7.4 \times 10^{-9}$ (infants), $1.4 \times 10^{-9}$ (children) and $4.3 \times 10^{-10}$ mSv $y^{-1}$ (adults) (Mohsin & Muttaleb, 2016).

# Results And Discussion

### Activity concentrations of radionuclides in water

The activity concentrations of $^{226}Ra$, $^{232}Th$, and $^{40}K$ were ascertained in water samples. The present study examined the distribution of naturally occurring radionuclides $^{226}Ra$, $^{232}Th$ and $^{40}K$, in water. Table 4 with Figure 2, presents the results of activity concentrations of natural radionuclides of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in water samples taken from 20 different locations such as (Shorja, Azady, Arafa, Horya, Ahmad aqha, Tapa, Rahym awa, Eskan, Musalah, Emam –Qasm, Qadseay Yeak, Hay Askari, Hay Qharnata, Qadseay Dwo, Hay Wasty, Hay Nasr, Zeeawiah, Panja Ali, Roonaky, Preeady), of Kirkuk-Iraq. That were ranged from (140.845 to 89.428) mBq.$L^{-1}$with an average value of 121.952 mBq.$L^{-1}$of $^{226}Ra$, from (106.894 to 47.398) mBq.$L^{-1}$with an average value of 81.523 mBq.$L^{-1}$of $^{232}Th$, and from (1550.516 to 379.551) mBq.$L^{-1}$with an average value of 1091.375 mBq.$L^{-1}$ $^{40}K$. From Table 4 the results show that the mean activity concentration values of $^{226}Ra$, $^{232}Th$ and $^{40}K$ were lower than the world average values suggested by UNSCEAR: 35, 30, 400 Bq.$kg^{-1}$, respectively) (UNSCEAR, 2000). The data showed that the average value of activity concentration of $^{40}K$ in the samples (1091.375 mBq.$L^{-1}$) is higher than the one of $^{232}Th$ (81.523 mBq.$L^{-1}$) and $^{226}Ra$ (121.952 mBq.$L^{-1}$).

Table 1 shows significant variations between the average activity concentrations of $^{226}Ra$, $^{232}Th$ and $^{40}K$ in the examined samples, where the average estimations of $^{226}Ra$ fluctuate between the maximum activity concentration in (Qadseay Dwo) and the minmum activity concentration in (Hay Qharnata), the average estimations of $^{232}Th$ fluctuate between the maximum activity concentration in (Qadseay Dwo) and the minmum activity concentration in (Roonaky), the average estimations of $^{40}K$ fluctuate between the maximum activity concentration in (Roonaky) and the minmum activity concentration in (Hay Qharnata) that is agree with (Nisar et al., 2018). As shown the results in this table, the radioactivity in water samples varied from one locaition to another depends on the locality geological conditions. The measured activities of $^{226}Ra$ in the samples did not exceed the guidance level recommended by (Mohsin & Muttaleb, 2016; WHO, 2011).

**Table 4** Radioactivity concentration ($mBq.L^{-1}$) of $^{232}Th$, $^{226}Ra$, and $^{40}K$

| No. | Locations | Code of Samples | Radioactivit concentration ($mBq.L^{-1}$) of $^{232}Th$, $^{226}Ra$, and $^{40}K$ | | |
|---|---|---|---|---|---|
| | | | Th ($mBq.L^{-1}$) | Ra ($mBq.L^{-1}$) | K ($mBq.L^{-1}$) |
| 1 | Shorja | SW01 | 105.673 | 140.421 | 482.098 |
| 2 | Hay Qharnata | SW02 | 66.137 | 89.428 | 379.551 |
| 3 | Azady | SW03 | 75.868 | 114.424 | 852.900 |
| 4 | Arafa | SW04 | 104.424 | 118.974 | 1190.301 |
| 5 | Horya | SW05 | 50.224 | 118.929 | 966.3128 |
| 6 | Ahmad aqha | SW06 | 91.656 | 128.425 | 1206.432 |
| 7 | Tapa | SW07 | 54.043 | 124.848 | 1162.982 |
| 8 | Rahym awa | SW08 | 100.218 | 122.022 | 1236.289 |
| 9 | Qadseay Dwo | SW09 | 106.894 | 140.845 | 976.782 |
| 10 | Musalah | SW10 | 53.255 | 138.244 | 1315.591 |
| 11 | Emam –Qasm | SW11 | 92.404 | 122.287 | 1302.99 |
| 12 | Eskan | SW12 | 101.814 | 124.741 | 1145.676 |
| 13 | Qadseay Yeak | SW13 | 88.493 | 128.972 | 1213.166 |
| 14 | Hay Askari | SW14 | 75.589 | 114.057 | 1144.541 |
| 15 | Hay Wasty | SW15 | 91.144 | 130.015 | 1204.174 |
| 16 | Hay Nasr | SW16 | 93.133 | 102.005 | 1084.195 |
| 17 | Zeeawiah | SW17 | 85.049 | 131.681 | 1122.327 |
| 18 | Panja Ali | SW18 | 85.058 | 126.267 | 1328.145 |
| 19 | Roonaky | SW19 | 47.398 | 135.851 | 1550.516 |
| 20 | Preeady | SW20 | 61.989 | 96.606 | 962.538 |
| | | Ave. | 81.523 | 121.952 | 1091.375 |
| | | Mix | 106.894 | 140.845 | 1550.516 |
| | | Min. | 47.398 | 89.428 | 379.551 |

To obtain uranium concentration content in the water samples, the value of $^{238}U$ concentrations in ppm were calculated using (1 ppm of $^{238}U$ =12.25 $Bq.Kg^{-1}$), the concentration contents of $^{238}U$ is ranged from (1.104 to 1.734) ppm with an average value of 1.506 ppm, the value of $^{232}Th$ concentration in ppm was calculated

using 1ppm ($^{232}$Th = 4.10 Bq.Kg$^{-1}$), the concentration of $^{232}$Th is ranged from (0.192 to 0.434) ppm with an average value of 0.331 ppm, and the concentration contents of $^{40}$K is ranged from (118.799 to 485.311) ppm with an average value of 341.601 ppm, as shown in Table 5.

The values of concentration followed by contents of concentration in 84% for $^{40}$K with average in 341.6005 ppm, 10 % for $^{232}$Th with average in 0.3309 ppm , and 16% for $^{226}$Ra ($^{238}$U) with average in 1.5061 ppm as shown in Table 5 and Figure 3. From the results found that the higher and lower values of radium, thorium and potasium in the drinking water samples in locations (Eskan) and (Hay Qharnata) have been found to be (0.363) ppm, (0.119) ppm, have been found to be (0.363) ppm, (0.119) ppm in the locations (Qadseay Dwo) and (Eskan) and have been found to be (1.864) ppm, (0.523) ppm, respectively. The results obtained were generally lower than the normal levels (which is lower than the normal rate of uranium concentration in nature that reaches (2-2.8) ppm and reaches (6-10) ppm in thorium (Mohammed, 2003). this considers as a secure situation for human environmental safety in the region so it has no danger on human is life. The aim of the present study is to measure the radioactivity concentration of radium, thoriom and potasium in drinking water in Kirkuk city. The reason for vibration in radon concentration could be a function of geological structure of the area, depth of the water source, also differences in the climate (Ali et al., 2019; Najeba et al., 2015). It was also observed that the concentration of $^{40}$K measured markedly exceeds the values of both radium and thorium, as it is the most abundant radioactive element considered.

**Table 5** Radioactivity concentration (ppm) of $^{232}$Th, $^{226}$Ra, and $^{40}$K

| No. | Code of Samples | Radioactivity concentration (ppm) of $^{232}Th$, $^{226}Ra$, and $^{40}K$ | | |
|---|---|---|---|---|
| | | Th(ppm) | Ra(ppm) | K(ppm) |
| 1 | SW01 | 0.429032 | 1.734199 | 150.8967 |
| 2 | SW02 | 0.268516 | 1.104436 | 118.7995 |
| 3 | SW03 | 0.308024 | 1.413136 | 266.9577 |
| 4 | SW04 | 0.423961 | 1.469329 | 372.5642 |
| 5 | SW05 | 0.203909 | 1.468773 | 302.4559 |
| 6 | SW06 | 0.372123 | 1.586049 | 377.6132 |
| 7 | SW07 | 0.219415 | 1.541873 | 364.0134 |
| 8 | SW08 | 0.406885 | 1.506972 | 386.9585 |
| 9 | SW09 | 0.43399 | 1.615936 | 305.7328 |
| 10 | SW10 | 0.216215 | 1.707313 | 411.7800 |
| 11 | SW11 | 0.37516 | 1.510244 | 407.8359 |
| 12 | SW12 | 0.413365 | 1.540551 | 358.5966 |
| 13 | SW13 | 0.359282 | 1.592804 | 379.7210 |
| 14 | SW14 | 0.306891 | 1.408604 | 358.2413 |
| 15 | SW15 | 0.370045 | 1.605685 | 376.9065 |
| 16 | SW16 | 0.37812 | 1.259762 | 339.3530 |
| 17 | SW17 | 0.345299 | 1.62626 | 351.2884 |
| 18 | SW18 | 0.345335 | 1.559397 | 415.7094 |
| 19 | SW19 | 0.192436 | 1.67776 | 485.3115 |
| 20 | SW20 | 0.251675 | 1.193084 | 301.2744 |
| Ave. | | 0.330984 | 1.506108 | 341.6005 |
| Mix. | | 0.43399 | 1.734199 | 485.3115 |
| Min. | | 0.192436 | 1.104436 | 118.7995 |

The activity concentrations radionuclide of $^{226}Ra$ were found to be slightly higher (but not significant) than that of $^{232}Th$, which may be attributed to the fact that $^{226}Ra$ is more soluble than $^{232}Th$ in water Whereas, the concentrations of $^{40}K$ was very much higher than $^{226}Ra$ and $^{232}Th$ because of its natural abundance that is agree with (Nisar et al., 2018). Potassium is an abundant element in all environmental media including water.

However, the isotope $^{40}K$ is radiologically less important compared to radium isotopes because it is homeostatically controlled in the human bodyand also an essential element (Nisar et al., 2018).

### Correlation between $^{226}Ra$, $^{232}Th$ and $^{40}K$

The values of ratio of specific activity concentrations of $^{232}Th$, $^{226}Ra$, $^{40}K$ for all samples ranged from (0.348 to 0.913) with a mean value 0.673 of $^{232}Th/^{226}Ra$, from (3.433 to 11.413) with a mean value 8.933 of $^{40}K/^{226}Ra$, and from (4.562 to 32.712) with a mean value 14.457 of $^{40}K$ / $^{232}Th$, a low $^{232}Th/^{226}Ra$ ratio (0.348) was recorded, which could be related to the systematic loss of thorium during the fabrication process that is agree with (Saifeldin et al., 2018).

A positive correlation between $^{226}Ra$ and $^{232}Th$ in the investigated samples was identified from the observed significant correlation, as showed in Table 6.

**Table 6** Ratio of specific activity of $^{232}Th$, $^{226}Ra$, and $^{40}K$

| No. | Code of Samples | Ratio of specific activity of $^{232}Th$, $^{226}Ra$, and $^{40}K$ | | |
|---|---|---|---|---|
| | | $^{232}Th/^{226}Ra$ | $K/\ ^{226}Ra^{40}$ | $^{40}K\ /^{232}Th$ |
| 1 | SW01 | 0.752 | 3.433 | 4.562 |
| 2 | SW02 | 0.739 | 4.244 | 5.738 |
| 3 | SW03 | 0.663 | 7.454 | 11.241 |
| 4 | SW04 | 0.877 | 10.004 | 11.398 |
| 5 | SW05 | 0.422 | 8.125 | 19.240 |
| 6 | SW06 | 0.713 | 9.394 | 13.162 |
| 7 | SW07 | 0.433 | 9.315 | 21.519 |
| 8 | SW08 | 0.821 | 10.131 | 12.336 |
| 9 | SW09 | 0.817 | 7.465 | 9.137 |
| 10 | SW10 | 0.385 | 9.516 | 24.703 |
| 11 | SW11 | 0.755 | 10.655 | 14.101 |
| 12 | SW12 | 0.816 | 9.184 | 11.252 |
| 13 | SW13 | 0.686 | 9.406 | 13.709 |
| 14 | SW14 | 0.662 | 10.034 | 15.141 |
| 15 | SW15 | 0.701 | 9.262 | 13.212 |
| 16 | SW16 | 0.913 | 10.628 | 11.641 |
| 17 | SW17 | 0.645 | 8.523 | 13.196 |
| 18 | SW18 | 0.673 | 10.518 | 15.614 |
| 19 | SW19 | 0.348 | 11.413 | 32.712 |
| 20 | SW20 | 0.641 | 9.963 | 15.527 |
| | Ave. | 0.673 | 8.934 | 14.457 |
| | Mix | 0.913 | 11.413 | 32.712 |
| | Min. | 0.348 | 3.433 | 4.562 |

## Evaluation of radiological hazard parameters

### Radium equivalent activity

The activity levels of $^{238}U$, $^{232}Th$ and $^{40}K$ are not uniformly distributed in water samples. Hence, the water samples would be examined by radium equivalent activity (Raeq). The acceptable maximum value of the radium equivalent activity is 370 $Bq.kg^{-1}$ **(**Abdalrahman & Riyadh,. 2019), therefore**,** The maximum value of

Raeq, in water samples must be less than 370 $Bq.kg^{-1}$ in order to be considered safe for use (ICRP, 1996). From Table 7, radium equivalent activity (Raeq) varied from (223.2445 to 369.9037) $mBq.kg^{-1}$ with a mean of 339.9506 $mBq.kg^{-1}$ which is less, lower than the worldwide average. These values are far below the allowable limit (370 $Bq.kg^{-1}$) recommended by the International Atomic Energy Agency (IAEA) (ICRP, 1996; Altaf & Nasima, 2015).

This study shows that the water samples in the kirkuk region do not have a biological danger that is agree with, it is clear that the values of in all samples were much less than the safe value 370 $Bq.kg^{-1}$ (Samat et al., 2012) which is equivalent to an external dose of 1.5$mSvy^{-1}$. Therefore, the water samples are within an acceptable safe limit (Nisar et al., 2018).

The Calculated values of the (Hex) of water samples are presented in Table 7. The total absorbed dose rate were varied from (96.1 to 321.2) nGy $h^{-1}$ with an average of 188.2 ± 59.4 $nGy.h^{-1}$ of radium. The obtained mean value is over 3.14 times than the reported population-weighted mean value of 60 nGy $h^{-1}$ for regular area given by (UNSCEAR, 2000). The mean value of absorbed dose for water samples is 9.62 nGy $h^{-1}$ and it is lower than the global average value of 55 $nGy.h^{-1}$. This difference in absorbed dose rate with the reported values of UNSCEAR could be attributed to differences in geology formation of area under study and geochemical structure of the sampling sites (Eric et al., 2016).

The calculated values of the external hazard (Hex) of water samples are presented in Table 7 that were ranged from 0.575 to 0.973 with a mean value of 0.871. Also, the internal hazard (Hin), its values ranged from 0.562 to 0.995 with a mean value of 0.881. All the samples had an internal hazard values below the recommended limit of 1.0 which implies that these samples are suitable to drinking by populations.

The mean value of the index of radiation risk Heks is 0.05 which shows that in the surrounding of Skopje there is no significant radiation risk for the population. The values of the external danger index obtained in this study, regardless of the location, did not exceed the security limits, pointing out the insignificant danger for radiation which arises from water radionuclides which are naturally present.

The estimated Dout ($nGy.h^{-1}$) values varied from 98.143 to 169.870 with the mean value was calculated to be 152.191 $nGy.h^{-1}$ within the typical range of worldwide average values (18 - 93) $nGy.h^{-1}$ reported in (UNSCEAR, 2000). And the estimated Din ($nGy.h^{-1}$) values varied from 185.388 to 321.403 with the mean value was calculated to be 289.181 $nGyh^{-1}$, in the water samples, respectively. The maximum value of the gamma index is neer around unity (1.177) as showed in the table 7 like reported by (ICRP, 1996). (Abdalrahman & Riyadh, 2019), also alpha index The internal alpha index Iα is rising because of the radon inhalation as shown in the Table 7 (Abdalrahman & Riyadh, 2019).

**Table 7** Evaluation of radiological hazard parameters of the water samples

| No. | Code of Samples | Outdoor hazard index | | | | Indoor hazard index | | |
|---|---|---|---|---|---|---|---|---|
| | | **Raeq** $mBq.L^{-1}$ | **Hex** | **Dout** $(nGy.h^{-1})$ | **Iγ** | **Hin** | **Din** $(nGy.h^{-1})$ | **Iα** |
| 1 | SW01 | 343.5966 | 0.8877 | 150.5272 | 1.1571 | 0.8596 | 283.9955 | 0.7021 |
| 2 | SW02 | 223.2445 | 0.5759 | 98.14307 | 0.7552 | 0.5625 | 185.3885 | 0.4471 |
| 3 | SW03 | 305.1676 | 0.7795 | 135.3253 | 1.0450 | 0.7961 | 256.9569 | 0.5721 |
| 4 | SW04 | 366.210 | 0.9722 | 169.1816 | 1.3154 | 0.8909 | 319.5466 | 0.5948 |
| 5 | SW05 | 294.6986 | 0.7162 | 126.1212 | 0.9696 | 0.8439 | 241.9661 | 0.5946 |
| 6 | SW06 | 368.199 | 0.9518 | 166.2519 | 1.2885 | 0.9453 | 315.4872 | 0.6421 |
| 7 | SW07 | 322.1253 | 0.7878 | 139.3712 | 1.0740 | 0.9168 | 267.346 | 0.6242 |
| 8 | SW08 | 369.9037 | 0.9737 | 169.8703 | 1.3199 | 0.9169 | 321.4032 | 0.6101 |
| 9 | SW09 | 369.2146 | 0.9694 | 167.3533 | 1.2962 | 0.9107 | 316.1034 | 0.6542 |
| 10 | SW10 | 352.2444 | 0.8527 | 151.3738 | 1.1656 | 0.9821 | 291.0123 | 0.6912 |
| 11 | SW11 | 367.6046 | 0.9582 | 167.8858 | 1.3039 | 0.9322 | 318.3876 | 0.6114 |
| 12 | SW12 | 368.4107 | 0.9684 | 168.3667 | 1.3067 | 0.9128 | 318.4112 | 0.6237 |
| 13 | SW13 | 366.3367 | 0.9424 | 164.8123 | 1.2767 | 0.9497 | 313.0498 | 0.6448 |
| 14 | SW14 | 326.8202 | 0.8381 | 147.0562 | 1.1396 | 0.8547 | 279.6436 | 0.5703 |
| 15 | SW15 | 369.7868 | 0.9536 | 166.5724 | 1.2904 | 0.9535 | 316.2061 | 0.6501 |
| 16 | SW16 | 322.4832 | 0.8606 | 149.9318 | 1.1670 | 0.7771 | 283.0265 | 0.5101 |
| 17 | SW17 | 359.772 | 0.9176 | 160.1548 | 1.2382 | 0.9454 | 304.4866 | 0.6584 |
| 18 | SW18 | 367.887 | 0.9458 | 166.1854 | 1.2888 | 0.9589 | 315.981 | 0.6313 |
| 19 | SW19 | 361.0547 | 0.8725 | 156.3476 | 1.2066 | 0.9956 | 301.162 | 0.6792 |
| 20 | SW20 | 274.251 | 0.7005 | 123.0036 | 0.9528 | 0.7225 | 234.0685 | 0.4830 |

The annual effective dose (3.25 to 12.60) $\mu Sv.y^{-1}$ caused criterion limit of 1 $mSv.y^{-1}$. Hence, yet pose no significant threat to the ecosystem, public health (Hossain et al., 2019).

Mean value of annual effective dose rate of 0.55 mSv. $h^{-1}$ is slightly higher than the world mean value which is 0.48 $mSv.h^{-1}$ recommended by UNSCEAR (Fatimh & El-Taher, 2019). But the obtained value is less than the recommended limit established by ICRP which is 1 mSv. $h^{-1}$ (Kakhaber et al., 2019). Based on measured activity concentrations of $^{222}Rn$, the calculated values of annual effective dose AEDE total were calculated as shown in Table 8. The AEDE from radon ranged between minimum and maximum values 208.329 and 120.3627 $\mu Sv.y^{-1}$ with an average value of 186.648 $\mu Sv.y^{-1}$.The recommended upper

limit of 1 $mSv.y^{-1}$ is not exceeded in all samples. This means that these rock samples are safety for human health (Nisar et al., 2018).

From the Table 8 the values of ELCR are ranged from 0.421 to 0.729 with an average value of 0.653. The results obtained show that the AEDE and ELCR in all water samples appeared lower than the world average values. The value of risk factor in the public is 0.05 per Sievert as recommended by ICRP for stochastic effects (Abdalrahman & Riyadh, 2019).The excess lifetime cancer risk (ELCR) have been calculated, its values were higher than the world's average value of ($0.29x\ 10^{-3}$). Also from Table 8 the values of AGDE is ranged from (67.964 to 118.415) $\mu Sv.y^{-1}$ with a mean value of 106.291 $\mu Sv.y^{-1}$ these values is a lower than the world average values 300 $\mu Sv.y^{-1}$.

**Table 8** The annual effective dose and the excess lifetime cancer risk on the public health

| Code of Samples | Dose ($nGy.h^{-1}$) | AEDE $x10^{-3}$ ($mSv.y^{-1}$) | ELCR $x10^{-3}$ | AGDE ($\mu Sv.y^{-1}$) |
|---|---|---|---|---|
| SW01 | 150.5272 | 184.6066 | 646.123 | 102.993 |
| SW02 | 98.14307 | 120.3627 | 421.2693 | 67.964 |
| SW03 | 135.3253 | 165.9629 | 580.8703 | 93.509 |
| SW04 | 169.1816 | 207.4843 | 726.1952 | 117.876 |
| SW05 | 126.1212 | 154.675 | 541.3625 | 88.849 |
| SW06 | 166.2519 | 203.8913 | 713.6196 | 115.775 |
| SW07 | 139.3712 | 170.9248 | 598.2368 | 97.856 |
| SW08 | 169.8703 | 208.329 | 729.1514 | 118.154 |
| SW09 | 167.3533 | 205.2421 | 718.3472 | 115.838 |
| SW10 | 151.3738 | 185.6448 | 649.7570 | 106.875 |
| SW11 | 167.8858 | 205.8951 | 720.6329 | 117.254 |
| SW12 | 168.3667 | 206.4849 | 722.6973 | 117.774 |
| SW13 | 164.8123 | 202.1258 | 707.4403 | 114.358 |
| SW14 | 147.0562 | 180.3497 | 631.2241 | 102.784 |
| SW15 | 166.5724 | 204.2844 | 714.9955 | 116.839 |
| SW16 | 149.9318 | 183.8764 | 643.5674 | 104.929 |
| SW17 | 160.1548 | 196.4139 | 687.4485 | 111.811 |
| SW18 | 166.1854 | 203.8098 | 713.3343 | 116.745 |
| SW19 | 156.3476 | 191.7447 | 671.1066 | 114.765 |
| SW20 | 123.0036 | 150.8516 | 527.9806 | 85.863 |
| Ave. | 152.1918 | 186.648 | 653.268 | 106.291 |
| Mix. | 169.8703 | 208.329 | 729.1514 | 118.154 |
| Min. | 98.14307 | 120.363 | 421.2693 | 67.964 |

**Resulting in the minimum detectable activity (MDA) in Radionuclide**

The activity concentrations of radium, thorium and potasium in the water samples are given in the Table 1. A less than sign (<) was used to indicate the below MDA values of the detector. The minimum detectable activity for each radionuclide was 1.97 $mBq.L^{-1}$ for $^{226}Ra$, 0.91 $mBq.L^{-1}$ for $^{232}Th$ and 0.38 $mBq.L^{-1}$ for $^{40}K$, as shown in both Tables ( 9,10).

**Table 9** The (Ave., Mix., and Min.) detectable activity (MDA) in radionuclide

| Case of radionuclides | $^{226}Ra$ | $^{232}Th$ | $^{40}K$ |
|---|---|---|---|
| MDA ($mBq.L^{-1}$) | 1.97 | 0.91 | 0.38 |
| Ave. Concentration ($mBq.L^{-1}$) | 121.952 | 81.523 | 1091.375 |
| Mix Concentration ($mBq.L^{-1}$) | 140.421 | 106.894 | 1550.516 |
| Min. Concentration ($mBq.L^{-1}$) | 89.428 | 47.398 | 379.551 |

**Table 10** The detectable activity (MDA) in radionuclide

| Radionuclide | Energy (keV) | MDA ($Bq.L^{-1}$) |
|---|---|---|
| $^{212}Bi$ | 727.33 | 0.49284 |
| $^{212}Pb$ | 238.63 | 0.15709 |
| $^{228}Ac$ | 911.20 | 3.10816 |
| | 968.97 | 2.46953 |
| $^{208}Tl$ | 510.77 | 0.18143 |
| | 583.19 | 0.44443 |
| | 860.56 | 0.23338 |
| | 2614.53 | 0.21398 |
| $^{214}Bi$ | 609.31 | 1.07910 |
| | 1120.28 | 1.16107 |
| | 1764.49 | 1.11676 |
| $^{214}Pb$ | 295.22 | 3.35913 |
| | 351.93 | 3.13970 |
| $^{40}K$ | 1460.83 | 38.1853 |

## Results of pH and Electrical Conductivity

A lower pH indicates acidity while a higher pH indicates alkalinity because PH is the measure of the acidity or alkalinity of a solution. A pH value of 7 is considered normal. This study measured the pH of 20 drinking water samples, Table 1 presented the pH, and concuctivity of the drinking water, the results indicate that the pH of different drinking water samples ranged from 4.67 (highly acidic) in SW04 to 8.49 (highly basic) in SW13 with an average (6.77/ considered normal) at the 22.5˚C that is agree with presented study (Kenya et al., 2014) which tended toward an normal behavior. The pH has effects on enamel, the low pH and high acid concentrations lead to adverse side effects such as enamel erosion. a low or high pH for an a long period of time may cause harmful side effects. cause enamel erosion (Richard et al., 2000). A nother experimental was achieved on the 20 of drinking water samples to know the electrical conductivity, the results indicate that the conductivity varied from (0.18 $mS.cm^{-1}$) in SW02 to (0.37 $mS.cm^{-1}$) in SW13 with an average of conductivity of the samples was (0.27) at the 22.5 ˚C, as showed in Table 1.

## Effective doses due to ingestion

According to an UNSCEAR report in 2000, the ingestion of drinking water was estimated (UNSCEAR, 2000) report to be 100, 75, and 50 l $y^{-1}$ for infants, children, and adults, respectively. Assuming the proportion of these groups in the population to be 0.05, 0.3 and 0.65, the estimated weight of consumption was determined as 60 l $y^{-1}$ (UNSCEAR, 2000; Nisar et al., 2018).

In addition, for exposure to radon from ingestion, annual effective doses from $^{226}Ra$, $^{232}Th$ and $^{40}K$ and $^{222}Rn$ were separately calculated for infants, children and adults. Annual effective dose due to intake of $^{232}Th$ ranged from 0.3507 to 0.7910 μSv.$y^{-1}$ with an average of 0.6032 μSv.$y^{-1}$ for infants (0–1 y), ranged from 0.0663 to 0.1496 μSv.$y^{-1}$ with an average of 0.1141μSv.$y^{-1}$ for children (2–7 y) and ranged from 0.0203 to 0.0459 μSv.$y^{-1}$ with an average of 0.0350μSv.$y^{-1}$ for adults (>17 y), respectively. Similarly, Annual effective dose due to intake of $^{226}Ra$ ranged from 42.03 to 65.99 μSv. $y^{-1}$ with an average of 57.312 μSv.$y^{-1}$ for infants (0–1 y), ranged from 5.54 to 8.70 μSv.$y^{-1}$ with an average of 7.557 μSv.$y^{-1}$ for children (2–7 y) and ranged from 2.5039 to 3.9317 μSv.$y^{-1}$ with an average of 3.4146μSv.$y^{-1}$ for adults (>17 y), respectively, also the annual effective dose due to intake of $^{40}K$ ranged from 0.0235 to 0.0961 μSv.$y^{-1}$ with an average of 0.0676 μSv.$y^{-1}$ for infants (0–1 y), ranged from 0.0079 to 0.0325 μSv.$y^{-1}$ with an average of 0.0229 μSv.$y^{-1}$ for children (2–7 y) and ranged from 0.0026 to 0.0107 μSv.$y^{-1}$ with an average of 0.0075 μSv.$y^{-1}$ for adults (>17 y), respectively. The age-dependent annual effective doses due to ingestion of $^{226}Ra$, $^{222}Rn$ $^{232}Th$ and $^{40}K$ were found to be below the WHO permissible limit of 0.1 mSv.$y^{-1}$ for all ages (WHO, 2011) the most radiotoxic radionuclide is radium because 20% of ingested radium is absorbed into the bloodstream and then distributed to bones and soft tissues. Tables (11, 12) with the Figure 4, and Figure 5, shows that average annual effective dose due to the intake of $^{226}Ra$ is higher for infants than children and adults (infants> children> adults). This study shows that infants are more vulnerable and comparatively at risk due to the intensive growth of bone.

**Table 11** Effective doses due to ingestion

| Code of Sam. | Ingestion of $^{232}$Th (μSv.y$^{-1}$) | | | (μSv.y$^{-1}$)Ra Ingestion of $^{226}$ | | | Ingestion of $^{40}$K (μSv.y$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Infants (0–1 y) | Children (2–7 y) | Adults (>17 y) | Infants (0–1 y) | Children (2–7 y) | Adults (>17 y) | Infants (0–1 y) | Children (2–7 y) | Adults (>17 y) |
| SW01 | 0.7819 | 0.1479 | 0.0454 | 65.99 | 8.7 | 3.9317 | 0.0298 | 0.0101 | 0.0033 |
| SW02 | 0.4894 | 0.0925 | 0.0284 | 42.03 | 5.54 | 2.5039 | 0.0235 | 0.0079 | 0.0026 |
| SW03 | 0.5614 | 0.1062 | 0.0326 | 53.77 | 7.09 | 3.2038 | 0.0528 | 0.0179 | 0.0058 |
| SW04 | 0.7727 | 0.1461 | 0.0449 | 55.91 | 7.37 | 3.3312 | 0.0737 | 0.0249 | 0.0082 |
| SW05 | 0.3716 | 0.0703 | 0.0215 | 55.89 | 7.37 | 3.3300 | 0.0599 | 0.0202 | 0.0066 |
| SW06 | 0.6782 | 0.1283 | 0.0394 | 60.35 | 7.96 | 3.595 | 0.0747 | 0.0253 | 0.0083 |
| SW07 | 0.3999 | 0.0756 | 0.0232 | 58.67 | 7.74 | 3.4957 | 0.0721 | 0.0244 | 0.0080 |
| SW08 | 0.7416 | 0.1403 | 0.0431 | 57.35 | 7.56 | 3.4166 | 0.0766 | 0.0259 | 0.0085 |
| SW09 | 0.7910 | 0.1496 | 0.0459 | 61.49 | 8.11 | 3.6636 | 0.0605 | 0.0205 | 0.0067 |
| SW10 | 0.3940 | 0.0745 | 0.0229 | 64.97 | 8.57 | 3.8708 | 0.0815 | 0.0276 | 0.0091 |
| SW11 | 0.6837 | 0.1293 | 0.0397 | 57.47 | 7.58 | 3.4240 | 0.0807 | 0.0273 | 0.0089 |
| SW12 | 0.7534 | 0.1425 | 0.0437 | 58.62 | 7.73 | 3.4927 | 0.0710 | 0.0240 | 0.0079 |
| SW13 | 0.6548 | 0.1238 | 0.0380 | 60.61 | 7.99 | 3.6112 | 0.0752 | 0.0254 | 0.0084 |
| SW14 | 0.5593 | 0.1058 | 0.0325 | 53.60 | 7.07 | 3.1935 | 0.0709 | 0.0240 | 0.0078 |
| SW15 | 0.6744 | 0.1276 | 0.0391 | 61.10 | 8.06 | 3.6404 | 0.0746 | 0.0252 | 0.0083 |
| SW16 | 0.6891 | 0.1303 | 0.0400 | 47.94 | 6.32 | 2.8561 | 0.0672 | 0.0227 | 0.0075 |
| SW17 | 0.6293 | 0.1191 | 0.0365 | 61.89 | 8.16 | 3.6870 | 0.0695 | 0.0235 | 0.0077 |
| SW18 | 0.6294 | 0.1190 | 0.0364 | 59.34 | 7.82 | 3.5354 | 0.0823 | 0.0278 | 0.0092 |
| SW19 | 0.3507 | 0.0663 | 0.0203 | 63.85 | 8.42 | 3.8038 | 0.0961 | 0.0325 | 0.0107 |
| SW20 | 0.4587 | 0.0867 | 0.0266 | 45.40 | 5.98 | 2.7049 | 0.0596 | 0.0202 | 0.0066 |
| Ave. | 0.6032 | 0.1141 | 0.0350 | 57.32 | 7.56 | 3.4146 | 0.0676 | 0.0229 | 0.0075 |
| Max. | 0.7910 | 0.1496 | 0.0459 | 65.99 | 8.70 | 3.9317 | 0.0961 | 0.0325 | 0.0107 |
| Min. | 0.3507 | 0.0663 | 0.0203 | 42.03 | 5.54 | 2.5039 | 0.0235 | 0.0079 | 0.0026 |

The values of specific activity and the calculated doses obtained in this study, did not exceed the safety limits, therefore, there is the insignificant danger for radiation which arises from the radionuclides in the water samples When choosing the methods of possible decontamination, one must pay attention to the half-life of

the radioactive isotopes. These results can be used as reference values for current assessment of doses due to natural radioactivity in the surrounding of the city of Kirkuk.

From the radioactivity analysis all values of the samples under the test are below of permissible values 370 $Bq.kg^{-1}$of radium content, recommended by Organization for Economic Cooperation and Development (OECD). Hence the area under investigation is safe as for as health hazards of radium and safe in radiological risks due to radium exposure from the water. But for this study the results of the specific activity of $^{226}Ra$, $^{232}Th$, $^{40}K$ (from this study have been found to be lower than) measured to be lower than the recommended reference limits by (UNSCEAR, 2000), 32 $Bq.kg^{-1}$ and 45 $Bq.kg^{-1}$, 412 $Bq.kg^{-1}$) (Ali et al., 2019; UNSCEAR, 2000).

On the other hand, relatively increased levels of $^{40}K$ were found in variation of radioactivity. It can be seen that the radium, thorium and potasium in the water samples changed from location to other. This variation in the concentration of radionuclides content in each water sample may be due to different degrees of agitation and change in meteorological parameters (Najeba et al., 2019).

**Table 12** Effective doses due to ingestion by radionuclides

| Parents | Case of radionuclides | Infants (0–1y) ($\mu Sv.y^{-1}$) | Children (2–7 y) ($\mu Sv.y^{-1}$) | Adults (>17y) ($\mu Sv.y^{-1}$) |
|---|---|---|---|---|
| $^{226}Ra$ | Minimum | 42.032 | 5.541 | 2.504 |
| | Maximum | 65.993 | 8.706 | 3.931 |
| | Average | 57.312 | 7.557 | 3.414 |
| $^{232}Th$ | Minimum | 0.351 | 0.066 | 0.020 |
| | Maximum | 0.791 | 0.149 | 0.046 |
| | Average | 0.603 | 0.114 | 0.035 |
| $^{40}K$ | Minimum | 0.0235 | 0.008 | 0.003 |
| | Maximum | 0.096 | 0.032 | 0.011 |
| | Average | 0.067 | 0.023 | 0.007 |
| | Av. Cumulative | 18.58 | 2.466 | 1.108 |

# Conclusions

In the present work, all Hex values were below unity in order for the safe, the Hex and Hin should be less than unity. Equivalent Activities and Internal Hazard Index (Hin) values for all the samples are below therecommended value of 370 $Bq.kg^{-1}$ and one, respectively. These values of Raeq are far below the allowable limit (370 $Bq.kg^{-1}$) recommended by the International Atomic Energy Agency (IAEA).The calculated Hex values for all samples should be below unity, which does not cause harm to the populations of the

investigated regions. Also, it is found that the average annual effective dose from natural radioactivity turn out to be below the reference value of 1.0 $mSv.y^{-1}$ recommended by ICRP for all ages. The results showed that the mean concentration values of radionuclides in water samples have declined in some sites of the investigated area, although this decline was not observed at some sites. The current data could therefore be useful in the monitoring of radioactive pollution in the water in environment of the kursiaian (kirkuk) in the future.The obtained results were compared with the standard accepted international values, and found to be within the acceptable limits. The obtained results can be contributed to the baseline data of radionuclide concentrations in this area. These results can be contributed to the data base of this area. It is very important to determine the level of radioactivity concentrations in water tap to ensure consumer safety. The obtained results provide useful information to carry out a dose assessment due to ingestion of the water samples, therefore, All achieved results have been found to be under the international limit standars.

# Declarations

**Acknowledgement** The authors wish to thank the school of physics (Koya University) for supported in experimental assistance, and financial supported has been provided by the Research University and my sponsor the Ministry of Higher Education (MHE) Kurdistan Regional Government.

### Conflict of Interest Statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

**Data availability**; Input data and additional results are provided in the Supporting Information.

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# Figures

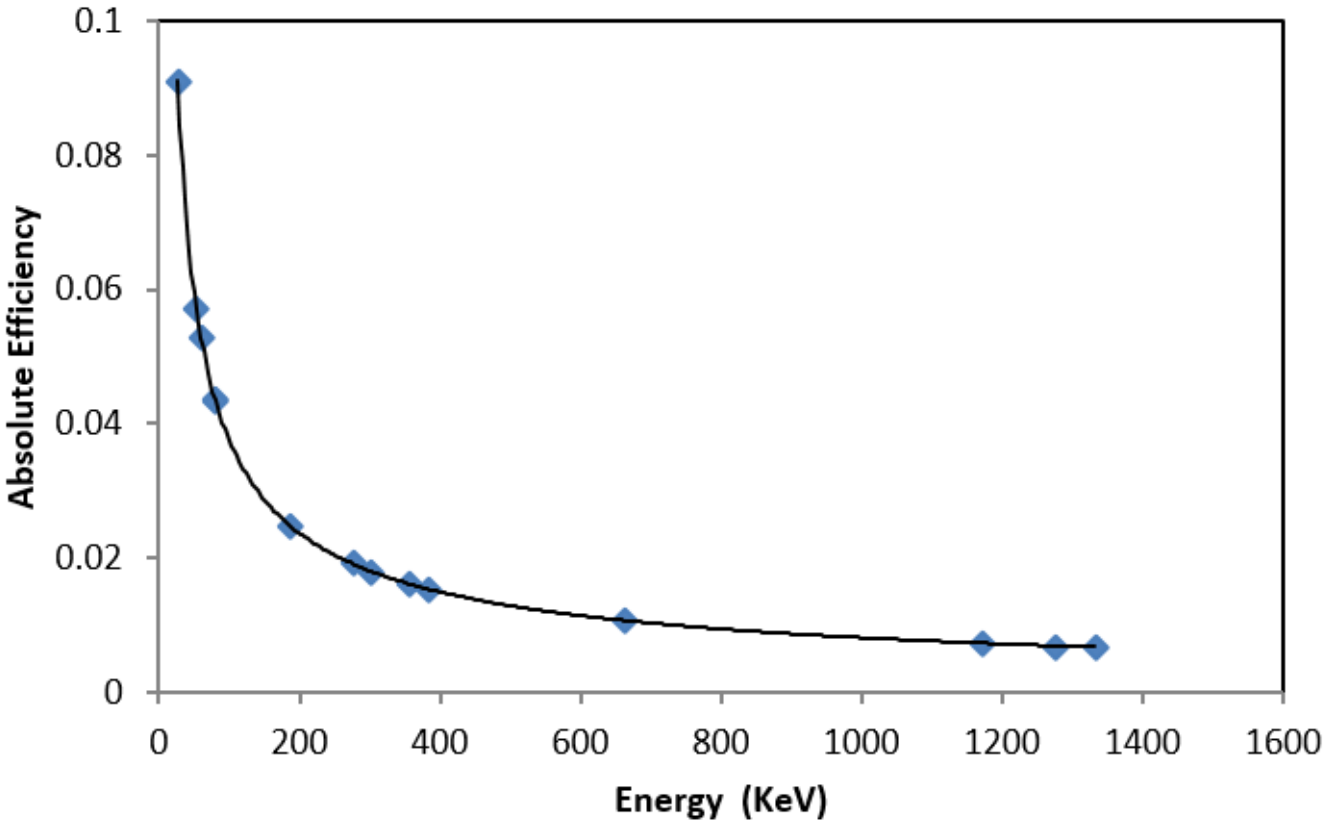



**Figure 1**

Efficiency calibration curve for the HPGe detector.

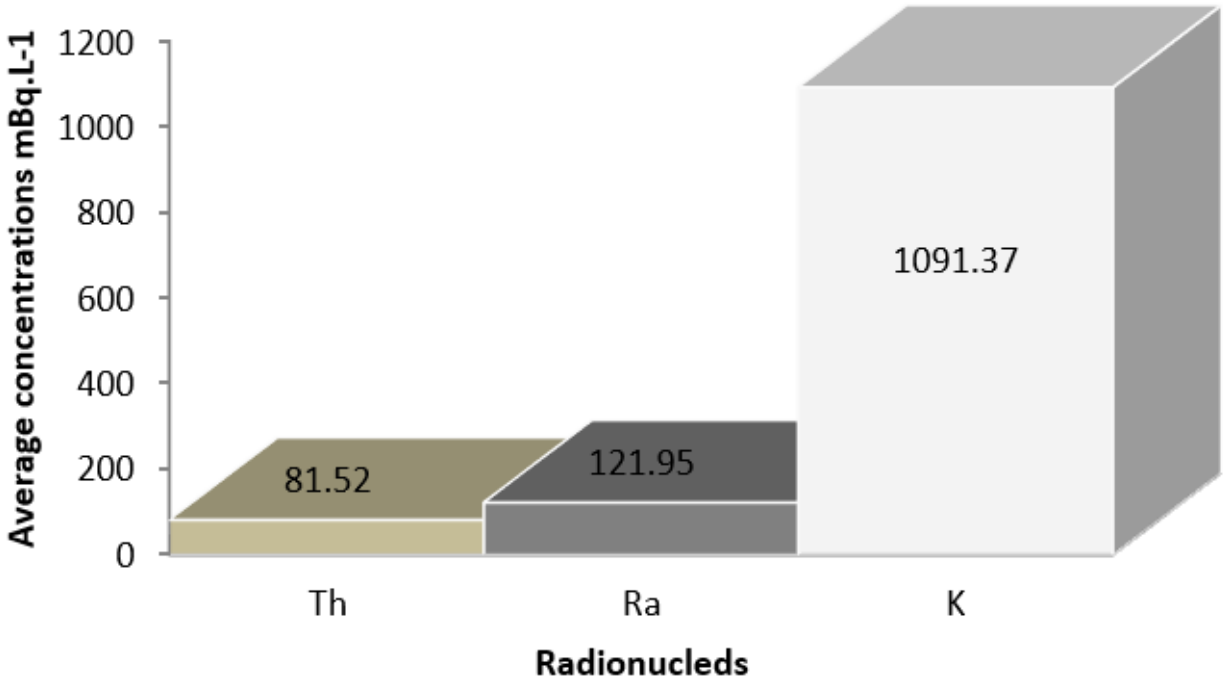



Figure 2

The average radioactivity concentration ($mBq.L^{-1}$) of $^{232}Th$, $^{226}Ra$, and $^{40}K$

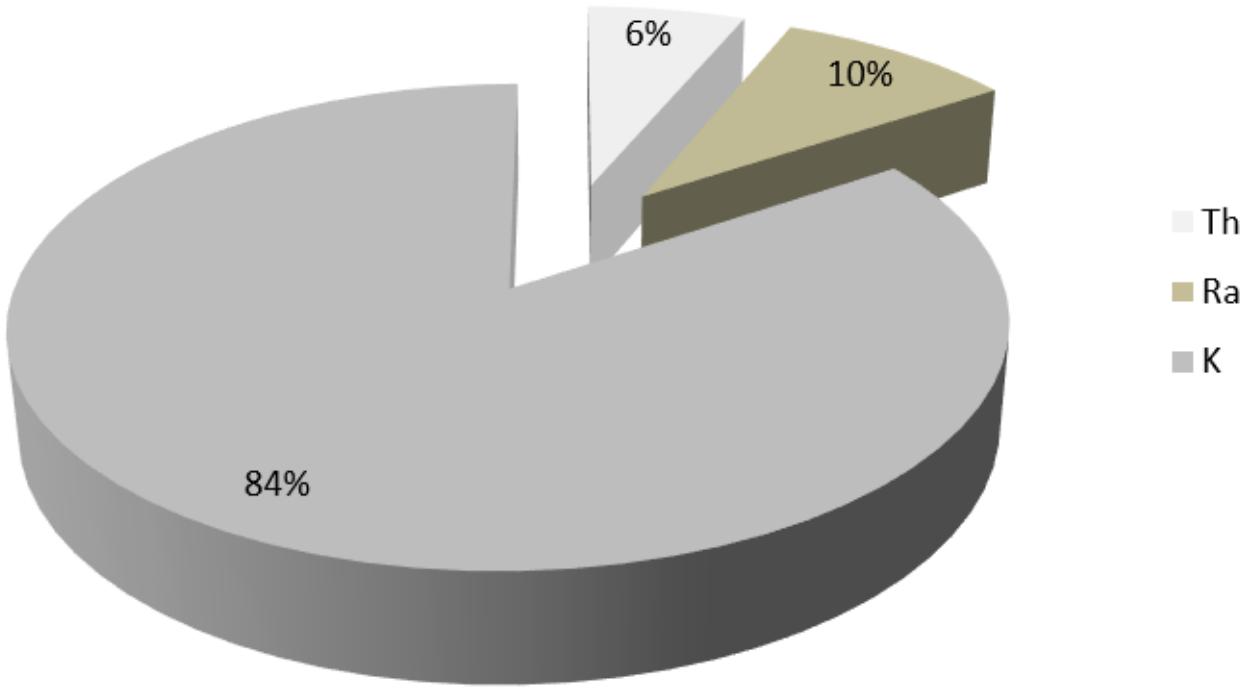
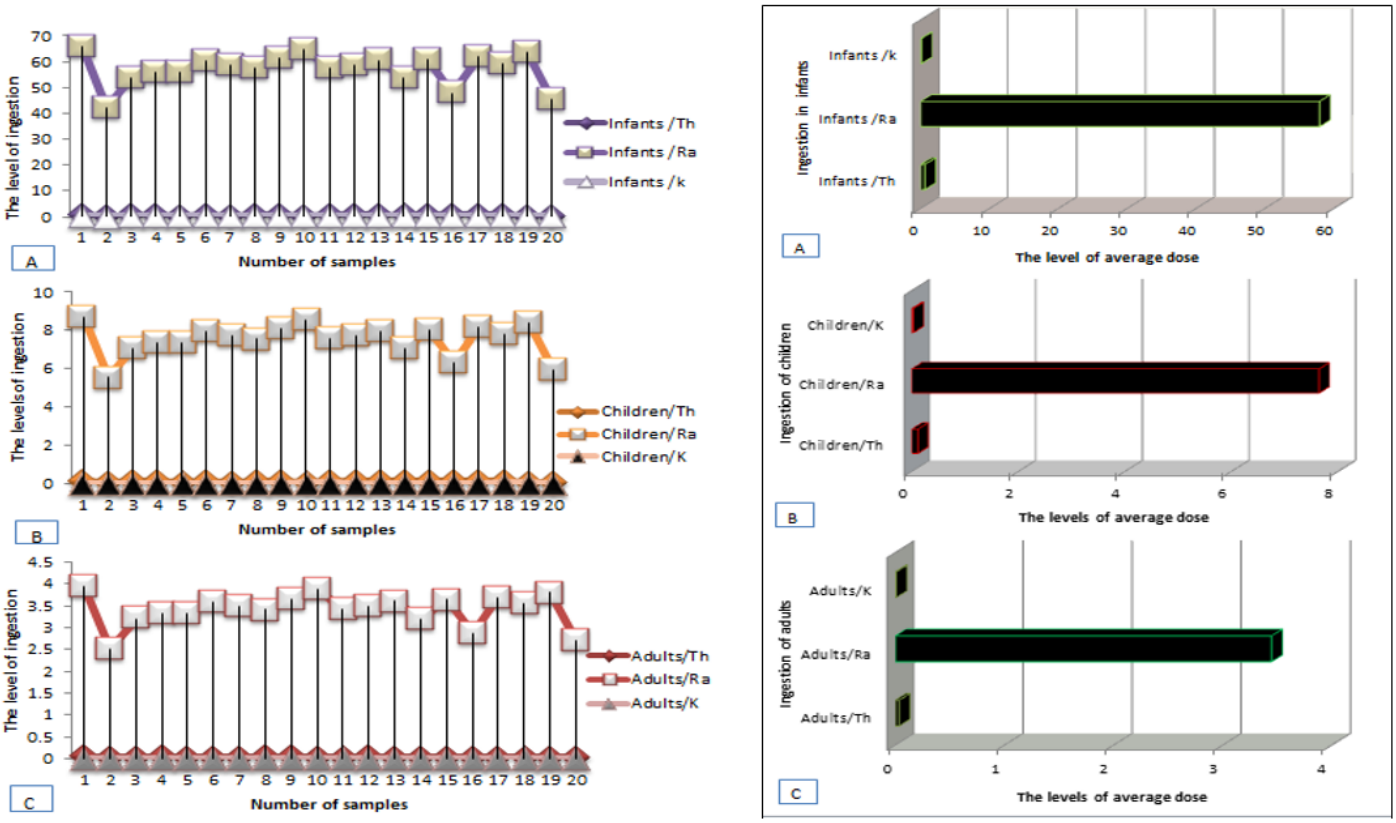



Figure 3

The ratio of radioactivity concentration (ppm) of $^{232}Th$, $^{226}Ra$, and $^{40}K$




## Figure 4

**(4a, 4b, 4c)** The effective doses due to ingestion by human. **(4D, 4E, 4F)** The levels of average of effective doses due to ingestion by human