Determination of Radioactivity Levels, Hazard, Cancer Risk and Radon Concentrations of Water and Sediment Samples in Al-Husseiniya River (Karbala, Iraq)

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Abstract. Natural radioactivity U-235, Th-232, and K-40 of eight samples of water and sediments from Al-Husseiniya River have been investigated by using gamma spectrometer with High-Purity Germanium HPGe detector. Radon concentrations have been measured for these samples by using CR-39 detector. The average activity concentrations were 15.8±2.421 for U-238, 11.2±2.385 for Th-232, and 311±21.826 Bq/kg for K-40 in sediment samples; and 1.9±0.557 for U-238, 1.2±0.396 for Th-232, and 10.1±1.437 Bq/L for K-40 in water samples respectively. These activities are compared with the worldwide limit. The average radium equivalent activity $R_{aeq}$ was 55.959±8.559 Bq/kg in sediment. The average value of hazard index $H$ was 0.344 in sediment samples. The average absorbed dose rate $D_{out}$ was 27.511±4.095 nGy/h and $D_{in}$ was 51.997±7.639 nGy/h in sediment samples respectively. The average of total annual effective dose equivalent $AEDE$ for sediment was 288.815 µSv/y. While the total of $ELCR$ was 1.011×10$^{-3}$. They are less than worldwide limits. Radon concentrations have been measured for the same samples. CR-39 detector was used for radon measurements. The average value in sediment was 6.00±0.759 Bq/kg, and 2.40±0.270 Bq/L in water samples. While the radium concentrations in sediment was 0.247±0.031 Bq/kg. Both are less than the worldwide limit. The average value of $E_a$ and $C_q$ in water was found to be 1.78±0.202 mBq/m$^2$.h and 46.890±255.245 Bq/L respectively. While the surface and mass exhalation rates of sediment sample was 35.283±4.458 mBq/m$^2$.h and 7.091±0.896 mBq/kg.h. The total annual effective dose $AED$ in water samples was 14.762 µSv/y which is less than the worldwide value 1mSv/y. Therefore, water of Al-Husseiniya River is safe with regards to the concentration of radon and natural radioactivity.

Keywords: Natural radioactivity; Radon concentrations; Water and sediment; Cancer risk; HPGe and CR-39 detectors; Iraq

1. Introduction

Al-Husseiniya River is a branch of the Euphrates River located north-east of Karbala Governorate/Iraq. It is about 5km length and is one of the most important rivers that feed the orchards and used for drinking. To our knowledge, there seems to be no information about radioactivity level in Al-Husseiniya River water and sediments so far. For this reason, water and sediment samples were collected along Al-Husseiniya River. Al-Husseiniya River padding by sediments was taken from the
sites of a military industrial facility belonging to the city of Karbala that may be contaminated with radioactive elements. Human exposure to natural radiation, from background radiation is responsible for large-scale population exposure to environmental radioactivity, and that it is present in different geological formations such as soil, rocks and plants, sand, water and air [1]. Humans also exposed to contamination of the food chain caused by direct deposition of radionuclides into plant leaves and root, absorption of contaminated soil, sediments, water, and direct ingestion of contaminated water [2]. The radiation dose received by human being from natural radiation sources is about 70% [3]. The presence of radioactive elements in water leads to the spread of contamination on the earth. The sediments were accumulated in river riverbeds, mostly on the bottom. These sediments include many natural radioactive isotopes, especially from the uranium chain, and often their concentration is higher than the average values in this area [4]. Long-term exposure to uranium, thorium and radium through inhalation has several health effects such as lung disease, anemia, mouth necrosis, nasal tumors, and leukemia, pancreas, and kidney cancers. Therefore, the distribution of radioactivity found in natural materials enables us to assess any possible radiation risk to humanity [1]. The worldwide average human exposure to natural sources is 2.4 mSv/y, and the weight of water and food is about 0.3 mSv/y [3, 5]. The characteristic of Solid State Nuclear Detectors (SSND’s) has made them an excellent tool for making inexpensive radiation measurements at the site. Plastic track detectors CR – 39 are more suitable for measuring alpha emitters in the environmental samples due to their high simplicity, sensitivity, rapidity and cheapen. A can technique is found to be the most appropriate and the most widely used technique because of its simplicity as well as being economical [6].

2. Materials and methods

2.1. Preparation of samples

The present study area of the Al-Husseiniya River in Karbala covered a total length of 5km, from which 8 consecutive sites (five sediment samples from different locations at each site as well as water), and thus 40 samples were collected. The samples were collected (60cm in depth) between May and June 2017. Sediment samples were placed in plastic bags, and marked with label. The samples were brushed and dried for 5 days under the sun until all moisture was completely lost. The dried samples are grinded into a fine powder using a stainless steel ball mill and sieved through 1mm mesh. Each sample of soil grain with weights about 1000g. As well, water samples were filtered using filter paper to get rid of the suspended minutes with samples. Each sample was placed in plastic containers used to collect water samples with a capacity of 1 liter after washing them with HCl. Then tightly sealed and labeled. The studied area from which the samples were collected was shown in Figure 1.

![Figure 1](image-url)
2.2. Calibration

2.2.1. Gamma-ray spectrometry. The Gamma-ray spectrometer used in this work is a High-Purity Germanium (HPGe) detector system, a coaxial cylindrical detector, manufactured by CANBERRA, its active volume is about 80 cm$^3$ and the size of the crystal is 3x3 inch with 65% relative efficiency. The shield, 12cm thick, was made of lead (99.9% purity) and the internal surface was degraded in atomic number with copper, aluminum and polyethylene. The energy, efficiency, resolution, detection limit and background measurement of high purity Germanium (HPGe) detector gamma spectrometry system have been done with standard source of known activity. Figures 2 and 3 show the energy and efficiency calibration curves of (HPGe) detector using a mixed standard source with different energy ranging from 59.5 keV for 241Am to 1836.06 keV for 88Y.

![Figure 2. Energy calibration curve of HPGe detector.](image1.png)

![Figure 3. Efficiency calibration curve of HPGe detector.](image2.png)

2.2.2. CR-39 Detector. Radon concentrations in sediments and water have been determined by using the Can technique. A known amount of sample was placed at the bottom of the can which was then closed for one month in order to reach equilibrium between radon and radium members of the decay
series. After one month, the CR-39 nuclear track detector, UK issued, of 500μm thickness and density of 1.36gm/cm$^3$, was cut into small pieces of 1cm×1cm area. Then, they were fixed inside the cover of the can, as shown in Figure 4. After two months of exposure, detectors in aqueous solution 6.25N of sodium hydroxide (NaOH) were etched at 60°C for 5hr. The detectors were rinsed with distilled water and dried in the air. The track density was recorded using an optical microscope with 400X. The density of the tracks (ρ) was obtained in the samples according to the following relationship [7]:

$$\text{Track density (ρ) = } \frac{\text{average number of total tracks (Nave)}}{\text{area of field view (A)}}$$

(1)

Radon concentration was measured using the relationship [8]:

$$\frac{C_X}{\rho_X} = \frac{C_S}{\rho_S}$$

(2)

Where $C_S, C_X$: are radon exposure (Bq.m$^{-3}$) for standard and sample respectively. $\rho_S, \rho_X$ are track density, in(Track.mm$^{-2}$), for standard and sample respectively.

and

$$C_X = C_S \frac{\rho_X}{\rho_S}$$

(3)

![Figure 4. Schematic diagram of the sealed-can technique used for sediments and water samples.](image)

![Figure 5. Relation between radon gas concentration and track density in soil standard samples.](image)
3. Parameters for sediments samples

3.1. Absorbed dose rate

To convert the activity concentration of $^{238}\text{U}$, $^{232}\text{Th}$, and $^{40}\text{K}$ radionuclides into doses in ($\text{nGy} h^{-1} \text{per Bq kg}^{-1}$), UNSCEAR (1988) [9] has given the dose conversion factors as 0.427, 0.662 and 0.043 respectively. Using these factors, the outdoor absorbed dose rate is calculated using the following equation:

$$D_{\text{out}} (\text{nGy} h^{-1}) = 0.427 A_U + 0.662 A_{Th} + 0.043 A_K \quad (4)$$

Where $A_U$, $A_{Th}$ and $A_K$ are the activity concentrations in ($\text{Bq kg}^{-1}$) of uranium, thorium and potassium respectively. The indoor gamma ray dose imparted by of $^{238}\text{U}$, $^{232}\text{Th}$, and $^{40}\text{K}$ radionuclides present indoor can be calculated by converting the absorbed dose rate to effective dose by using the conversion factors 0.92, 1.1 and 0.081 $\text{nGy} h^{-1} \text{per Bq kg}^{-1}$ respectively. By using these factors following, the following equation is used to calculate the indoor dose rate, given by UC European Commission (1999) [10]:

$$D_{\text{in}} (\text{nGy} h^{-1}) = 0.92 A_U + 1.1 A_{Th} + 0.081 A_K \quad (5)$$

3.2. Radium equivalent activity $Ra_{eq}$

The absorbed activity dose is not provided as an exact indication of radiation hazard associated with sediments or any other materials because the concentration of U-238, Th-232 and K-40 are not uniformly distributed in sediments and most of environmental materials throughout the world. So that, for uniformity with respect to the exposure to radiation UNSCEAR (2000) [11] has defined the radium equivalent activity expressed by the following equation:

$$Ra_{eq} (\text{Bq kg}^{-1}) = A_U + 1.43 A_{Th} + 0.077 A_K \quad (6)$$

Where $A_U$, $A_{Th}$ and $A_K$ are the activity concentration of U-238, Th-232 and K-40 in ($\text{Bq kg}^{-1}$) respectively. 1, 1.43 and 0.077 are the activity conversion rates of uranium, thorium and potassium respectively which outcome in same gamma dose rate at maximum permissible $Ra_{eq}$ of 370 $\text{Bq kg}^{-1}$. $Ra_{eq}$ is measured in $\text{Bq kg}^{-1}$ and its definition is based on the assumption that specific activity of 370 $\text{Bq kg}^{-1}$ for Ra-226 uniformly distributed in any environmental sample can perform in the annual effective dose of $1\text{mSv}$ at a height of 1 m above the ground level [12].
3.3. Hazard index \( H \)

Other radiological hazards are external (\( H_{\text{ex}} \)) and internal (\( H_{\text{in}} \)) hazard indices. \( H_{\text{ex}} \) is the radiation hazard due to external exposure to gamma ray. The external hazard index can be calculated from the following equation [11]:

\[
H_{\text{ex}} = \frac{R_{\text{eq}}}{370 \text{ Bq.kg}^{-1}}
\]  

OR:

\[
H_{\text{ex}} = \frac{A_U}{370 \text{ Bq.kg}^{-1}} + \frac{A_{Th}}{259 \text{ Bq.kg}^{-1}} + \frac{A_K}{4810 \text{ Bq.kg}^{-1}}
\]  

It is assumed that 370 Bq.kg\(^{-1}\) of Ra-226, 259 Bq.kg\(^{-1}\) of Th-232, and 4810 Bq.kg\(^{-1}\) of K-40, produce the same gamma dose rate [13]. The internal radiation exposure is quantified by the internal hazard index (\( H_{\text{in}} \)) given by UNSCEAR (2000) [11]:

\[
H_{\text{in}} = \frac{A_U}{185 \text{ Bq.kg}^{-1}} + \frac{A_{Th}}{259 \text{ Bq.kg}^{-1}} + \frac{A_K}{4810 \text{ Bq.kg}^{-1}}
\]  

The internal exposure to radon Rn-222 and its decay products is controlled by internal hazard index (\( H_{\text{in}} \)) and for safe use UNSCEAR (2000) [11] provided that the value of the above indexes must be less than unity for the radiation hazard to be regarded as insignificant.

3.4. Annual effective dose equivalent (AEDE)

The outdoor annual effective dose equivalent (\( AEDE_{\text{out}} \)) was estimated to convert the outdoor absorbed dose in air to effective dose. While the indoor annual effective dose equivalent (\( AEDE_{\text{in}} \)) is estimated from indoor absorbed dose in air to convert it to the effective dose. UNSCEAR (2000) [11] reported the value 0.7 Sv.Gy\(^{-1}\) as conversion coefficient from absorbed dose in the air to the effective dose received by adults. While 0.2 and 0.8 represent the outdoor and indoor occupancy factors respectively. The annual effective dose equivalent can be calculated from the following equations as reported by UNSCEAR (2000) [11]:

\[
AEDE_{\text{out}}(\mu\text{Sv/yr}) = D_{\text{out}}(\text{nGy/h}) \times 8760(\text{h/yr}) \times 0.20 \times 0.7(\text{Sv/Gy}) \times 10^{-3}
\]  

\[
AEDE_{\text{in}}(\mu\text{Sv/yr}) = D_{\text{in}}(\text{nGy/h}) \times 8760(\text{h/yr}) \times 0.80 \times 0.7(\text{Sv/Gy}) \times 10^{-3}
\]

3.5. Annual gonadal dose equivalent (AGDE)

The United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1988) [9] has been interested active bone marrow and bone surface cells as organs. Therefore, 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 \( \mu\text{Sv/yr per Bqkg}^{-1} \) respectively, was calculated using the following equation [14]:

\[
AGDE(\mu\text{Sv/yr}) = 3.09A_U + 4.18A_{Th} + 0.314A_K
\]

3.6. Life-time cancer risk (ELCR)

The excess life-time cancer risk (\( ELCR \)) was estimated from annual effective dose equivalent using the equation [15]:

\[
ELCR_{\text{out}} = AEDE_{\text{out}} \times DL \times RF
\]

\[
ELCR_{\text{in}} = AEDE_{\text{in}} \times DL \times RF
\]

Where \( DL \) and \( RF \) are the duration of life (70 years), and risk factor (0.05/Sv), respectively. Defined the risk factor as fatal cancer risk per Sievert is assigned a value of 0.05 by ICRP (2012) [16] for the public for random effects, for low-level radiations.
4. Parameters for water samples

4.1. Annual effective dose (AED)

The **annual effective dose** \( AED_{ing} \) due to the ingestion of radon was calculated for the individual consumer due to **intake of radon** from the consumption of drinking water in unit \( (\mu S\text{v}/y) \) according to the following equation [17,18]:

\[
AED_{ing} (\mu S\text{v}/y) = CR_n \cdot CR_w \cdot D_{cw}
\]  

(15)

Where \( CR_n \) is the concentration of radon in the water in \( (Bq/L) \) units, \( CR_w \) is the annual intake of drinking and is equal to 730 L/y for adults, and \( D_{cw} \) is the ingested dose conversion factor and is equal to \( 5 \times 10^{-9} \text{ Sv/Bq} \) [11].

The **annual effective dose** \( AED_{inh} \) due to the **inhalation of radon**, resulting from the radon concentration in indigenous water, was calculated according to the following expression UNSCEAR (2000) [11]:

\[
AED_{inh} (\mu S\text{v}/y) = C_{Rn-w} \cdot R_{a-w} \cdot E\text{qF} \cdot E\text{xT} \cdot 9nSv \cdot (kBq \cdot h \cdot L^{-1})^{-1}
\]  

(16)

Where \( C_{Rn-w} \) is the average radon concentration in water, in \( kBq \cdot L^{-1} \), \( R_{a-w} \) is the air–water concentration ratio \( (10^{-4}) \), \( E\text{qF} \) is the equilibrium factor between indoor radon and its short lived progeny \( (0.4) \), \( E\text{xT} \) is the exposure time to this concentration, in hours (assumed to be 7000 h per year), and \( 9nSv \cdot (kBq \cdot h \cdot L^{-1})^{-1} \) is the dose conversion factor.

4.2. Radium concentration \( C_{Ra} \)

The **radium concentration** of the sample (sediment) was calculated using the following relation [19]:

\[
C_{Ra} = \frac{\rho h A}{KT M}
\]  

(17)

Where \( C_{Ra} \) is the effective radium content of sample \( (Bq/kg) \), \( \rho \) is the track density \( (track/mm^2) \), \( M \) is the mass of the sample \( (kg) \), \( h \) is the distance between the detector and the top of the soil sample, \( A \) is the surface area from which radon is exhaled \( (m^2) \), \( t \) is the exposure time and \( K \) is the calibration constant which was determined to be: \( K = 8.497 \times 10^{-3} \text{track/mm}^2 \) h per \( Bq/m^3 \), and \( T_e \) is the effective exposure time, which is related to the actual exposure time \( t \), by the following relation [20]:

\[
T_e = t - 1/\lambda (1 - e^{-\lambda t})
\]  

(18)

5. Determination of some radon parameters for water samples

5.1. Radon exhalation rate \( E_A \)

The **surface radon exhalation rate** \( E_A \) of the sample is defined as the flux of radon released from its surface. Since Rn-222 is one of the most important isotopes in the U-238 series and it is a short lived progenies, it can be regarded as a major indicator to lung dose. The radon exhalation rate in terms of area (surface exhalation rate) in units of \( (Bq \cdot m^{-2} \cdot h^{-1}) \) can be calculated according to the following equation [21,22,23]:

\[
E_A = \frac{CV\lambda}{A [T + 1/\lambda (e^{-\lambda T} - 1)]}
\]  

(19)

Moreover, the **radon exhalation rate in terms of mass** \( E_M \) \( (Bq \cdot kg^{-1} \cdot h^{-1}) \) is determined by the following equation [22]:

\[
E_M = \frac{CV\lambda}{M [T + 1/\lambda (e^{-\lambda T} - 1)]}
\]  

(20)

Where \( C \) is the integrated radon exposure as measured by CR-39 \( (Bq \cdot h/m^3) \) for sediment or \( (Bq \cdot h/L) \) for water, \( V \) is the volume of hollow air in cup \( (m^3) \) or (Liter), \( \lambda \) is the radon decay constant \( (h^{-1}) \),
\( A \) is the surface area of the sample from which radon is exhaled \((m^2)\), \( M \) is the mass of the sample \((kg)\), and \( T \) is the exposure time \((h)\).

5.2. Dissolved radon concentration in water \( C_d \)

The dissolved radon concentration \( C_d \) in water was calculated in the unit \((Bq/L)\) according to the following equation [22]:

\[
C_d (Bq/L) = C_{Rn} \lambda h T / L
\]  

(21)

Where \( C_{Rn} \) is the concentration of radon in the air above the water sample \((Bq/L)\), \( \lambda \) is the decay constant of radon gas and is equal to 0.181452 \(day^{-1} \), \( h \) is the high of detector from the surface of the water \((9cm)\), \( T \) is the exposure time of the detector to water sample \((60days)\), and \( L \) is the height of the water inside the can \((5cm)\).

The concentration of radon in the can air above the water samples was determined by measuring the tracks density on the detector according to the following relation [22]:

\[
C_{Rn} = \frac{\rho}{KT}
\]  

(22)

Where \( C_{Rn} \) is the activity concentration of radon in the ingested water \((Bq/L)\), \( \lambda \) is the decay constant of \(^{222}\)Rn \((h^{-1})\), \( h \) is the distance from the surface of water sample in cup to the detector \((m)\), and \( T \) is the exposure time of the sample \((h)\) and \( L \) is the depth of the sample \((m)\).

6. Results and discussion

Gamma spectroscopy was used to determine the activities of U-238, Th-232, and K-40. The activity concentrations of Th-232 and U-238 were calculated assuming secular equilibrium with their decay products. The gamma ray transitions of energies 186.3 keV \((Ra-226)\), 609.3 keV \((Bi-214)\) and 351.9 keV \((Pb-214)\) were used to determine the concentration of the U-238 series. The gamma-ray lines at 911.0 keV \((Ac-228)\) and 583.3 keV \((Tl-208)\) were used to determine the concentration of the Th-232 series. The 1460 keV gamma-ray transition was used to determine the concentration of K-40. Cs-137 does not exist in water and sediment naturally because it is producer of radioactivity repercussions.

Table 1 shows the activity concentrations of main gamma emitting radionuclides of U series, Th series, and K-40 in the water and sediment samples. The average concentrations of U-238, Th-232, and K-40 were found to be 15.8±2.421, 11.2±2.385, and 311.0±21.826 \(Bq/kg\) in sediment samples, respectively. The average concentrations of U-238, Th-232, and K-40 were found to be 1.9±0.557, 1.23±0.396 and 10.08±1.437 \(Bq/L\) in water samples, respectively. The worldwide concentrations of the radionuclides U-238, Th-232, and K-40 have averages in sediment samples of 25, 25, and 373 \(Bq/kg\) respectively (UNSCEAR, 1988) [9]. Our results show that the mean activity concentrations of these radionuclides are lower than the worldwide concentrations according to the UNSCEAR report [24,25]. See Figure 7 and 8.

From these results, we can see that the concentration of U-238, Th-232 and K-40 in sediment samples was higher than that in water samples by 87.98%, 89.02% and 96.76% respectively. This is because the rapid movement of water and its constant change lead to the deposition of radionuclides, so their presence in the water is very low. Table 2 shows the comparison of specific activity of U-238, Th-232, and K-40 in sediment and water samples with other references. A comparison of radiological hazard indices \( Ra_{eq} \), \( H_{ex} \), \( H_{in} \), \( D_{out} \), \( D_{in} \), \( AEDE_{out} \), \( AEDE_{in} \), \( AGDE \), \( ELCR_{out} \), \( ELCR_{in} \), and total \( ELCR \) is given in Table 3.

Table 3 presented the measured radium equivalent activity \( Ra_{eq} \) in sediment samples which were ranged from 43.804 to 62.847 \(Bq/kg\) with an average value 55.959±8.559\(Bq/kg\). The results are lower than the recommended limit 370 \(Bq/kg\) reported by UNSCEAR (1988, 2000) [9, 11], see Figure 9.

The calculated external hazard index \( H_{ex} \) ranged from 0.118 to 0.170 in sediment samples with an average value 0.151±0.023. While the calculated internal hazard index \( H_{in} \) ranged from 0.152 to 0.218
with an average value 0.193±0.029, which is lower than the worldwide limit ≤1 recommended by UNSCEAR (2000) [11]. These results are indicated in Table 3 and Figure 10.

Table 1. Average activity concentration of U-238, Th-232, and K-40 in sediment and water samples in Al-Husseiniya River.

| Sample Code* | U-238 (Bq/kg) | Th-232 (Bq/kg) | K-40 (Bq/kg) | Sample Code* | U-238 (Bq/L) | Th-232 (Bq/L) | K-40 (Bq/L) |
|--------------|---------------|----------------|--------------|--------------|---------------|----------------|--------------|
| S-1          | 17.1          | 10.2           | 319.4        | W-1          | 1.3           | 0.95           | 10.6         |
| S-2          | 12.5          | 8.3            | 252.4        | W-2          | 2.4           | 1.17           | 6.7          |
| S-3          | 18.0          | 13.0           | 341.0        | W-3          | 2.0           | 1.80           | 10.6         |
| S-4          | 15.4          | 13.3           | 331.0        | W-4          | 1.9           | 1.23           | 10.08        |
| Min.         | 12.5          | 8.3            | 252.4        | Min.         | 2.4           | 1.80           | 12.4         |
| Max.         | 18.0          | 13.3           | 341.0        | Max.         | 1.9           | 1.23           | 10.08        |
| Ave.         | 15.8          | 11.2           | 311.0        | Ave.         | 1.9           | 1.23           | 10.08        |
| SD           | ±2.421        | ±2.385         | ±21.826      | SD           | ±0.557        | ±0.396         | ±1.437       |
| Worldwide     | 4400          | 517           | 23870        |              | 123         | 25             | 370          |

* Each sample code is an average of five samples collected from different locations at the same site.

Table 2. Activity concentration of U-238, Th-232 and K-40 in sediment and water samples.

| Sample Radio- | Present Work | Ref. Range       |
|--------------|--------------|------------------|
| Sediment      | U-238        | 15.8±2.421       | 18.220±1.404 Tigris River in AL-Amara city [26] |
|               | Th-232       | 11.2±2.385       | 13.792±1.302 Tigris River in AL-Amara city [26] |
|               | K-40         | 311.0±21.826     | 317.34±16.997 Tigris River in AL-Amara city [26] |
| Water         | U-238        | 1.9±0.557        | 142±2.16 Madlloom Region in Al-Najaf Al-Asrha [30] |
|               | Th-232       | 1.23±0.396       | B.D.L. Tigris River in AL-Amara city [26] |
|               | K-40         | 10.08±1.437      | 6.818±1.999 Tigris River in AL-Amara city [26] |

Table 3 shows the calculated outdoor absorbed dose $D_{out}$ due to the presence of U-238, Th-232 and K-40 in the sediments of Euphrates River that ranged from 21.685 to 30.955 nGy/h with an average value of 27.511±4.095 nGy/h which is lower than the worldwide limit of 59 nGy/h as presented by UNSCEAR (2000) [11]. The values of indoor absorbed dose $D_{in}$ calculated during present study range from 41.074 to 58.481 nGy/h with an average of 51.997±7.639 nGy/h, which is lower than the worldwide limit of 84 nGy/h as recommended by UNSCEAR (2000) [11]. The total average absorbed dose 99.508 nGy/h is greater by 1.687 times of the outdoor limit and greater by 1.185 times of the indoor limit. See Figure 11.
The values of outdoor annual effective dose equivalent $AEDE_{out}$ for Euphrates River sediments ranges from 26.595 to 37.963 $\mu Sv/y$ with an average of 33.739±5.021 $\mu Sv/y$ which is lower than the worldwide average of 70 $\mu Sv/y$. The $AEDE_{in}$ calculated with a range from 201.493 to 286.884 $\mu Sv/y$ with an average value 255.076±37.476 $\mu Sv/y$ which is less than the worldwide limit of 450 $\mu Sv/y$ reported by UNSCEAR (2000) [11]. The total average annual effective dose equivalent was estimated to be 288.815 $\mu Sv/y$ which is 1.80 times lower than the worldwide limit of 520 $\mu Sv/y$ as predicted by UNSCEAR (2000) [11]. Spatial distribution of total annual effective dose equivalent in studied area is shown in Figure 12. From Table 3 it can be seen that the estimated values of annual effective dose equivalent are relatively on higher side.

The obtained values of $AGDE$ are listed in Table 3. The values of $AGDE$ varied from 152.573 to 217.034 $\mu Sv/y$ and the average value was found to be 193.122±28.395 $\mu Sv/y$. The average value of AGDE was found to be 550.5 $m Sv/y$ in Rize, Turkey [32]. Also, the average value of $AGDE$ was found to be 2850 $m Sv/y$ in Kerala, India [33]. These two values of $AGDE$ are higher than our result. See Figure 13.

The excess lifetime cancer risk $ELCR$ for outdoor exposure calculated for sediment, given in Table 3 varied between 0.093×$10^{-3}$ and 0.133×$10^{-3}$ with average value of 0.118×$10^{-3}$ and standard deviation of 0.018×$10^{-3}$. This value was found to be less than the limit of 0.29×$10^{-3}$ set by UNSCEAR (2000) [11]. For indoor exposure it is varied from 0.705×$10^{-3}$ to 1.004×$10^{-3}$ with an average of 0.893×$10^{-3}$. It is less than the limit 1.16×$10^{-3}$ [11]. The total $ELCR$ ranges from 0.798×$10^{-3}$ to 1.137×$10^{-3}$ with an average value of 1.011×$10^{-3}$. The total $ELCR$ is 1.434 times less than the worldwide limit of 1.45×$10^{-3}$. The behavior of $ELCR$ in samples is shown in Figure 14.

The average value of $ELCR$ was found to be 3.21×$10^{-3}$ in the sediment of Hunza, Gilgit and Indus Rivers from Northern Pakistan [34] which is higher than the world permissible value of 0.29×$10^{-3}$ given by (UNSCEAR, 2000), while the calculated average value was 0.202×$10^{-3}$ for surface sediment samples of Ponnaiyar River in India [35]. This average value of ELCR is less than the worldwide limit given by (UNSCEAR, 2000). Also the ELCR in sediment samples in the Eastern Black Sea, Turkey is 0.19×$10^{-3}$ [36]. These last two values are lower than the world permissible value of 0.29×$10^{-3}$. However, the average ELCR value of present sediments is lower than the values obtained by Qureshi et al. (2014) [34] for sediment samples of Pakistan and higher than the average value obtained by Ramasamy et al. (2011) [35] and that obtained by Baltasa et al. (2018) [36] for sediment samples of India and Turkey respectively.

As is known the natural river water contains dissolved radon from the uranium series present in soil and rocks. Dissolved radon is easily released into the air when the water is used for showering, cleaning and other everyday purposes in homes. However, breathing radon released to air from water increases the risk of lung cancer. Some radon stays in the water; drinking water containing radon also presents a risk of developing internal organ cancers [37].

To be safe, several international health organizations determined the acceptable limit for radon concentrations in water. The USEPA (1991) has proposed that the allowed maximum contamination level (MCL) for radon concentration in water is 11 Bq/L [38], WHO (1993) defined the value 11.1 Bq/L [39], USEPA (1999) defined a value of 11.1 Bq/L for radon concentration in water [40], EPA (2000) defined a value of 10.0 Bq/L [41], UNSCEAR (2011) defined a value of 40 Bq/L [42], and the WHO (2012) defined a value of 100 Bq/L as an action limit [43]. While UNSCEAR (2012) [24] has proposed that the permissible limit of radon concentration in sediments is 30$Bq/kg$.

The purpose of this study was to investigate the radon concentrations in sediments and water of Euphrates River used for constructions, irrigation or drinking in some areas of Karbala governorate. Samples of sediments and water collected were examined to determine Rn-222 concentrations. Table 4 presents the radon concentrations in sediments samples. The average value in sediment samples was 6±0.759 $Bq/kg$. This result showed that the radon concentration in sediment samples was below the permissible limit of radon exposure 30 $Bq/kg$, according to the UNSCEAR report [11], see Figure 15. The Current results in Table 4 show that the average value of radon concentration in water samples was 2.40±0.270 $Bq/L$, see Figure 16 This value is lower than the maximum worldwide
contaminant level $11.1 \text{Bq/L}$ set by WHO (1993) [38] and USEPA (1999) [40]. The total average radon concentration in sediment is greater 2.5 times that in water. It is clear that there is no significant difference in the concentration of radon in the waters of the Al-Husseiniya River, although this river carries mud, soil and various types of elements due to its passage in a military area. This should increase the probability of containing a large amount of radium element to appear in increasing the concentration of radon in the samples. The radon concentrations vary from $78.6\pm21.3$ to $606.8\pm157.3 \text{Bq/kg}$ in the marine and coastal sediments of Khor-Abdullaha south of Iraq, northern west of the Arabian Gulf [44]. While the average radon concentration of Vakilabad river water in Mashhad City was $9.917\pm0.004 \text{Bq/L}$ [45]. Also Radon concentration is $6.120(\text{Bq/L})$ in tap water, $15.775(\text{Bq/L})$ in drill well water, and $11.790(\text{Bq/L})$ in ground water in Al-Hindiyah city of Karbala Governorate, Iraq [46].

The results of annual effective dose obtained are shown in Table 4. The estimated annual effective dose due to ingestion $AED_{ing}$ ranged from 7.556 to 9.965 $\mu \text{Sv/y}$ in water samples. The average of total annual effective dose obtained in this study is $8.733\pm0.985 \mu \text{Sv/y}$. It was evident that the total annual effective dose resulting from radon in intake water are significantly lower than the permissible limit of 1 $\mu \text{Sv/y}$ provided by International Atomic Energy Agency, IAEA [47], Environmental Protection Agency (EPA, 2000) [41], United Nations Scientific Committee on the Effects of Radiation (UNSCER, 2012) [24], (ICRP, 1993) [48] and World Health Organization (WHO, 2012) [43]. The International Commission on Radiological Protection ICRP (1993) has recommended that the annual effective dose limit should be 1 $\mu \text{Sv/y}$ for each member of the public and 20 $\mu \text{Sv/y}$ for radiation workers. These dosage limits have been established on the utilization pattern approach assuming no threshold dose below which there would be no effect [48]. Thus, the water in Al-Husseiniya River is safe as far as radon concentration is concerned. Differences in the values of radon concentrations were observed in water samples. These differences can arise due to differences in the nature and content of the nuclei in these samples.

As can be observed from Table 4, the annual effective dose due to inhalation $AED_{inh}$ for the members of local population was ranged from 5.216 to 6.880 $\mu \text{Sv/y}$ . The calculated average dose of the four codes is $6.029\pm0.680 \mu \text{Sv/y}$ , which is not exceeded the 1 $\mu \text{Sv/y}$ exposure limits for the members of the public [11]. In general, from a radiological health point of view, these slightly elevated the effective doses due to ingestion of water from sources in the studied areas are not expected to pose any significant health concerns to the local population since there are other optional available water sources. Also, these results do not represent a large value when compared with extreme value ~100 $\mu \text{Sv/y}$ which does not constitute any harmful effects [11]. The total annual effective dose of Vakilabad river water in Mashhad City was 36.578 $\mu \text{Sv/y}$ [45].

The result for radium activity and radon exhalation rate in sediment samples in selected locations of Al-Husseiniya river, are presented in Tables 4. The radium activity in sediment samples were found to vary from 0.213 to 0.287 $\text{Bq/kg}^{-1}$. The radon exhalation rate in terms of area of Al-Husseiniya River sediments varies from 30.413 to 41.037 $\text{Bq/m}^2.h$. Whereas the radon exhalation rate in sediment samples in terms of mass varies from 6.112 to 8.247 $\text{Bq/kg}$. The values of radium concentration and radon exhalation rate are also found to be maximum in sample code S-3 and minimum in sample code S-2. The exhalation rate in terms of area of Al-Husseiniya River water varies from 1.542 to 2.037 $\text{mBq/m}^2.h$. The values of exhalation rate in terms of area of Al-Husseiniya River are, generally, found to be more in sediment samples compared with water samples. The values of radium activity determined in sediment are less than the permissible value $30 \text{Bq/kg}^{-1}$, which is acceptable for safe use as recorded by UNSCEAR (2000) [11]. The dissolved radon concentration in water $C_d$ varied from 40.509 to 53.562 $\text{Bq/L}$ with average value is 46.890±255.245 $\text{Bq/L}$ respectively. These results are given in Table 4. It was noticed that annual effective dose $AED_1$, surface exhalation rate $E_A$, mass exhalation rate $E_M$ and the dissolved radon concentration in water $C_d$ are increase with radon concentration. Thus, results show that the area is safe as far the health hazard effects are concerned.
Table 3. Measured values of $Ra_{eq}$, $H_{ex}$, $H_{in}$, $D_{ex}$, $AEDE$, $AGDE$, and $ELCR$ for sediment samples from Al-Husseiniya River.

| Sediment Sample Code | $Ra_{eq}$ (Bq/kg) | $H_{ex}$ | $H_{in}$ | $D_{out}$ (nGy/h) | $D_{in}$ (nGy/h) | $AEDE_{out}$ (µSv/y) | $AEDE_{in}$ (µSv/y) | $AGDE$ (µSv/y) | $ELCR_{out}$ × 10^{-3} | $ELCR_{in}$ × 10^{-3} | $ELCR$ × 10^{-3} |
|-----------------------|-------------------|----------|----------|-------------------|------------------|----------------------|---------------------|----------------|------------------------|------------------------|-----------------|
| S-1                   | 56.280            | 0.152    | 0.198    | 27.790            | 52.823           | 34.082               | 259.129             | 195.767        | 0.119                  | 0.907                  | 1.026           |
| S-2                   | 43.804            | 0.118    | 0.152    | 21.685            | 41.074           | 26.595               | 201.493             | 152.573        | 0.093                  | 0.705                  | 0.798           |
| S-3                   | 62.847            | 0.170    | 0.218    | 30.955            | 58.481           | 37.963               | 286.884             | 217.034        | 0.133                  | 1.004                  | 1.137           |
| S-4                   | 60.906            | 0.162    | 0.203    | 29.613            | 55.609           | 36.317               | 272.796             | 207.115        | 0.127                  | 0.954                  | 1.081           |
| Min.                  | 43.804            | 0.118    | 0.152    | 21.685            | 41.074           | 26.595               | 201.493             | 152.573        | 0.093                  | 0.705                  | 0.798           |
| Max.                  | 62.847            | 0.170    | 0.218    | 30.955            | 58.481           | 37.963               | 286.884             | 217.034        | 0.133                  | 1.004                  | 1.137           |
| Ave                   | 55.959            | 0.151    | 0.193    | 27.511            | 51.997           | 33.739               | 255.076             | 193.122        | 0.118                  | 0.893                  | 1.011           |
| SD                    | ±8.559            | ±0.023   | ±0.029   | ±4.095            | ±7.639           | ±5.021               | ±37.476             | ±28.395        | ±0.018                 | ±0.131                  | ±0.149          |

Worldwide* 370**  

*SUNSCEAR (2000) [11]  
**SUNSCEAR (1988) [9]

Table 4. Radon and radium concentrations, surface and mass exhalation rates of sediment samples. Radon concentration, Annual effective dose ($AED$), surface exhalation rate, and dissolved radon concentration of water samples, in Al-Husseiniya River.

| Sediment Samples | Sample Code | $\rho$ (track/mm²) | Radon concentration (Bq/kg) | Radium concentration (Bq/kg) | $E_A$ (mBq/m².h) | $E_M$ (mBq/kg.h) |
|------------------|-------------|---------------------|-----------------------------|-----------------------------|------------------|-----------------|
|                  | S-1         | 551.02              | 5.74                        | 0.236                       | 33.746           | 6.782           |
|                  | S-2         | 496.60              | 5.17                        | 0.213                       | 30.413           | 6.112           |
|                  | S-3         | 670.07              | 6.98                        | 0.287                       | 41.037           | 8.247           |
|                  | S-4         | 586.74              | 6.11                        | 0.251                       | 35.934           | 7.221           |
|                  | Min.        | 496.60              | 5.17                        | 0.213                       | 30.413           | 6.112           |
|                  | Max.        | 670.07              | 6.98                        | 0.287                       | 41.037           | 8.247           |
|                  | Ave.        | 576.11              | 6.00                        | 0.247                       | 35.283           | 7.091           |
|                  | SD          | ±72.785             | ±0.759                      | ±0.031                      | ±4.458           | ±0.896          |

Worldwide 30 (Bq/kg)

| Water Samples | Sample Code | $\rho$ (track/mm²) | Radon concentration (Bq/L) | $AED_{in}$ (µSv/y) | $AED_{out}$ (µSv/y) | $E_A$ (mBq/m².h) | $C_d$ (Bq/L) |
|---------------|-------------|---------------------|---------------------------|-------------------|--------------------|------------------|--------------|
| W-1           | 370.75      | 2.73                | 9.965                     | 6.880             | 2.037              | 53.562           |
| W-2           | 280.61      | 2.07                | 7.556                     | 5.216             | 1.542              | 40.509           |
| W-3           | 321.43      | 2.37                | 8.651                     | 5.972             | 1.766              | 46.448           |
| W-4           | 324.83      | 2.40                | 8.760                     | 6.048             | 1.815              | 47.035           |
| Min.          | 280.61      | 2.07                | 7.556                     | 5.216             | 1.542              | 40.509           |
| Max.          | 370.75      | 2.73                | 9.965                     | 6.880             | 2.037              | 53.562           |
| Ave.          | 324.41      | 2.40                | 8.733                     | 6.029             | 1.783              | 46.890           |
| SD            | ±36.855     | ±0.270              | ±0.985                    | ±0.680            | ±0.202             | ±255.245         |

Worldwide 11.1 Bq/L [47,49,50,51]  

1 mSv/y [47,49,50,51]  

0.2-0.8 [39,40]  

with average 0.3 mSv/y [11]  

1.2 mSv/y [11]  

11.1 Bq/L [47,49,50,51]  

0.2-0.8 [39,40]  

with average 0.3 mSv/y [11]  

1.2 mSv/y [11]
Figure 7. Activity of U-238, Th-232, and K-40 in sediment samples.

Figure 8. Activity of U-238, Th-232, and K-40 in water samples.

Figure 9. Radium equivalent activity of sediment samples.

Figure 10. Hazard index of sediment samples.

Figure 11. Absorbed dose of sediment samples.

Figure 12. Annual effective dose equivalent of sediment.
Figure 13. Excess lifetime cancer risk of sediment.

Figure 14. Radon and radium concentration in sediment samples.

Figure 15. Radon concentration in water samples.

Figure 16. Annual effective dose for water samples.

Figure 17. Surface and mass exhalation rate for sediment samples.
7. Conclusions

In the present work, twenty samples of sediments and twenty samples of water were collected from Al-Husseiniya River in Karbala governorate, and it is clear from the analysis of gamma-ray spectroscopic (HPGe), the radioactivity concentrations of 238U, 232Th, and 40K radionuclides are within normal range. From the measured values, the Radium equivalent activities $R_{a_{eq}}$ are less than the approved value. The external hazard $H_{ext}$ and the internal hazard $H_{in}$ indices were under the risk limit. The measured gamma dose rate $D_{\gamma}$ is comparable to the worldwide average were found less than the suggested world average. The average values of $D_{out}$ and $D_{in}$ was below the assigned worldwide values. The values of Radon concentrations appear in the safe limit from the radiation protection point of view were found to be less than the value of 11.1Bq/L given by USEPA (2012). The annual effective dose values were lower than the UNSCEAR and WHO limit for members of the public of 1mSv/y. These values were all below the assigned worldwide values. Hence, the consumption of this water does not cause any health risk to the population around Al-Husseiniya River.

The results obtained showed that the radon concentrations in sediments and water are below the allowed maximum contamination level. The measured radon concentrations in Euphrates River sediments and water will pose none serious health risks and hence the study area is considered safe use of these sediments as building materials and water for irrigation or drinking and other uses for the population. Although these water and sediment materials contain low-level radioactivity but the accumulated dose can be high.

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