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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, 1.23±0.396 for Th-232, and 10.1±1.437Bq/L for K-40 in water samples respectively. These activities are compared with the worldwide limit. The average radium equivalent activity Ra_{eq} was 55.959±8.559Bq/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±4.095nGy/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±0.031Bq/kg. Both are less than the worldwide limit. The average value of E_A and C_d in water was found to be 1.783±0.202$mBq/m^2.h$ and 46.890±255.245Bq/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/ywhich are 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 5days 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**.
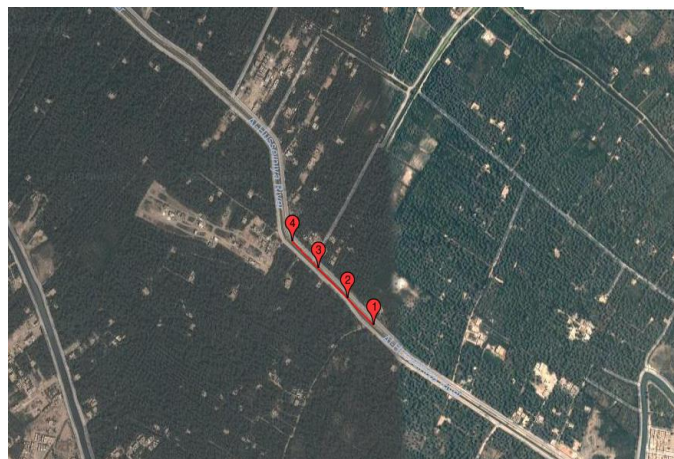

Figure 1. Area of the study.

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.
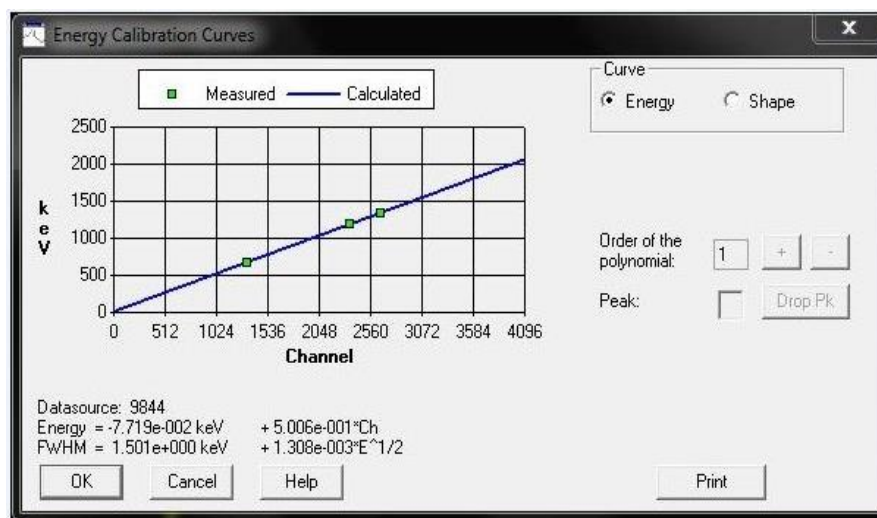

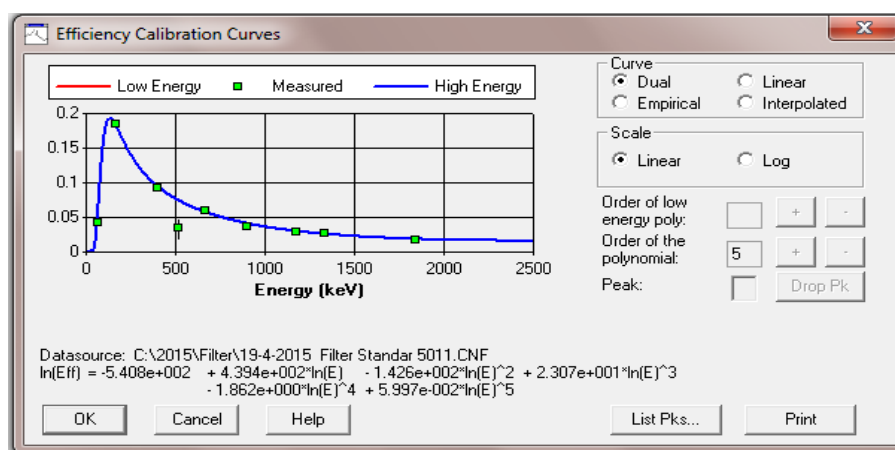**Figure 2.** Energy calibration curve of HPGe detector.

Figure 3. Efficiency calibration curve of HPGe detector.

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 6.25*N* 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]:

$$Track\ density\ (\rho) = \frac{average\ number\ of\ total\ tracks\ (N_{ave})}{area\ of\ field\ view\ (A)} \tag{1}$$

Radon concentration was measured using the relationship [8]:

$$\frac{C_X}{\rho_X} = \frac{C_S}{\rho_S} \tag{2}$$

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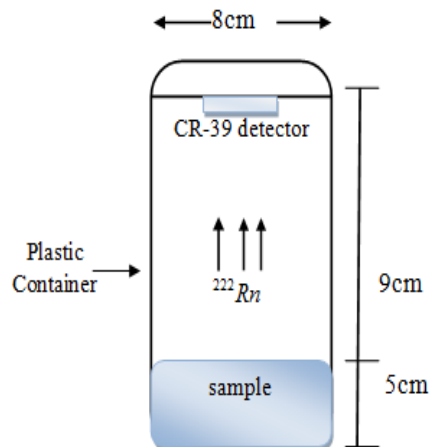
and
$$C_X = C_S \frac{\rho_X}{\rho_S} \tag{3}$$

Figure 4. Schematic diagram of the sealed-can technique used for sediments and water samples.
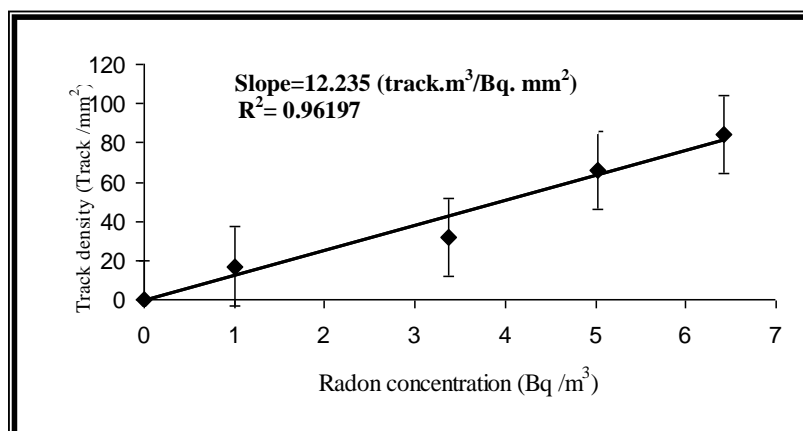
Figure 5. Relation between radon gas concentration and track density in soil standard samples.
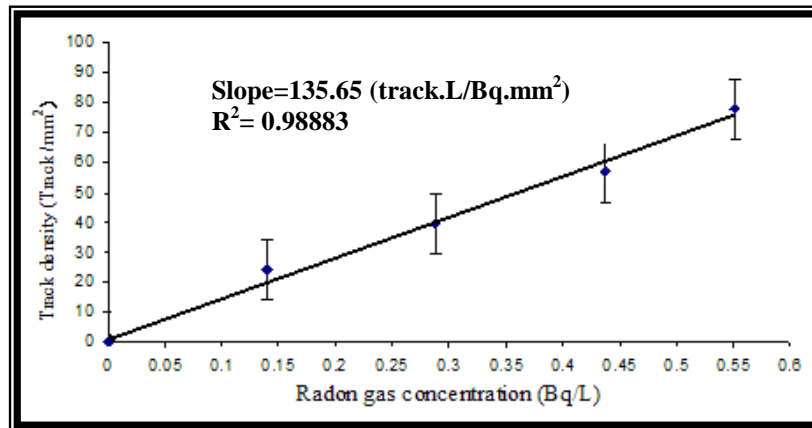
Figure 6. Relation between radon gas concentration and track density in water standard samples.

3. Parameters for sediments samples

3.1. Absorbed dose rate D

To convert the activity concentration of [238]U, [232]Th, and [40]K radionuclides into doses in ($nGyh^{-1}$ per $Bqkg^{-1}$), 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:

$$D_{out}(nGyh^{-1}) = 0.427\,A_U + 0.662A_{Th} + 0.043\,A_K \qquad (4)$$

Where A_U, A_{Th} and A_K are the activity concentrations in ($Bqkg^{-1}$) of uranium, thorium and potassium respectively. The indoor gamma ray dose imparted by of [238]U, [232]Th, and [40]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 $nGyh^{-1}$ per $Bqkg^{-1}$ respectively. By using these factors following, the following equation is used to calculate the **indoor dose rate,** given by UC European Commission (1999) [10]:

$$D_{in}(nGyh^{-1}) = 0.92\,A_U + 1.1A_{Th} + 0.081\,A_K \qquad (5)$$

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:

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

Where A_U, A_{Th} and A_K are the activity concentration of U-238, Th-232 and K-40 in ($Bqkg^{-1}$) 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 $Bqkg^{-1}$. Ra_{eq} is measured in $Bqkg^{-1}$ and its definition is based on the assumption that specific activity of 370 $Bqkg^{-1}$ for Ra-226 uniformly distributed in any environmental sample can perform in the annual effective dose of $1mSv$ at a height of 1 m above the ground level [12].

3.3. Hazard index H

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

$$H_{ex} = \frac{Ra_{eq}}{370 \, Bq.kg^{-1}} \tag{7}$$

OR:

$$H_{ex} = \frac{A_U}{370 \, Bq.kg^{-1}} + \frac{A_{Th}}{259 \, Bq.kg^{-1}} + \frac{A_K}{4810 \, Bq.kg^{-1}} \tag{8}$$

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_{in}) given by UNSCEAR (2000) [11]:

$$H_{in} = \frac{A_U}{185 \, Bq.kg^{-1}} + \frac{A_{Th}}{259 \, Bq.kg^{-1}} + \frac{A_K}{4810 \, Bq.kg^{-1}} \tag{9}$$

The internal exposure to radon Rn-222 and its decay products is controlled by internal hazard index (H_{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** ($AEDE_{out}$) was estimated to convert the outdoor absorbed dose in air to effective dose. While the **indoor annual effective dose equivalent** ($AEDE_{in}$) is estimated from indoor absorbed dose in air to convert it to the effective dose. UNSCEAR (2000) [11] reported the value 0.7 $SvGy^{-1}$ 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]:

$$AEDE_{out}(\mu Sv/y) = D_{out}(nGy/h) \times 8760(h/y) \times 0.20 \times 0.7(Sv/Gy) \times 10^{-3} \tag{10}$$

$$AEDE_{in}(\mu Sv/y) = D_{in}(nGy/h) \times 8760(h/y) \times 0.80 \times 0.7(Sv/Gy) \times 10^{-3} \tag{11}$$

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 $\mu Sv/y$ per $Bqkg^{-1}$ respectively, was calculated using the following equation [14]:

$$AGDE(\mu Sv/y) = 3.09A_U + 4.18A_{Th} + 0.314A_K \tag{12}$$

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]:

$$ELCR_{out} = AEDE_{out} \times DL \times RF \tag{13}$$

$$ELCR_{in} = AEDE_{in} \times DL \times RF \tag{14}$$

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 $(\mu Sv/y)$ according to the following equation [17,18]:

$$AED_{ing}(\mu Sv/y) = CR_n \, CR_w \, D_{cw} \tag{15}$$

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 5×10^{-9} 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]:

$$AED_{inh}(\mu Sv/y) = C_{Rn-w} \, R_{a-w} \, EqF \, ExT \, 9nSv \, (kBq \, h \, L^{-1})^{-1} \tag{16}$$

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

$$C_{Ra} = \frac{\rho h A}{K T_e M} \tag{17}$$

Where C_{Ra} is the effective radium content of sample (Bq/kg), ρ 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: $K = 8.497 \times 10^{-3} track/mm^2$ 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]:

$$T_e = t - 1/\lambda(1 - e^{-\lambda t}) \tag{18}$$

5. Determination of some radon parameters for water samples

5.1. Radon exhalation rate E

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 $(Bq.m^{-2}.h^{-1})$ can be calculated according to the following equation [21,22,23]:

$$E_A = \frac{CV\lambda}{A[T+1/\lambda(e^{-\lambda T}-1)]} \tag{19}$$

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

$$E_M = \frac{CV\lambda}{M[T+1/\lambda(e^{-\lambda T}-1)]} \tag{20}$$

Where C is the integrated radon exposure as measured by CR-39 $(Bq.h/m^3)$ for sediment or $(Bq.h/L)$ for water, V is the volume of hollow air in cup (m^3) or (Liter), λ 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]:

$$C_d \ (Bq/L) = C_{Rn} \ \lambda \ h \ T \ / \ L \qquad (21)$$

Where C_{Rn} is the concentration of radon in the air above the water sample (Bq/L), λ 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), 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]:

$$C_{Rn} = \frac{\rho}{KT} \qquad (22)$$

Where C_{Rn} is the activity concentration of radon in the ingested water (Bq/L), λ 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), 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 62.847Bq/kg with an average value 55.959±8.559Bq/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*	Sediment Samples (Bq/kg)			Sample Code*	Water Samples (Bq/L)		
	U-238	Th-232	K-40		U-238	Th-232	K-40
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	——	0.98	12.4
S-4	15.4	13.3	331.0	W-4	2.0	1.80	10.6
Min.	12.5	8.3	252.4	Min.	1.3	0.95	6.7
Max.	18.0	13.3	341.0	Max.	2.4	1.80	12.4
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 [9]	25	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-Nuclide	Present Work	Ref. Range
Sediment (Bq/kg)	U-238	15.8±2.421	18.220±1.404 Tigris River in AL-Amara city [26] 16-113 Turkey (Fırtına River) [27] 2.00±0.077 mg/kg to 2.71±0.076 mg/kg Sediments in North central part of Nigeria [28] 4100 Beaches of Brazil [29]
	Th-232	11.2±2.385	13.792±1.302 Tigris River in AL-Amara city [26] 17-87 Turkey (Fırtına River) [27] 4.38±0.037mg/kg to 10.08±0.15mg/kg Sediments in North central part of Nigeria [28] 57000 Beaches of Brazil [29]
	K-40	311.0±21.826	317.343±16.997 Tigris River in AL-Amara city [26] 51-1605 Turkey (Fırtına River) [27] 0.0041±0.024% to 3.31±0.025% Sediments in north central part of Nigeria [28] 3000 Beaches of Brazil [29] 142±2.16 Madloom Region in Al-Najaf Al-Ashraf [30]
Water (Bq/L)	U-238	1.9±0.557	B.D.L. Tigris River in AL-Amara city [26] 0.0182 ± 0.0015 water at Johor bahru, Malaysia [31]
	Th-232	1.23±0.396	B.D.L. Tigris River in AL-Amara city [26] 0.0389 ± 0.0034 water at Johor bahru, Malaysia [31]
	K-40	10.08±1.437	6.818±1.999 Tigris River in AL-Amara city [26] 1.22 ± 0.05 water at Johor bahru, Malaysia [31]

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 μSv/y with an average of 33.739±5.021 μSv/y which is lower than the worldwide average of 70 μSv/y. The $AEDE_{in}$ calculated with a range from 201.493 to 286.884 μSv/y with an average value 255.076±37.476 μSv/y which is less than the worldwide limit of 450 μSv/y reported by UNSCEAR (2000) [11]. The total average annual effective dose equivalent was estimated to be 288.815 μSv/y which is 1.80 times lower than the worldwide limit of 520 μSv/y as predicted by UNSCEAR (2000) [11]. Spatial distribution of total annual effective dose equivalent in studied area is shown in **Figure12.** 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 152.573to 217.034μSv/y and the average value was found to be 193.122±28.395μSv/y. The average value of AGDE was found to be 550.5 mSv/y in Rize, Turkey [32]. Also, the average value of $AGDE$ was found to be 2850 mSv/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 $30Bq/kg$.

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 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±21.3 to 606.8±157.3 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±0.004Bq/L [45]. Also Radon concentration is 6.120(Bq/L) in tap water, 15.775(Bq/L) in drill well water, and 11.790(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 µSv/y in water samples. The average of total annual effective dose obtained in this study is 8.733±0.985 µSv/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 mSv/y provided by International Atomic Energy Agency, IAEA [47], Environmental Protection Agency (EPA, 2000) [41], United Nations Scientific Committee on the Effects of Radiation (UNSCEAR, 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 mSv/y for each member of the public and 20 mSv/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 of radon AED_{inh} for the members of local population was ranged from 5.216 to 6.880 µSv/y . The calculated average dose of the four codes is 6.029±0.680µSv/y , which is not exceeded the 1 mSv/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 mSv/y which does not constitute any harmful effects [11]. The total annual effective dose of Vakilabad river water in Mashhad City was 36.578 µSv/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$Bqkg^{-1}$. The radon exhalation rate in terms of area of Al-Husseiniya River sediments varies from 30.413 to 41.037$mBq/m^2.h$. Whereas the radon exhalation rate in sediment samples in terms of mass varies from 6.112 to 8.247$mBq/kg.h$. 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$mBq/m^2.h$. 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 value30$Bqkg^{-1}$, 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 53.562Bq/L with average value is 46.890±255.245 Bq/L respectively. These results are given in **Table 4**. It was noticed that annual effective dose AED, 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_{γ}, $AEDE$, $AGDE$, 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)	$ELCR_{out}$ $\times 10^{-3}$	$ELCR_{in}$ $\times 10^{-3}$	$ELCR$ $\times 10^{-3}$
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*' **	≤1	≤1	59	84	70	450	1000	0.29	1.16	1.45

*UNSCEAR (2000) [11]

** UNSCEAR (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	ρ (track/mm^2)	Radon concentration (Bq/kg)	Radium concentration (Bq/kg)	E_A (mBq/m^2.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) [11]			

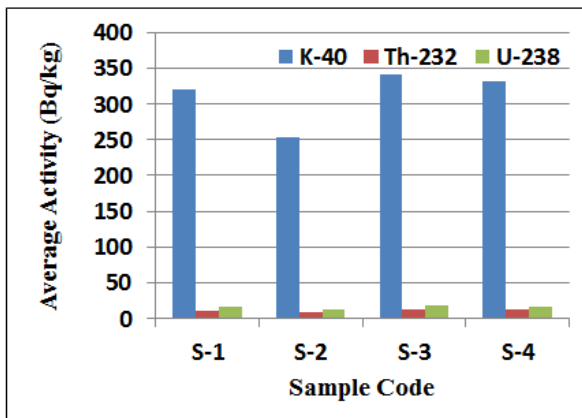| Water Samples					
Sample Code	ρ (track/mm^2)	Radon concentration (Bq/L)	AED_{ing} (μSv/y)	AED_{inh} (μSv/y)	E_A (mBq/m^2.h)	C_d (Bq/L)
W-1	370.75	2.73	9.965	6.880	2.037	53.562
W-2	280.61	2.07	7.556	5.216	1.542	40.509
W-3	321.43	2.37	8.651	5.972	1.766	46.448
W-4	324.83	2.40	8.760	6.048	1.785	47.035
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 [39,40]	0.1 mSv/y [47,49,50,51] 0.2-0.8 with average 0.3 mSv/y [11]	1 mSv/y [24,41,43,48] 0.2-10 with average 1.2 mSv/y [11]		

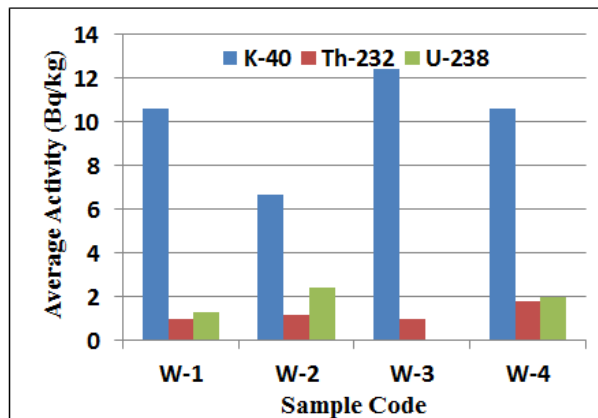**Figure 7.** Activity of U-238, Th-232, and K-40 in sediment samples.

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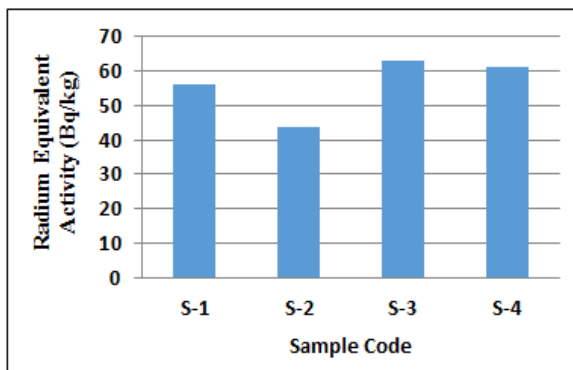

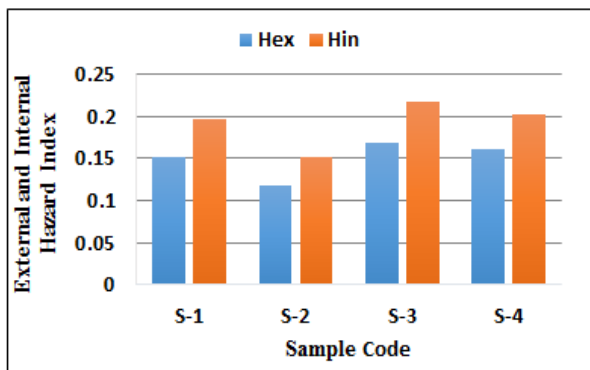**Figure 9.** Radium equivalent activity of sediment samples.
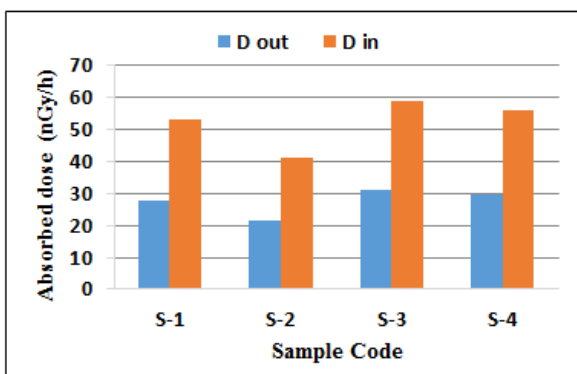

Figure 10. Hazard index of sediment samples.
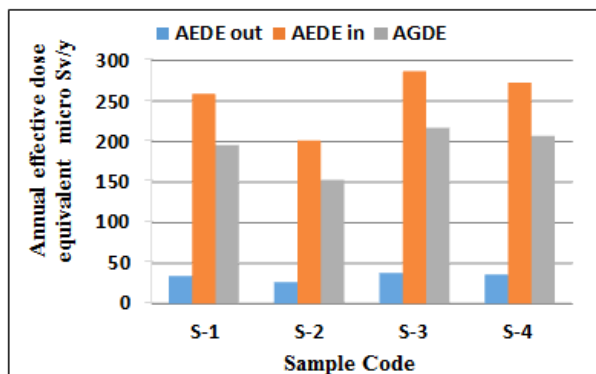

Figure 11. Absorbed dose of sediment samples.

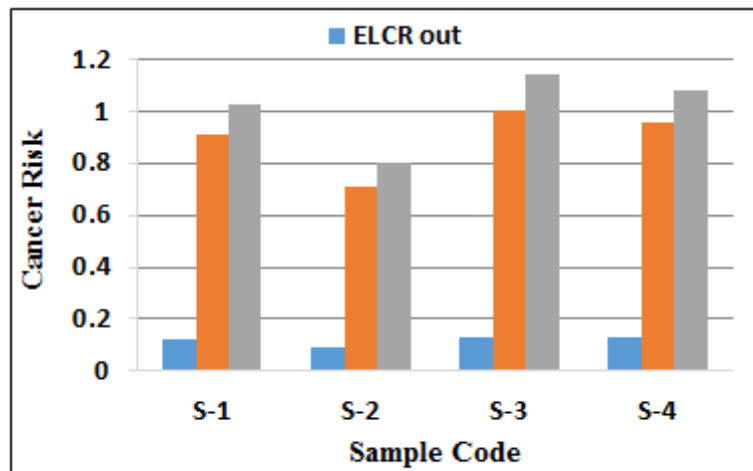**Figure 12.** Annual effective dose equivalent of sediment

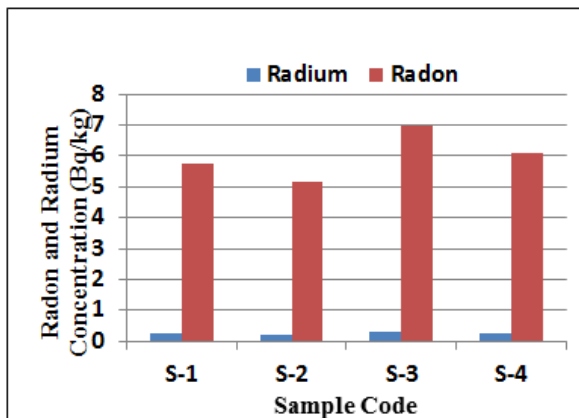**Figure 13.** Excess lifetime cancer risk of sediment

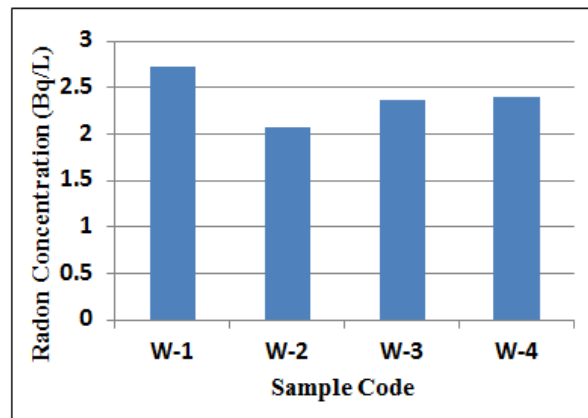**Figure 14.** Radon and radium concentration in sediment samples.
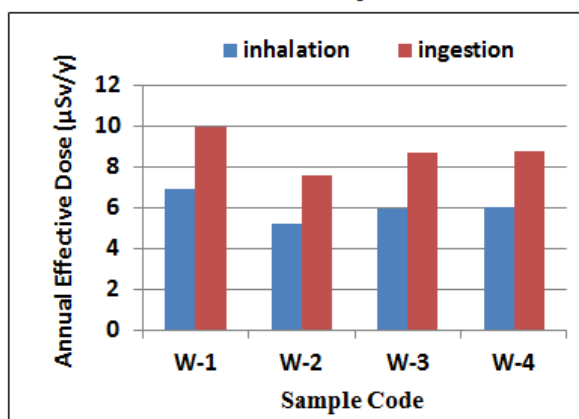

Figure 15. Radon concentration in water samples.

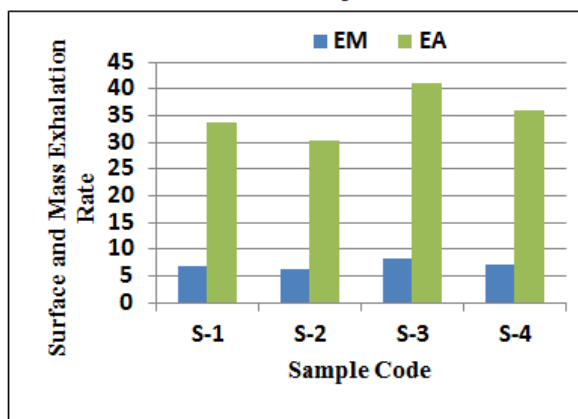**Figure 16.** Annual effective dose for water samples.

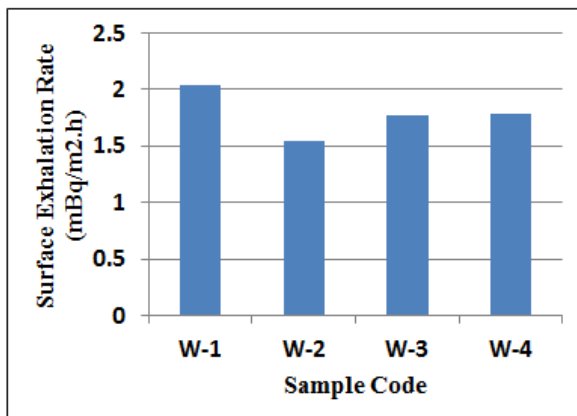**Figure 17.** Surface and mass exhalation rate for sediment samples.

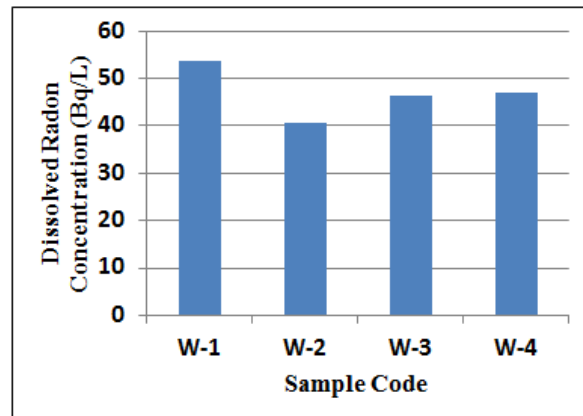**Figure 18.** Surface exhalation rate for water samples.

Figure 19. Disolved radon concentration in water 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 Ra_{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_{γ} 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.

Acknowledgments

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