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Determining of radioactivity and the accompanying radiological hazards in the sediments of the Euphrates River and wells in Babylon governorate – Iraq

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***Abstract*---**The radioactivity and radiological hazards associated with sediment samples collected from 13 locations along the Euphrates River as well as 12 associated irrigation wells were tested using a high-purity germanium system (HPGe). The radioactivity of isotopes ^{226}Ra, ^{232}Th, and ^{40}K (Iso-RTK) in these sites exceed the worldwide limits, which makes them a human health risk. The estimated radiological parameters of the Euphrates and the well sediments exceed the radium equivalent (RE), absorbed dose rate (ADR), annual effective dose external (AEDE), internal - external hazards indices (IEHI), and gamma index (Iγ). The radioactivity of ^{238}U and ^{232}Th (Iso-UT) are constant along the Euphrates River; ^{40}K (Iso-K) concentrations are elevated after the Hindyia barrage and exceed worldwide limits.

***Keywords*---**determining, radioactivity, radiological hazards, sediments.

Introduction

Pollution has increased the heavy metals concentrations in water, soil, and river sediments. Radionuclides threaten human life at high concentrations, and studies are needed to measure these species and ensure the health of soil, irrigation

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water, drinking water, river sediments, and building materials. [1] Active radionuclides are unevenly distributed in earth's crust. Knowing their spread and presence in the soil and rocks can prevent exposure dangers. There are 80,000 cases of cancer in the Euphrates River basin [2, 3, 4]. These may be linked to the high concentrations of ^{226}Ra in the surface waters of the Euphrates River and the groundwater extracted from the scattered wells. Prior work used 140 groundwater samples.

Globally, many studies studied the effects and resources of the radioactive material [5]. People have assessed the radioactivity magnitudes in rock, soil, and sediments in Anoka Zamfara State. The Gamma-Ray Spectrometry (GRS) was used to measure Iso-RTKU concentrations. Exposure to ionizing radiation was attributed to mining in Anoka. Prior work [6] used a HPGe detector to measure the radionuclides in sediments in Thazhankuda east of Tamilnadu. The average value of uranium, thorium and potassium were measured. A statistical method was used to understand the relationship in between the measured radionuclides. Other work [7] collected 15 random samples from the coastal soils of Akwa Ibom in southern Nigeria to measure natural radionuclides with a Peg detector. The Iso-RTK concentrations were below 1000, 1000, and 4000 Bq kg^{-1}, respectively; thus soil sediments were concluded to be safe.

Others [8] characterized the radiological hazards of industrial ^{137}Cs and normal Iso-RTK of Bafa Lake using a HPGe detector. The visual distribution of these radionuclides offer good information for future studies. HPGe was also used to measure the forgoing nuclides concentrations in the Tuomo River, Nigeria [9]. The mean values of the active radionuclides are within the world allowable limits (safe for human health). The active concentrations of the considered nuclides and their accompanying hazards were also measured in Puliyanthangal Lake, Tamil Nadu using HPGe [10]: The dose rates were 95 $nGyh^{-1}$ above global permissible limit 84$nGyh^{-1}$. The radioactivity magnitude of stream sediments were measured over 50 points in Gabal El Seila (deser of southeastern Egypt) [11]. The GRS was used to determine the^{40} K, ^{238}U and ^{232}Th concentrations. The radiological hazard indices were estimated and compared with global ranges.

Exposure of the public to gamma rays (GR) from heavy radioactive minerals of the radionuclides from Wadi sediments was also reported [12]. The geological analysis included sediments resulted from the peripheral granite (syeno granite, quartz, syenite alkaline, and feldspar). The radiological hazards indicate that people were exposed to emitted GR that may induce bad health effects. The main conclusion is that the use of Polluted sediments with the nuclides radioactivity in building material industry is not recommended. HPGe and X-ray fluorescence (XR) analysis were employed used to evaluate the ^{238}U and ^{232}Th natural radioactivity of granite rock [13]. Thirteen trace elements were estimated by XR. The strontium, zirconium, and barium radioactivity was high in all 24 samples but uranium was not. Granite from southern Egypt are not recommended for building materials [14] due to high radioactivity.

Another study evaluated the radioactivity of a set of soil samples and phosphate tailings and in the labs of Jožef Stefan Institute with samples from Kpogamé mining site. A HPGe detector helped calculate the ADR and RE, IEHI, AEDE, high

Iy, and excess lifetime cancer risk for outdoor exposure. High concentrations of (ISO-RT) (319.3 and 57.9 Bq kg^{-1}, respectively) were compared to the worldwide limit. The results reveal that the possibility of getting cancer is very high at locations around the Kpogamé phosphate mine. Alternative sites that do not endanger the public are needed.

Another study tested 30 surface soil samples from Babylon, Iraq for Iso-RTKU using XR NaI (TI) detector [15]. The radionuclide concentrations and radiological hazards were within the global limits [16]. The coefficient of gamma mass attenuation for samples of soils polluted with oil from Kirkuk city, Iraq was measured [17]. The obtained coefficients at energies 59.5, 356.5, 662, 1173, and 1332 keV using Geant4 and XCOM codes were compared with experimental results. They agree well with Monte Carlo simulation code Geant4. In addition, γ-ray spectrometer data was used for radioactive sediment estimation in Wadi Diit Sermatai [18]. The sediments enriched with ilmenite, sphene, zircon, aptite, rutile, and garnet and entered in industries that reflect adverse health effects. The measured radiological radionuclides exceed the worldwide limits except for ^{232}Th. Radiological hazard parameters reveal that emitted gamma radiation cannot cause any unfavorable health effects [19].

The natural magnitudes of Iso-RTK concentricity from 89 soil and 84 sediment samples from the Nile River basin and delta were analyzed. The study aimed to assess the effect of transportable sediment radioactivity from the high plateau of Ethiopia. The hazard indices indicate a direct contact or usage of mud bricks reflecting low radiological exposure. Radiation levels were measured in rare minerals containing thorium [20]; these minerals were from Pulmodai, Sri Lanka mines and emit ionizing alpha and gamma on decay. This study then correlated the data to the frequency of cancer in people living nearby. A correlation study was carried out on subjects between 35-45 years and of both sexes. Measurements on soil samples were obtained via gamma spectrometry and a survey meter. Here, five cm^3 of venous blood was drawn for MN assays of cancer markers. The radionuclides were measured by a survey meter. The ^{232}Th, ^{226}Ra, and ^{210}Pb from soil samples obtained from the Lanka Mineral Sands were the highest. The basic radioactivity concentrations correlated with micronuclei but with a small correlation magnitude (R=0.176 and P=0.04). This indicates that exposing to low doses for long periods may lead to genpoisoning.

Radionuclides in surface sedimentations brought from Nile River and Red Sea coasts were recently reviewed [21]. The samples were studied via neutron analysis. The hazardous indices in the marine and Nile sedimentations and were found above the permissible magnitudes. Dotted granite from eastern desert of Egypt was tested by HPGe and coupled plasma spectroscopy with releasing spectroscopy for chemical analysis [22]. The mean magnitudes of Iso-RTKU concentricity were found above than the global limits in the construction materials. HPGe was employed to examine the radioactivity of iso-TKU concentricity, and ^{137}Cs in sediments taken from Şavşat Black Lake, Turkey [23]. The results indicate that radioactivity will not impact human health. In addition, 16 samples of sediments taken from the lake of Namal, Pakistan were studied [24]. HPGe examined isotopes ^{137}Cs, ^{40}K, ^{226}Ra, ^{228}Ra, and ^{232}Th. The ERICA software tool was used to analyze fish from the lake; there was no toxicity.

A radiological survey was done on building materials including granitoids from Nikeiba desert in southern Egypt [25].

The radioactivity of ^{238}U, ^{232}Th, ^{40}K, and granitoids was examined by aGS-256 spectrometer with 0.35 liters of sodium iodide and a thallium activated detector. The hazard characteristics due to ^{238}U and ^{232}Th were determined with a variance 89.76% derived by PCA. Environmental contamination was studied in Boraboy Lake, Turkey including heavy metals and natural radioactivity [26]. This lake is used for agriculture and tourism. The study investigated the effects of the radioactivity on public health, heavy metal (such as Cadmium, Magnesium Iron, mercury, nickel, Zinc, Aluminum and Chrome) concentricity, radiological hazards, and the relationship between physiochemical characteristics (such as pH, Ec, saturation) and heavy metal concentrations in the lake. All hazard indices are within the acceptable limits of atomic radiation [16]; the heavy metals in soil, water, and sediments were also within tolerable limits. The GR was examined in images disassembling to be employed for Iso-Cs remediation of waste disposable materials by converting long live isotopes to other half live or unstable. The work is based on MATLAB calculations for reduction process. It was found that GR flux $\leq 10^{17}\, cm^{-2}s^{-1}$ is insufficient to perform incineration of Iso-Cs but GR flux $\geq 10^{18}\, cm^{-2}s^{-1}$ can offer incineration a hundred times faster [27]. Our goal here was to expand on this literature with samples from the Euphrates River and wells scattered randomly throughout the area. These waters are used in irrigation and for drinking water. The results showed that radioactive and carcinogenic substances increased in some sites after the Al-Hindyia Barrage. The others were originally present in the riverbed. Radioactive materials in the sediments of water wells exceeded global levels due to natural geological formations.

Study purposes

This study evaluated radioactive materials in the sediments of the Euphrates River as well as wells in Euphrates River basin. We compared the levels with permissible global limits and identified the sources of these contaminants

The study area

The province of Babylon is located in the sedimentary plain area in central Iraq between longitudes (44°00 '- 45°08') East and latitudes (32°70 '- 31°90') North; it is 27 meters above sea level (a.s.l.), north part of Middle Euphrates Region. The Euphrates River enters the governorate from its northern side and branches into the Al-Hindyia Barrage (with worldwide coordinates $E44^{\circ}, 16.9', 12''$ and $N32^{\circ}, 43.39', 36''$) to the Hillah Rivers. The Euphrates River latter passes through Al-Kifl City, where the Hillah River passes through Hillah and is the main source of urban and irrigation water. The geographic map and the locations of sediment sampling are shown in Fig. 1.

Materials and Methods

Sampling methodology

There were 25 specimen based on the administrative map and the use of GPS. Thirteen sediment samples were denoted by SR1 to SR13 and collected from specified locations along the Euphrates River; 12 sediment samples were denoted by SW1 to SW12 were extracted from the bottom of the existing wells chosen so that to cover most of the study area. The samples were taken during March to October 2021 (the season of water scarcity were radioactive pollutant levels would be highest). All sample locations were fixed in the map location of Fig. 1.

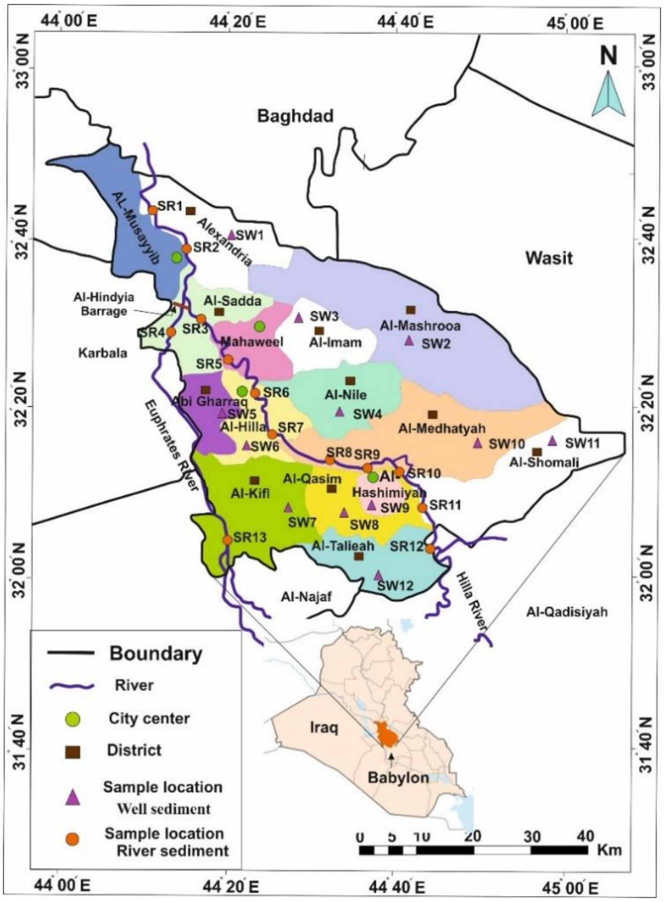

Fig 1. Location map of Babylon and Euphrates River

HPGe

The HPGe is usually employed to examine the collected samples. The crystal size was 209 cm^3 with a 63-mm diameter. It has an efficiency of 40%, reparability of 1.75 keV at an energy of 1.332 MeV returning to the cobalt-60 isotope. It operates with an operating voltage 2100 V. The germanium detector is surrounded by a lead shield (12 x 50 x 50 cm) to isolate the background radiation from the samples for accurate measurement. The inside lead shield is covered with a layer of copper and a layer of cadmium to attenuate the X-rays [16] [1]. The sensitivity of the detector is about 0.5 Bq, and the detector is cooled to 77 K using liquid nitrogen. A europium-152 standard source in a Marinelli beaker was used to calibrate the system, Fig. 2.

(A) (HPGe)

(B) Marinelli beaker

Fig 2. Examination devices

Issues during measurement

Radiation background

The radiation background must be measured and subtracted from sample radioactivity. The radiation background is measured by placing an empty Marinelli beaker on the face of the germanium crystal for the same period of time. This process is repeated three times to obtain the average value.

Geometric shape of the sample

A Marinelli beaker was used to measure the radioactivity of all samples. Samples were carefully placed in a geometric beaker with a known capacity. Standard sources of the same geometric shape as the unknown samples were used to calculate the efficiency of the HPGe.

Samples preparation for HPGe system

The radiological examination of the sediment samples requires them to be placed in plastic bags with a capacity of 1 kg. The samples were prepared by exposing them to sunlight for 72 hours to ensure a complete drying in order to obtain dry weights. The samples were ground with an electric mill, and a metal clip was used after grinding. This contains holes with a diameter of 1 milliliter to obtain homogeneous samples. Next, one kilogram of each specimen was prepared and placed in a clean Marnelli container. The container was used after washing by dilute hydrochloric acid and distilled water. The Iso-RTK were estimated by the following equation [28]:

$$A_s\left(\frac{Bq}{kg}\right) = Ca/\varepsilon\, P_\tau M_s \qquad \ldots\ldots\ldots.(1)$$

Where As: is the active concentricity for the radio nucleus samples, Ca is the net total rate below the ultimate value, P_τ is the absolute transition probability of the specific ɣ ray, M_s is the mass of the sample in kg, and ε is the detector efficiency at a specific ɣ ray energy.

Estimation of radiological hazard

The following hazard factors were calculated corresponding to the Iso-RTK concentricity.

ADR in air

To evaluate the rate of the absorbed dose resulting from exposure of the body to the ground gamma rays, the conversion factor for the Iso-RTK were measured due to the following equation [16]:

$$D\left(\frac{nGy}{h}\right) = 0.462C_u + 0.604C_{Tb} = 0.0417C_k \quad \ldots\ldots (2)$$

Annual Effective Dose Rate (AED)

To determine this equivalent, the outdoor (0.2) or indoor (0.8) occupancy factor were used. In addition, the factor (0.7 Sv.Gy^{-1}) was used to change ADR into AEDE, which is usually acquired by human body, [29].

$$AEDE\ msv.y^{-1}(outdoor) = (DnG.h^{-1}) * (8760h.y^{-1}) * 0.2 * (0.7sv.Gy^{-1}) * 10^{-6} \quad \ldots\ldots(3)$$

$$AEDE\ msv.y^{-1}(indoor) = (DnG.h^{-1}) * (8760h.y^{-1}) * 0.8 * (0.7sv.Gy^{-1}) * 10^{-6} \quad \ldots\ldots(4)$$

RE Activity

The index Ra_{eq} represents the concentricity of Iso-RTK in one batch considering the associated radiation hazards. It may be estimated by Eq.5 [30]:

$$Ra_{eq}\left(\frac{Bq}{kg}\right) = 1.43(A_{Th}) + A_{Ra} + 0.077(A_k) \qquad ......(5)$$

Considering that $A_{Th}, A_{Ra}, , and\, A_k$ are the specific activity of Iso-RTK concentricity measured in Bq / kg^{-1}.

(Iγ) Estimation

The hazard index $\boldsymbol{I_\gamma}$ was estimated for sediment samples via the following equation, [31]:

$$\boldsymbol{I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500}} \qquad ....(6)$$

External and Internal Hazard Factors (H_{ex}) & (H_{in})

We next assessed the external and internal radiation risk factors that result from the decomposition of radioactive materials and the occurrence of the radioactive field. Risk factors ratios <1 ensure low risk of exposure. The risk factors may be estimated by the following equations [15]:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} = \frac{A_k}{4810} \quad \leq 1 \qquad ....(7)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} = \frac{A_k}{4810} \quad \leq 1 \qquad ....(8)$$

Results and Discussion

Radioactive concentricity of Euphrates sediments

The concentricity of Iso-RTK in Euphrates River the sediments and the existing wells that irrigate the agricultural lands were measured. The ^{226}Ra concentration is one of the most important radionuclides of the ^{238}U series and is high at 79.2±8 Bq.kg^{-1} at SR5 in Al-Mahaweel region, Fig. 1. The lowest concentration is 31.5±25 Bq.kg^{-1} at SR9 in the Al-Hashimiyah region. A higher concentration of ^{232}Th is 47.8±11 Bq.kg^{-1} at SR10 in Al-Medhatya and the lowest concentration (12.3±2 Bq.kg^{-1}) is at location SR1 in Al-Alexandria. The highest ^{40}K concentration 453.2±46 Bq /.kg is at SR8 in Al-Medhatya, and the minimum concentration (33.4±5.3 Bq.kg^{-1}) is at SR13 in Al-Kifl as shown in Table 1 and Fig. 3.

Table 1
Radioactivity of Euphrates Sediments in Bq/.kg

Remarks	^{226}RaBq/.Kg	^{323}Th Bq /.Kg	^{40}K Bq./ Kg
SR1	35.2±5	12.3±2	140.8±17

SR2	78.6±14	38.4±6	155.6±47
SR3	72.2±16	22.6±4	367.5±20
SR4	65.4±20	34.7±18	378.5±40
SR5	79.2±8	38.3±9	226.7±21
SR6	57.4±17	28.5±6	436.3±22
SR7	77.3±13	34.2±6	451.6±25
SR8	68.3±11	36.7±6.1	453.2±46
SR9	31.5±25	13.4±22	229.7±79
SR10	70.8±39	47.8±11	423.2±11
SR11	60.6±19	22.1±4.9	198.4±26
SR12	68.5±7	39.2±6	170.3±24
SR13	75.3±19	43.1±6	33.4±5.3
Average	64.64	31.638	281.93
Max.	79.2	47.8	453.2
Min.	31.5	12.3	33.4

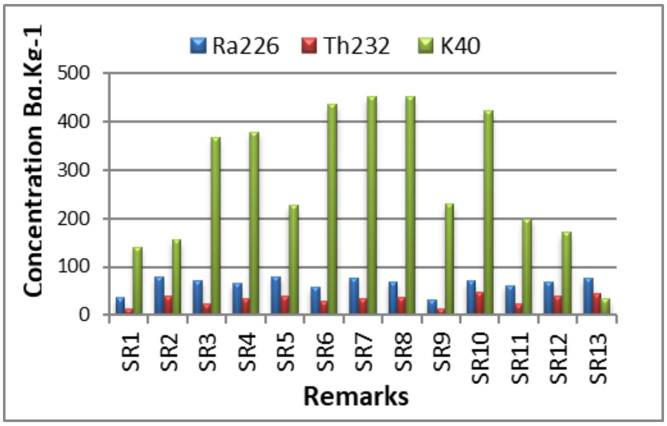

Fig 3. Concentrations of radioactive isotopes of Euphrates sediments

Radioactivity of wells sediments

The results indicate that the Maximum and Minimum concentricity of ^{226}Ra are 137.2±25 Bq/kg and 55.6±22 Bq/.kg in SW8 and SW5, respectively. The maximum and minimum concentrations of ^{232}Th were 81.6±15 Bq/.kg and 10.3±6 Bq/.kg in SW6 and SW11, respectively. The highest and lowest ^{40}K values were 852.8±54 Bq/.kg and 370.2±77 Bq/.kg at SW8 and SW1, respectively, Table 2 and Fig. 4

Table 2
Radioactive concentrations of wells sediments (Bq Kg^{-1})

Remarks	^{40}K	^{232}Th	^{226}Ra
SW1	370.2±77	32.8±6	76.4±7
SW2	624.2±24	40.5±6	114.1±7
SW3	743.4±25	19.2±3.9	67.6±15

SW4	552.6±20	11.7±4	70.8±6.7
SW5	690.1±111	48.5±6	55.6±22
SW6	723.2±39.7	81.6±15	109.2±30
SW7	651.6±30	32.6±9	91.8±8
SW8	852.8±54	54.1±18	137.2±25
SW9	797.4±53	51.8±19	92.4±23
SW10	760.1±20	50.7±5	110.6±27
SW11	472.2±19	10.3±6	75.2±32
SW12	526.5±33	18.5±28	68.9±4
Average	647.025	37.691	89.15
Max.	853.8	81.6	137.2
Min.	370.2	10.3	55.6

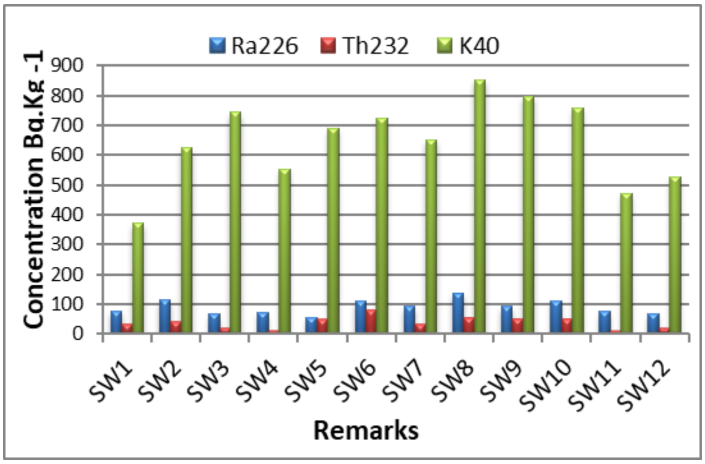

Fig 4. Concentrations of radioactive isotopes in sediments of existing wells

There was an increase in some isotope concentrations in the well sediments versus the Euphrates River sediments. Both exceed the permissible limit. This is attributed to many reasons including human activities, the use of agricultural phosphate and potassium fertilizers, facilities built on the river, the geological nature of the river waterway, and the disposal of waste. These factors change the river chemistry and play an important role in dissolving and depositing radioactive materials.

Radioactive parameters

The radium equivalent of Euphrates sediments has the maximum magnitude value 171.74 Bq/.kg at SR10. The lowest value is 63.6374 Bq/.kg^{-} in SR1 with a mean magnitude of 131.59 Bq/.kg. For well sediment, the maximum magnitude is 281.57 Bq/.kg at SW6, and the minimum is 126.28 Bq/.kg at SW11 with a mean magnitude 192.87 Bq/.kg. See Figs. 5, 6, 7, and 8 as well as Tables 3 and 4.

Table 3
RE, ADR in the air, AEDE, AEDI, hazard indices Hex, Hin and Iy of Euphrates River sediments

Remarks	Raeq Bq. kg-1	D nGy. h-1	AEDE out mSv.y-1	AEDE in mSv.y-1	H in	H ex	I γ
SR1	63.63	29.56	0.036	0.145	0.267	0.172	0.452
SR2	145.49	65.99	0.081	0.324	0.605	0.393	1.012
SR3	132.82	62.33	0.076	0.306	0.554	0.359	0.952
SR4	144.17	66.96	0.082	0.329	0.566	0.389	1.035
SR5	151.42	69.18	0.085	0.339	0.623	0.409	1.062
SR6	131.75	61.93	0.076	0.304	0.511	0.356	0.959
SR7	160.98	75.20	0.092	0.369	0.644	0.435	1.158
SR8	155.68	72.62	0.089	0.356	0.605	0.420	1.124
SR9	68.35	32.23	0.039	0.158	0.269	0.185	0.497
SR10	171.74	79.23	0.097	0.389	0.655	0.464	1.232
SR11	107.49	49.62	0.061	0.243	0.454	0.290	0.757
SR12	137.67	62.43	0.077	0.306	0.557	0.372	0.962
SR13	139.50	62.21	0.076	0.305	0.580	0.377	0.955
Average	131.59	60.73	0.074	0.298	0.530	0.355	0.935
Max.	171.74	79.23	0.097	0.389	0.655	0.464	1.232
Min.	63.63	29.56	0.036	0.145	0.267	0.172	0.452

Table 4
RE, ADR in the air, AEDE, AEDI, hazard indices Hex, Hin and Iy of well sediments

Remarks	Ra_{eq} Bq. kg^{-1}	D nGy. h^{-1}	AEDE $_{out}$ mSv.y^{-1}	AEDE $_{in}$ mSv.y^{-1}	H $_{in}$	H $_{ex}$	I $_γ$
SW1	151.8	70.55	0.087	0.346	0.61	0.410	1.084
SW2	220.0	103.21	0.127	0.506	0.90	0.595	1.582
SW3	152.2	73.83	0.091	0.362	0.59	0.411	1.138
SW4	130.0	62.82	0.077	0.308	0.54	0.351	0.957
SW5	178.0	83.76	0.103	0.411	0.63	0.481	1.316
SW6	281.5	129.89	0.159	0.637	1.05	0.761	2.026
SW7	188.5	89.27	0.109	0.438	0.75	0.509	1.372
SW8	280.2	131.62	0.161	0.646	1.12	0.757	2.024
SW9	227.8	107.23	0.132	0.526	0.86	0.616	1.666
SW10	241.6	113.42	0.139	0.556	0.95	0.653	1.751
SW11	126.2	60.65	0.074	0.298	0.54	0.341	0.919
SW12	135.8	64.96	0.079	0.319	0.55	0.367	0.995
Average	192.8	90.93	0.112	0.446	0.76	0.520	1.4026
Max.	281.57	131.62	0.161	0.646	1.12	0.761	2.026
Min.	126.28	60.65	0.074	0.298	0.543	0.341	0.919

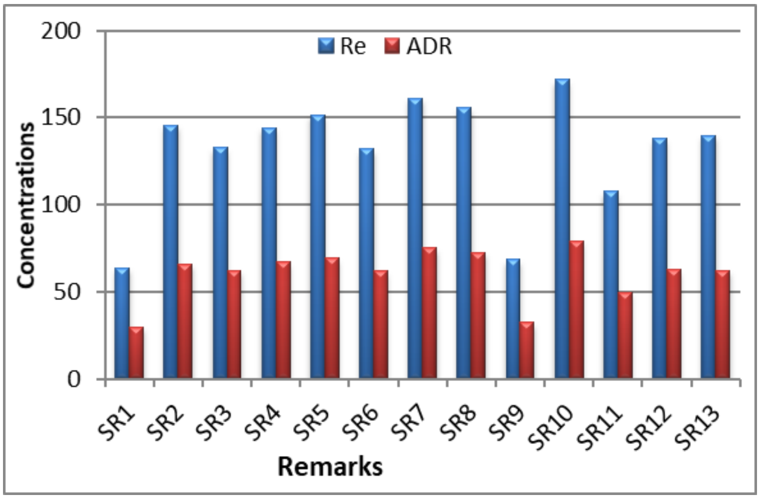

Fig. 5. RE (Bq/kg) and ADR (nGy/h) in the air of Euphrates River sediments.

The rate of absorbed dose in the sediments of the Euphrates River was the max at 79.23 nGy/.h in SR10 and the min dose 29.56 nGy/.h in SR1. The mean dose was 60.73 nGy/.h. The well sediments had the highest value of 131.62 $nGy.h^{-1}$ in SW8, and the lowest dose of 60.65 $nGy.h^{-1}$ in SW11; the average was 90.93 $nGy.h^{-1}$. The AEDE for the sediments of the Euphrates River has the max magnitude of 0.097 mSv/year in SR10; the min magnitude was 0.036 mSv/year in SR1 with an average of 0.074 $mSv/year^{-1}$. The max magnitude of the internal dose was 0.389 mSv/year in SR10, and the min magnitude was 0.145 mSv/year in the SR1 with a mean magnitude of 0.298 mSv /year. The max external dose magnitude for well sediments was 0.161 mSv/year in SW8; the min magnitude was 0.074 mSv/year in SW11 with a mean magnitude of 0.112 mSv/year. The max and min internal doses were 0.646 mSv/year and 0.298 mSv/year in SW8 and SW11, respectively, with an average of 0.446 mSv/year.

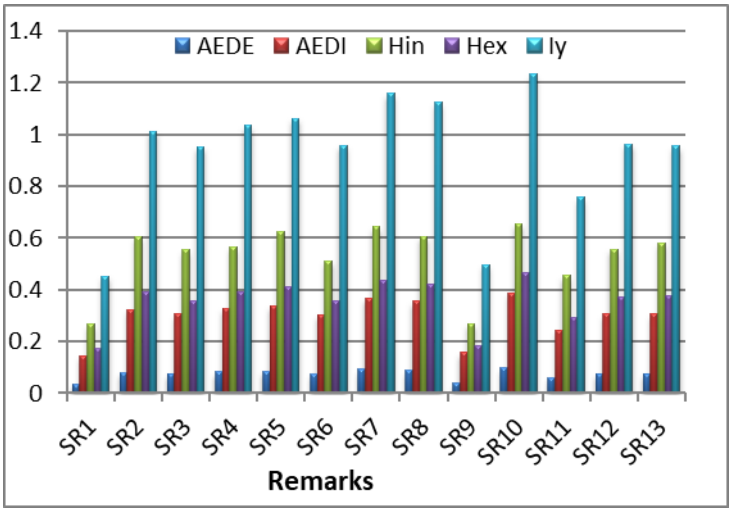

Fig. 6. AEDE (mSv/year), AEDI (mSv/year), Hex. and Hin, and Iɣ, for Sedimentations of Euphrates River

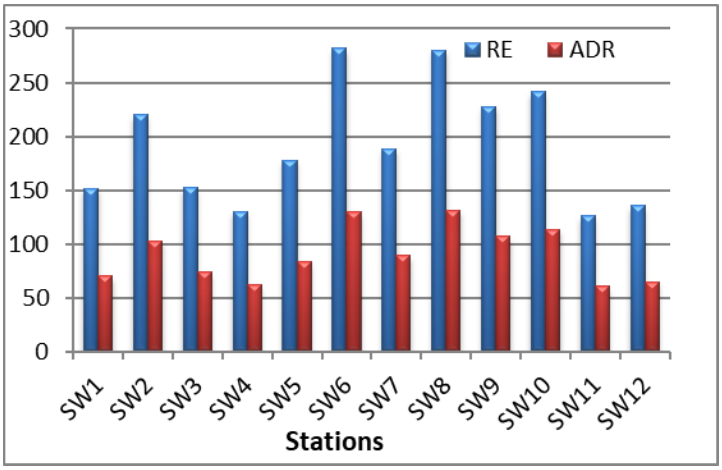

Fig 7. RE (Bq/kg) and ADR (nGy/h) in the air for Sedimentations of some existing wells

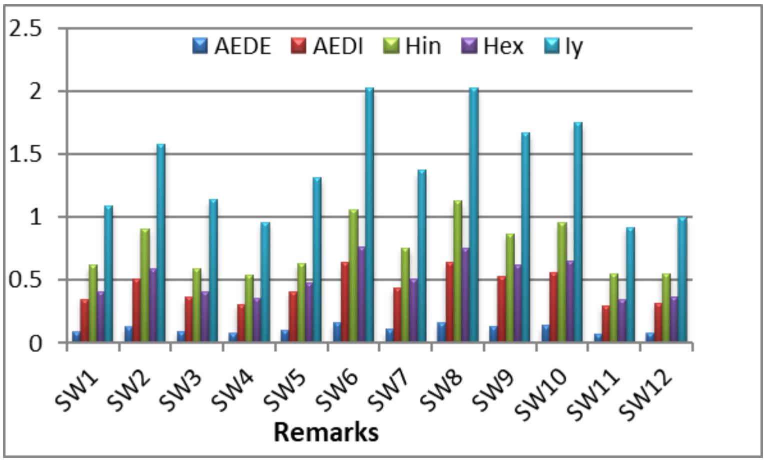

Fig 8. AEDE (mSv/year), AEDI (mSv/year), Hex. and Hin, and Iɣ for sedimentations of some wells in Babylon governorate

Two factors Hex and Hin were evaluated for each collected specimen. The Max and min magnitudes these indices for Euphrates River sediments were 0.464 and 0.172 at SR10 and SR1, respectively, with a mean of 0.355. The max and min magnitudes of Hin were 0.655 and 0.267 in SR10 and SR1, respectively, with a mean magnitude of 0.530. The well sediments had the max and min external indicator values of 0.761 and 0.341 in SW6 and SW11, respectively, with a mean of 0.520. The max and min of Hin were 1.128 and 0.543 at SW8 and SW4, respectively, with a mean of 0.762. The Iγ is also an important factor and was evaluated for all sediment samples. The highest and lowest values of river sediments were 1.232 and 0.452 at SR10 and SR1, respectively, with an average of 0.935. For well sediments, the highest and lowest values were 2.026 and 0.919 at SW6 and SW11, respectively, with an average of 1.4026.

Conclusions

The most important findings are that AED rate and GR rate exceeded the permissible limits. Other results were within the global permissible limits for Euphrates River drinking water. The well sediments had radioactivity that exceeded the global permissible limits: ADR, AEDE,AEDI, Hin, and Iy. The radioactivity magnitudes of Iso-TUK for Euphrates and the existing wells sedimentations were mostly more than the magnitude of the isotopes' global limits of 25 Bq/kg, 25 Bq/kg and, 370 Bq/kg respectively. The main important conclusion is that ^{238}U and ^{232}Th are present at constant rates in the Euphrates River before and after Al Hindyia Barrage but ^{40}K suddenly increases after the barrage and continues with the same rates without any response to the natural purification of the river. This may be due to the geology of the river waterway and human activities on land, i.e., phosphate and potash fertilizers and disposal of waste water. These factors change the geochemistry of the river and play an important role in dissolving and precipitating radioactive materials.

Table 5
List of abbreviations

Phrases	Abbreviation
high-purity germanium system	HPGe
Isotopes^{226}Ra, ^{232}Th, ^{40}K	Iso-RTK
Isotopes^{226}Ra, ^{232}Th	Iso-RT
Isotopes^{226}Ra, ^{232}Th, ^{238}U	Iso-RTU
Isotopes^{226}Ra, ^{232}Th, ^{238}U, ^{40}K	Iso-RTUK
Isotopes, ^{232}Th, ^{238}U, ^{40}K	Iso-TUK
Isotopes ^{137}Cs	Iso-Cs
Gamma-ray spectrometry	GRS
Gamma ray	GR
X-ray fluorescence	XR
Radium equivalent	RE
Absorbed dose rate	ADR
Internal-external hazards indices	IEHI
Internal hazard index	Hin
External hazard index	Hex
Gamma index	Iy
Annual effective dose	AED
Annual effective dose external	AEDE
Annual effective dose internal	AEDI
Above mean sea level	a.s.l,

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