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Radioactivity Levels in Water Samples of Tigris River in Baghdad City, Iraq

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Abstract
The natural radioactivity levels in water samples along the Tigris river (one of the major rivers of the world) within Baghdad city were investigated to determine and evaluate the radioactivity risks in the water of the river. The specific activity of the radionuclides (^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs) for thirty different water samples from Tigris river within Baghdad city were measured using gamma-ray spectrometer, employing a NaI(Tl) scintillation detector. The results showed that the average value of the specific activity for ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs were (24.20, 16.70, 329.22, and 19.40) Bq/l, respectively. The calculated average annual effective doses for different age groups were found to be (3.80, 6.57, and 5.59) mSv/y for infants, children, and adults, respectively, which are much higher than the globally allowed annual limits of the dose (0.26, 0.2 and 0.1) mSv/y for infants, children and adults, respectively, and it has harmful effects on health.

Keywords: specific activity, radionuclides, gamma-ray spectrometer, River water Annual effective dose.

مستويات النشاط الإشعاعي في عينات مياه نهر دجلة في مدينة بغداد ، العراق

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الخلاصة
تم فحص مستويات النشاط الإشعاعي الطبيعي في عينات المياه على طول نهر دجلة (أحد الأنهار الرئيسية في العالم) داخل مدينة بغداد لتحديد وتقييم مخاطر النشاط الإشعاعي في مياه النهر. تم قياس النشاط النوعي للنويدات المشعة (^{238}U, ^{232}Th, ^{40}K و ^{137}Cs) لثلاثين عينة مياه مختلفة من نهر دجلة داخل مدينة بغداد ، العراق باستخدام مطياف أشعة غاما والكاشف الوميضي NaI(Tl). أظهرت النتائج أن متوسط قيمة النشاط المحدد لـ (^{238}U, ^{232}Th, ^{40}K و ^{137}Cs) كانت (24.20 و 16.70 و 329.22 و 19.40) بيكريل / لتر على التوالي. وجد أن متوسط الجرعات الفعالة السنوية المحسوبة للفئات العمرية المختلفة هو (3.80 ، 6.57 ، 5.59) ملي سيفرت / سنة للرضع والأطفال والبالغين على التوالي ، وهو أعلى بكثير من الحد السنوي المسموح به عالميا للجرعة (0.26، 0.2، 0.1) ملي سيفرت / سنة للرضع والأطفال والبالغين على التوالي ولها آثار ضارة على الصحة .

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1. Introduction

Radiation is present in every aspect of our lives; it is a natural part of our environment and has been since the beginning of time. As a result, life has evolved in an environment with significant ionizing radiation levels. Radiation comes from all directions, including the ground (terrestrial), the space (cosmic), and even our own bodies. It exists in the air we breathe, the food and the water we consume, and even in the construction materials used to build our homes [1].

Natural sources (gamma-rays, cosmic rays, and radon gas) account for about eighty four percent of human exposure. The remaining sixteen percent comes from man-made radiation sources. The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth; for most individuals, this exposure exceeds that from all man-made sources combined [2]. As the public becomes more aware of the dangers of nuclear radiation, all sources of nuclear radiation must be monitored [3].

Water quality is an important consideration in ecological studies. The presence of radioactivity in surface water is primarily due to the presence of limited amounts of radioactive isotopes such as uranium, thorium, and radium, in addition to potassium, in the earth's crust. Radioactive decay of ^{238}U and ^{232}Th produces several series of daughter radioisotopes of different elements and different physical characteristics, such as half-life, modes of decay, and types and energies of emitted radiation [4]. Various human activities such as nuclear weapons testing, nuclear power plants, and manufacture and use of radioactive sources have recently increased the amount of natural radioactive materials in the environment. Each of the processes or exercises can cause radioactive materials to reach surface waters through various channels. Surface overflow of rainwater can pollute rivers by transporting radionuclides from urban areas, mine waste, soil weathering, and agricultural areas [5]. Moreover, another type of water contamination occurs as a result of geological formation of soil containing radioactive components referred to as Naturally Occurring Radioactive Materials (NORM). NORM can be conveyed to rivers by rain and floods [6]. The discharge of treated wastewater into the river may have an impact on the concentration of radioactive materials in the river's water.

In general, one of the essential parts of radiological studies is to offer the scientific foundation for predicting the effects of various radionuclides on man and his environment. Measurements of radiation and radioactivity are essential to determine the radiation exposure and estimate the associated human radiation dose. This information can then be linked to epidemiological studies that attempt to link radiation exposures to human health effects.

Water radiological investigations is very important to study the impact of radioisotopes (natural or man-made), released into waters, on aquatic ecosystems [7].

The Tigris River, which is 1850 kilometers long, originates in the mountains of eastern Turkey, flows south and enters Iraqi territory from the north to the south, serving as a major source of water and dividing the urban zone of the capital Baghdad into two sides for about 50 km [8].

The Tigris plain is a densely populated area, with many towns, cities, and villages extending along its banks due to the easy access to water, fertile soil, and suitable landscape. Domestic and industrial wastewater from Baghdad (which has a population of about 7 million people) is discharged directly into the river without adequate treatment [9].

2. Materials and methods

2.1. Study area

Water samples were collected from various locations along the Tigris river in Baghdad. The survey area was extended from Al-Muthana Bridge in the north of Baghdad city through all the eleven bridges within Baghdad and ends at the confluence of the Tigris river with Diyala river south of Baghdad, covering roughly 50 kilometers as shown in Figure 1 and Table 1.

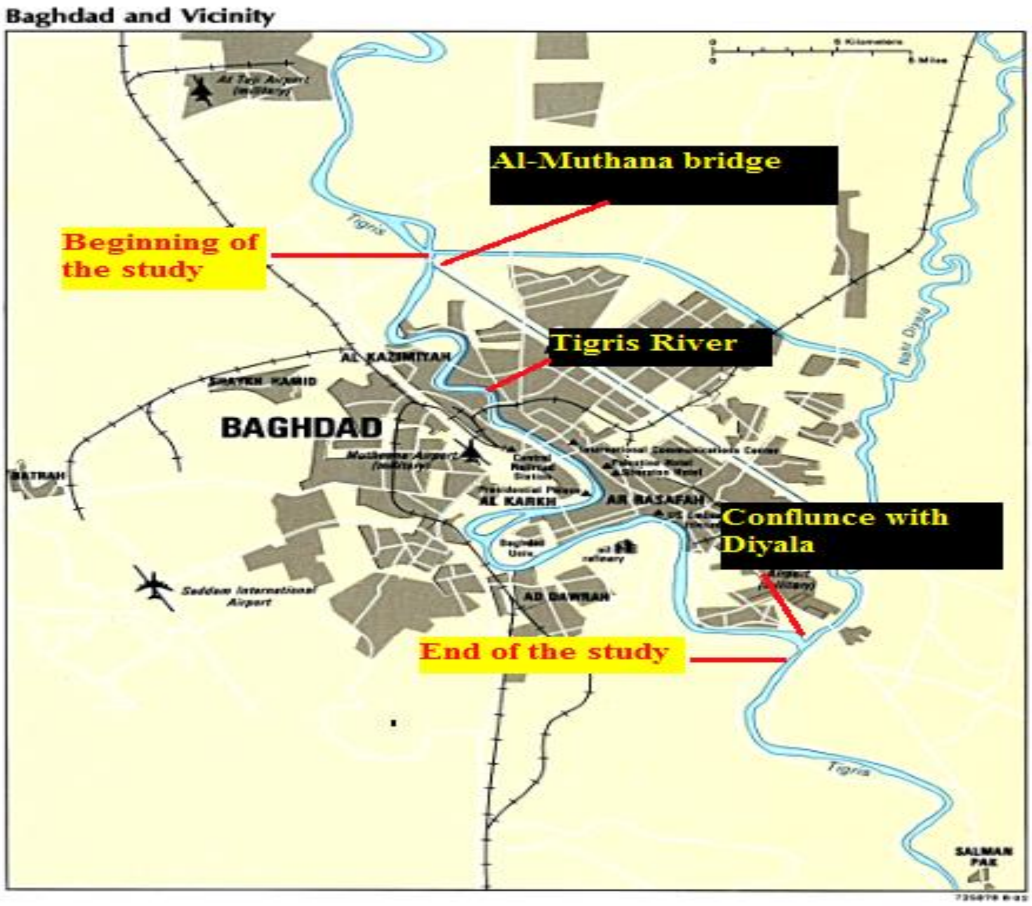

Figure 1-Tigris River study site [10].

Table 1- Locations of the water samples taken from Tigris river –Baghdad (Iraq).

Sample code	Location coordinates		Site name
	Latitude "N"	Longitude "E"	
W1	33.431737	44.346064	Al Muthanna Bridge
W2	33.413637	44.342835	Saba' Abkhar
W3	33.403459	44.3379	Al-Gherai'at 1
W4	33.395938	44.333833	Al-Gherai'at 2
W5	33.389366	44.343255	Al- Gherai'at Clinic
W6	33.392329	44.350689	Al-Dahalik Health Center
W7	33.390516	44.358517	Al-Amal Medical Complex
W8	33.375151	44.355284	Al-Aimmah Bridge
W9	33.360575	44.351384	Al- Numan Hospital
W10	33.361364	44.370679	Cornich Al-Adammiyah
W11	33.352645	44.373485	Al-Sarafia Bridge

W12	33.34417	44.373973	Medical City
W13	33.343368	44.379059	Bab Al-Muadham Bridge
W14	33.338813	44.388224	Al-Shuhada'a Bridge
W15	33.332678	44.396674	Al-Ahrar Bridge
W16	33.32847	44.40068	Al-Sinak Bridge
W17	33.324797	44.404804	Al-Jumariyah Bridge
W18	33.314024	44.414154	Abu- Nawas
W19	33.300572	44.414748	Karrada
W20	33.295527	44.400004	Suspension Bridge
W21	33.283761	44.374229	Jadriya Bridge
W22	33.280261	44.406475	Two Stories Bridge
W23	33.290206	44.447478	Dora Expressway Bridge
W24	33.2859	44.453293	Electricity station south of Baghdad
W25	33.279807	44.455111	Al- Rasheed Military Hospital
W26	33.25899	44.453462	Al-Saadia
W27	33.231252	44.457817	Pepsi Baghdad Co.
W28	33.229419	44.491283	Al-Zafaraniyah
W29	33.232682	44.516492	Diyala River
W30	33.209116	44.497786	Confluence of Tigris River with Diyala River

2.2. Sample collection and preparation

Thirty water samples were collected from thirty different places on the river. All the samples were collected in 2021. Water samples were taken directly from the edge of the river using plastic bottles with a capacity of 5 liters. The water samples were heated with an electric heater to 100^o C for 6 hours to reduce the volume of water from (5 to 1) litter. Boiling water aims to get rid of excess water and increase the concentration of radionuclides. After that, the one liter of each sample was sealed in Marinelli beakers and stored for 30 days to ensure radioactive equilibrium between ^{226}Ra and ^{232}Th and their decay products before gamma ray analysis [11]. Each sample was measured for 7200 sec using gamma-ray spectrometry with NaI(Tl) detector.

3. Experimental method for γ -spectroscopy

In the present work, gamma spectrometry system, sodium iodide NaI(Tl) detector (3"×3") coupled to PCMCA (4096 channel) (model Canberra, USA), voltage (750V), based on high efficiency (60%), was used to read the specific activity spectral data. The detector was analyzed using (GINE-2000) computer software. It was maintained in a vertical position surrounded by a shield of lead to isolate it from radiation background radiation background.

Energy and efficiency calibration of gamma spectrometer were carried out using a standard source of 1.0 L Marinelli beaker of mixed radionuclides with energies (59.53, 88.34, 661.7, 1173.24, and 1332.5) keV for ^{214}Am, ^{109}Cd, ^{137}Cs, and ^{60}Co, respectively. The counting time

was 7200 sec to measure the radioactivity of the natural and artificial radionuclides in water samples [12].
Using the activity concentrations of the 214Bi at energy (609.31) keV as equivalent to the activity concentration of 238U, the activity concentration of 228Ac at energy (911.0) keV as equivalent to the activity concentration of 232Th. The activity concentration of 40K and 137Cs was determined directly at energy (1460.8) keV and (661) keV, respectively.
4. Measurements of radioactivities
4.1. Calculation of activity concentrations in s The specific activity concentration of each sample in the spectrum was calculated by the following equation [13]: amples under investigation

$$A = \frac{N}{P(E\gamma) \times Eff \times Tc \times V}$$

where: A is The specific activity concentration of radionuclides measured in (Bq/l), N is the net area under the peak, $V$is the volume of the water sample (l), $Eff$is the The efficiency of the detectors at energy Eγ, $P(E\gamma)$ is the intensity at energy Eγ and Tc is The time of measurement which was equal to (7200 s).

4.2 Annual Effective Dose Estimation

The dose resulting from the consumption of Tigris river water was calculated using the following equation [14,15] to quantify the contribution of these radionuclides to public exposure from natural radioactivity:

$$DR_w\ (mSv/y) = A_w \times IR_w \times ID_F$$

where: DR_w stands for annual effective dose(mSv/y), A_w stands for activity (Bq/l), IR_wstands for annual water intake (l/y), and ID_F stands for effective dose conversion factor (mSv/Bq). Doses were calculated using a consumption rate of 150, 350, and 500 l/y for infants, children, and adults, respectively, as well as conversion factors of (9.6×10^{-4} , 4.5×10^{-4}, and 4.2×10^{-5} mSv/Bq) for ^{226}Ra, ^{232}Th, and ^{40}K, for infants, (8.0×10^{-4}, 2.9×10^{-4} and 1.3×10^{-5} mSv/Bq) for children and (2.8×10^{-4}, 2.3×10^{-4}, and 6.2×10^{-6} mSv/Bq) for adults reported by IAEA, ICRP, and WHO [16,17,18] .

5. Results and discussion

The distribution of the detected radionuclides ^{226}Ra, ^{232}Th, ^{40} K, and ^{137} Cs in the water samples are shown in Table 2**.** Activity concentration of ^{226}Ra recorded lowest value of 5.44 Bq/l in W21 location and the highest value of 39.66 Bq/l in W13 location with average 24.20 Bq/l. Activity concentration of ^{232}Th recorded lowest value 2.37 Bq/kg in W9 location and the highest value of 35.43 Bq/l in W18 location with average 16.70 Bq/l. Activity concentration of ^{40}K recorded lowest value 23.30 Bq/l in W25 location and the highest value of 760.06 Bq/l in W5 location with average 429.22 Bq/l. Activity concentration of ^{137}Cs recorded lowest value 10.34 Bq/l in W28 location and the highest value of 28.25 Bq/l in W30 location with average 19.40 Bq/l. Figure 2 shows the average specific activity of ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs (Bq/l) in water samples for various locations in the Tigris river**.**

Table 2-Activity concentration of ^{226}Ra, ^{232} Th, ^{40}K, and ^{137}Cs in the water samples of Tigris river in Baghdad

Sample code	^{226}Ra (Bq/l)	^{232}Th(Bq/l)	^{40}K (Bq/l)	^{137}Cs(Bq/l)
W1	23.35	20.97	315.24	24.40
W2	30.04	22.88	295.13	12.75
W3	28.32	10.45	663.70	23.87
W4	38.86	12.48	131.60	17.27
W5	28.31	24.11	760.06	22.86
W6	31.44	20.58	587.40	17.69
W7	19.63	9.48	554.10	20.22
W8	35.71	10.41	316.18	20.94
W9	32.60	2.37	421.03	17.56
W10	37.41	17.34	474.08	23.30
W11	32.87	14.96	86.70	26.60
W12	16.68	17.15	388.38	27.88
W13	39.66	6.26	530.20	15.24
W14	22.93	6.81	747.80	16.51
W15	16.64	27.41	385.56	17.99
W16	20.89	21.09	548.40	15.52
W17	20.11	15.19	737.10	19.98
W18	17.90	35.43	362.33	19.87
W19	17.55	23.73	554.70	12.05
W20	24.71	22.13	436.10	12.82
W21	5.44	16.99	426.99	22.55
W22	19.04	20.16	299.23	26.48
W23	32.66	11.35	233.93	20.21
W24	19.98	22.06	190.30	18.20
W25	22.65	27.07	23.30	19.36
W26	21.97	5.99	758.80	15.85
W27	19.20	5.83	369.23	11.22
W28	15.06	15.55	307.55	10.34
W29	16.47	23.75	666.83	24.29
W30	18.08	10.94	304.57	28.25
MAX	39.66	35.43	760.06	28.25
MIN	5.44	2.37	23.30	10.34
AVE.	24.20	16.70	429.22	19.40

The worldwide average concentrations of the radionuclides ^{238}U, ^{232}Th, and ^{40}K reported by UNSCEAR (2000) [19] are 10.0 Bq/l, 1.0 Bq/l and 10.0 Bq/l, respectively. Our results show that the average activity concentrations of ^{238}U ,^{232}Th and ^{40}K in our samples are much higher than the worldwide average concentrations.

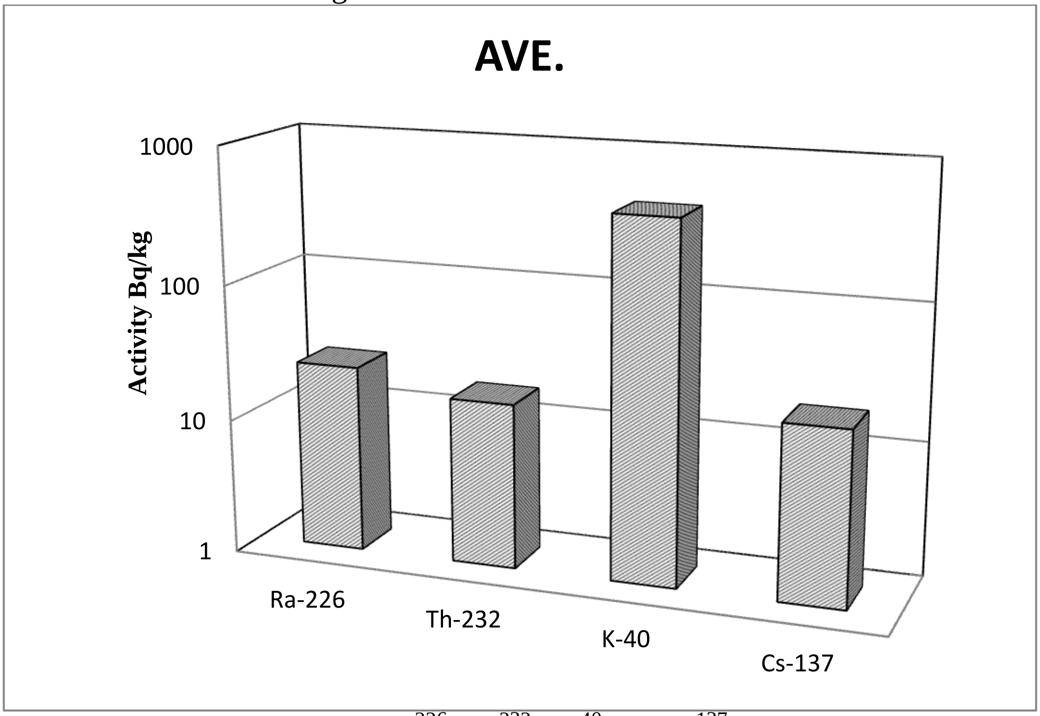

Figure 2-Average specific activity of, ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}C (Bq/kg) in water samples for various locations in the study area

The calculated annual effective dose for various age groups (infants, children and adults), based only on the ingestion of 226Ra, 232Th and 40K are shown in Table 3. From the table, the doses ranged from 7.72 mSv/y to 0.77 mSv/y with average value of 3.80 mSv/y, from 13.68 mSv/y to 1.10 mSv/y with average value of 6.57 mSv/y, and from 10.16 mSv/y to 1.91 mSv/y with average value of 5.59 mSv/y for infants, children and adults, respectively. From Figure 2, it can be seen that the highest total annual effective dose for the three age groups (infants, children and adults) were in W18 location, while the lowest doses were in W9. Figure 3 illustrates the total annual effective dose (DRw)(in mSv/y) due to ingestion of 226Ra, 232Th and 40K as calculated from the water samples of Tigris river in Baghdad for the different age groups. The average doses due to ingestion of 226Ra was higher than the average doses due to ingestion of 232Th and 40K. From the results which are also illustrated in Figure 4, one can see that the doses received by children are higher than that received by infants and adults. Thus, children are the age group at risk because of their rigorous bone growth and restricting their intake is very important.

The doses obtained in this study are much higher than the recommended reference levels of 0.26, 0.2 and 0.1 mSv/y for effective annual dose for infants, children and adults, respectively, recommended by IAEA, WHO and UNSCEAR [20,21,22]for 1 year consumption of drinking water. As a result, it is possible to conclude that the investigated waters are not acceptable for life-long human consumption and that a reduction in consumption or radionuclide concentration is required.

Table 3-Total annual effective dose (DRw)(mSv/y) due to ingestion of ^{226}Ra, ^{232}Th and ^{40}K for the different age groups as calculated from the water samples of Tigris river in Baghdad.

Sample code	^{226}Ra, (mSv/y)			^{232}Th, (mSv/y)			^{40}K, (mSv/y)			Total ingestion (mSv/y)		
	Infant	Child.	adult	Infant	Child.	adult	Infant	Child.	adult	Infant	Child.	adult
W1	3.02	5.87	2.94	1.42	2.13	2.41	0.20	0.14	0.98	4.63	8.14	6.32
W2	3.29	6.41	3.20	1.54	2.32	2.63	0.19	0.13	0.91	5.03	8.86	6.75
W3	1.51	2.93	1.46	0.71	1.06	1.20	0.42	0.30	2.06	2.63	4.29	4.72
W4	1.80	3.49	1.75	0.84	1.27	1.44	0.08	0.06	0.41	2.72	4.82	3.59
W5	3.47	6.75	3.37	1.63	2.45	2.77	0.48	0.35	2.36	5.58	9.54	8.50
W6	2.96	5.76	2.88	1.39	2.09	2.37	0.37	0.27	1.82	4.72	8.12	7.07
W7	1.37	2.65	1.33	0.64	0.96	1.09	0.35	0.25	1.72	2.35	3.87	4.14
W8	1.50	2.91	1.46	0.70	1.06	1.20	0.20	0.14	0.98	2.40	4.12	3.63
W9	0.34	0.66	0.33	0.16	0.24	0.27	0.27	0.19	1.31	0.77	1.10	1.91
W10	2.50	4.85	2.43	1.17	1.76	1.99	0.30	0.22	1.47	3.97	6.83	5.89
W11	2.15	4.19	2.09	1.01	1.52	1.72	0.05	0.04	0.27	3.22	5.75	4.08
W12	2.47	4.80	2.40	1.16	1.74	1.97	0.24	0.18	1.20	3.87	6.72	5.58
W13	0.90	1.75	0.88	0.42	0.63	0.72	0.33	0.24	1.64	1.66	2.63	3.24
W14	0.98	1.91	0.95	0.46	0.69	0.78	0.47	0.34	2.32	1.91	2.94	4.05
W15	3.95	7.67	3.84	1.85	2.78	3.15	0.24	0.18	1.20	6.04	10.63	8.18
W16	3.04	5.91	2.95	1.42	2.14	2.43	0.35	0.25	1.70	4.81	8.30	7.08
W17	2.19	4.25	2.13	1.03	1.54	1.75	0.46	0.34	2.29	3.68	6.13	6.16
W18	5.10	9.92	4.96	2.39	3.60	4.07	0.23	0.16	1.12	7.72	13.68	10.16
W19	3.42	6.65	3.32	1.60	2.41	2.73	0.35	0.25	1.72	5.37	9.31	7.77
W20	3.19	6.20	3.10	1.49	2.25	2.55	0.27	0.20	1.35	4.96	8.64	7.00
W21	2.45	4.76	2.38	1.15	1.72	1.95	0.27	0.19	1.32	3.86	6.68	5.66
W22	2.90	5.65	2.82	1.36	2.05	2.32	0.19	0.14	0.93	4.45	7.83	6.07
W23	1.63	3.18	1.59	0.77	1.15	1.31	0.15	0.11	0.73	2.55	4.44	3.62
W24	3.18	6.18	3.09	1.49	2.24	2.54	0.12	0.09	0.59	4.79	8.50	6.22
W25	3.90	7.58	3.79	1.83	2.75	3.11	0.01	0.01	0.07	5.74	10.34	6.97
W26	0.86	1.68	0.84	0.40	0.61	0.69	0.48	0.35	2.35	1.74	2.63	3.88
W27	0.84	1.63	0.82	0.39	0.59	0.67	0.23	0.17	1.14	1.47	2.39	2.63
W28	2.24	4.35	2.18	1.05	1.58	1.79	0.19	0.14	0.95	3.48	6.07	4.92
W29	3.42	6.65	3.33	1.60	2.41	2.73	0.42	0.30	2.07	5.44	9.36	8.12
W30	1.58	3.06	1.53	0.74	1.11	1.26	0.19	0.14	0.94	2.51	4.31	3.73
MAX	5.10	9.92	4.96	2.39	3.60	4.07	0.48	0.35	2.36	7.72	13.68	10.16
MIN	0.34	0.66	0.33	0.16	0.24	0.27	0.01	0.01	0.07	0.77	1.10	1.91
AVR.	2.40	4.68	2.34	1.13	1.69	1.92	0.27	0.20	1.33	3.80	6.57	5.59

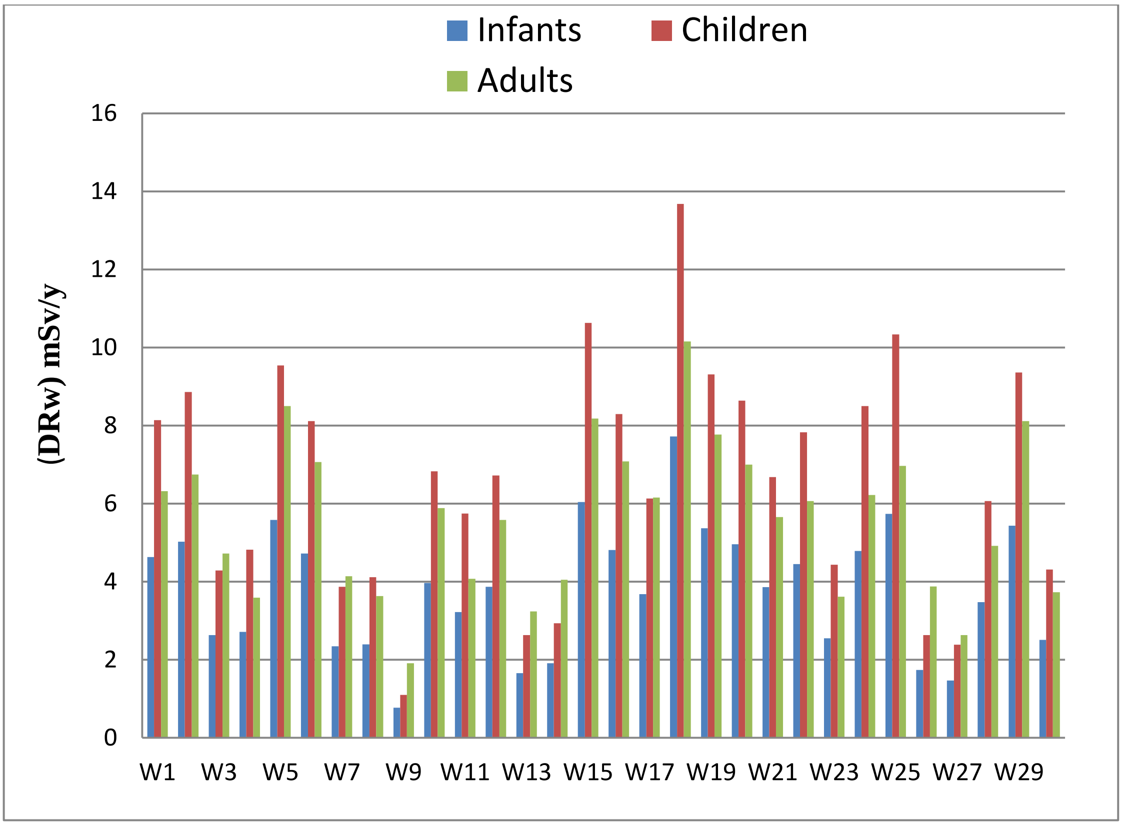

Figure 2-Total annual effective dose (DRw) mSv/y due to the ingestion of Tigris river water within Baghdad city for different age groups as calculated from the investigated water samples.

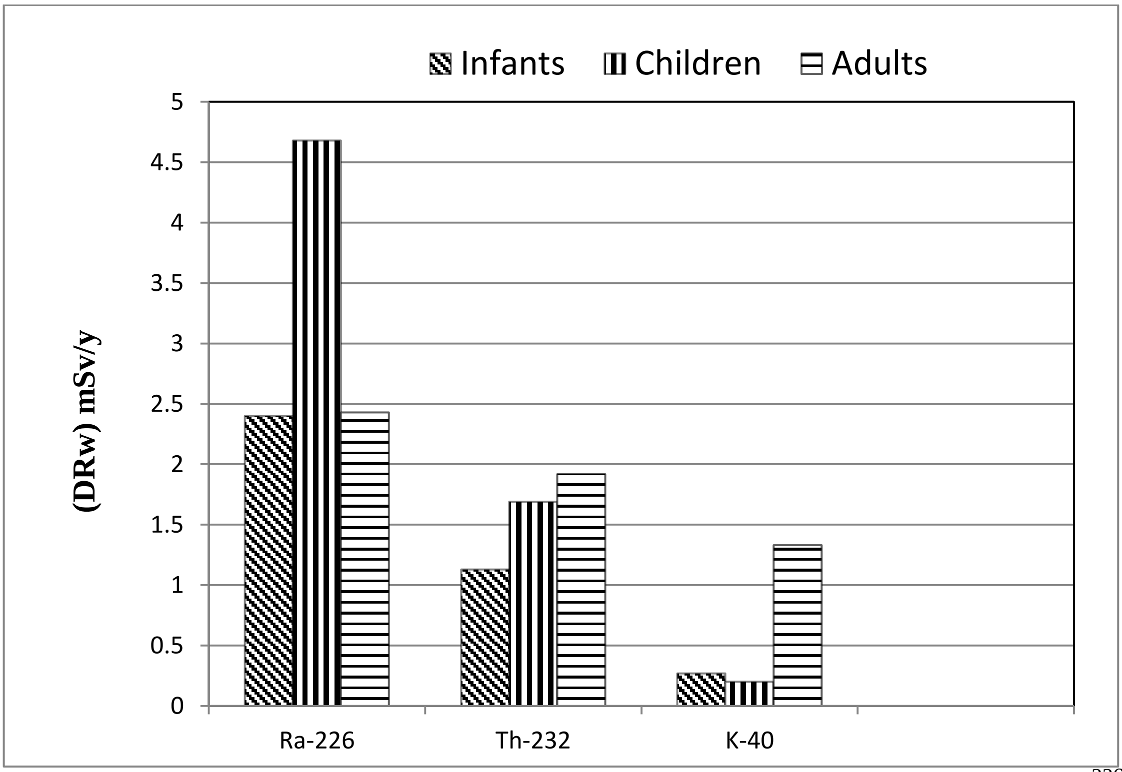

Figure 3-Average of the total annual effective dose (DRw) mSv/y due to ingestion of ^{226}Ra, ^{232}Th and ^{40}K for the different age groups in water samples.

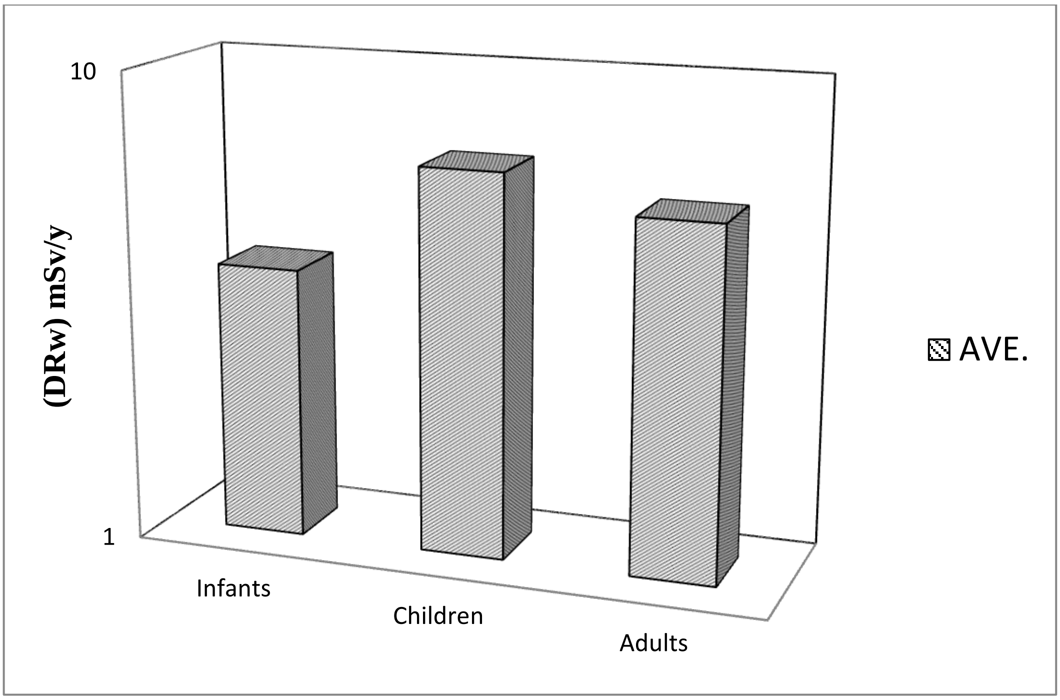

Figure 4-Average of the total annual effective dose (DRw) (mSv/y) for the different age groups due to the the consumption of Tigris river water within Baghdad city.

6. Conclusion

The study covers wide regions in Tigris River within Baghdad city, Iraq. The obtained data were provide information about the radionuclide concentrations in water of the Tigris river using gamma-ray spectroscopy with a NaI(Tl) detector. Our results showed that the average concentrations of ^{238}U, ^{232}Th and ^{40}K in water samples are much higher than the recommended global limits.

Based on our measurements the values of annual effective dose rate were also found to be much higher than those limits recommended by IAEA, WHO and UNSCEAR, which could have harmful health effects especially for children. For this reason, it is concluded that the investigated water are not acceptable as drinking water and serious steps should be taken to improve the water quality in Tigris river within Baghdad city in particular.

This study can serve as a basis for future research, and the data gathered could be useful for natural radioactivity mapping. It appears that determining the radioactivity concentrations in water from other parts of Iraq is necessary. The results could also be used as a baseline for future monitoring of radioactivity pollution.

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