Radioactivity Investigation In Water of Tigris River in Salah Al-Din Governorate, Iraq

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ABSTRACT

The specific activity of naturally radionuclides (226Ra, 212Pb, and 40K) in water samples of Tigris river was tested using a NaI(Tl) scintillation detector at 30 separate locations in tigris river in Iraq's Salah Al-Din Governorate. The activity concentrations of activity of 226Ra, 212Pb, 137Cs, and 40K ranged from (0.056, 0.702, 0.15, 105.12 Bq/L) to (805.6, 75.12, 27.6, 1149.4 Bq/L) respectively. The average The radium equivalent activity was found to be (397.4 Bq/kg). The absorbed dose rate in air for the samples was also investigated, and its average of (185.6 nGyh⁻¹). For one year, the outdoor annual effective doses with an average of (0.23 mSv/y), and the indoor annual effective doses with an average of (0.911 mSv/y). The external hazard indices, as well as the internal hazard indices, were found to be more than one higher than the global limit, with average values of 2.04 and 2.89, respectively, higher than the global limit. The International Commission on Radiological Safety and Ionizing Radiation's Biological Effects Radiation risk factors is used to measure the excess lifetime cancer risk.

Keywords: NaI(Tl) scintillation detector, γ-spectrometry, Radium-equivalent activity, Activity concentration, Internal hazard index, External hazard index, annual effective dose.

1. INTRODUCTION

The geological composition of the region is reflected in the chemical composition of the water. The precise activity of radio elements and heavy metals in water is largely determined by tropospheric geological formation and mineralization. Radionuclide distribution in waters is a major concern because of their geochemical versatility, which allows them to travel around freely and pollute different components of the atmosphere. Primitive radionuclides are present in varying amounts in the water due to weathering, sedimentation, and chemical reactions in the earth's crust. The uranium, actinium, and thorium series of naturally occurring radionuclides account for around half of the natural background external radiation[1]. The bulk of internal and external exposure to the human body is caused by gamma radiation released by naturally occurring radioactive materials found in all waters and soil [2]. The natural environment is thought to be responsible for about 85 percent of the radiation dose obtained by humans[3]. Certain anthropogenic behaviors have been found to increase the levels of these doses. The value of health physics is increasing as the need for population safety and protection from radiation exposure grows. Studies on the distribution of radionuclides in the
atmosphere and their corresponding doses can be useful as radiological baseline knowledge for developing radiation safety rules and regulations[4,5]. Numerous experiments have been performed in many parts of the world and in various geological formations in order to collect reference data for natural environmental radioactivity and related exposure [6,7].

The aim of this research was to assess radioactivity in water of Tigris river in Salah al-Din governorate and investigate of radiation hazard indicators of these naturally occurring radionuclides (\(^{226}\)Ra, \(^{228}\)Ac and \(^{40}\)K) in 30 water samples in Tigris river from Salah Al-Din Governorate, Iraq using scintillation detector NaI(Tl)[9,10].

2. The Study Area.

The Salah Al-Din government is located about 55 kilometers north of Baghdad and tigris river cross it from north to south by 293km. The coordinates for the site are 34°27′00″N 43°35′00″E. The Salah Al-Din government was divided into equal-sized sectors, and the analysis included 12 sectors in the Salah Al-Din government, as shown in Figure 1 and Table 1. Salah Al-governement Din's has a population of 1.595.354 people. And this knowledge clearly demonstrates the significance of the Salah Al-Din government in the search.

![Figure 1. Mao of Water Samples of Tigris river in Salah Al-Din Governorate.](image-url)

| Samples Code | Location       | Longitude  | Latitude  |
|--------------|----------------|------------|-----------|
| SD1          | AlSherqat-ba'aja | 35.54947   | 43.23117  |
| SD2          | AlSherqat-mashro' | 35.509302  | 43.25472  |
| SD3          | AlSherqat-kosom  | 35.477081  | 43.2709   |
| SD4          | Biji-mahzam      | 35.137094  | 43.44965  |
| SD5          | Biji-elbojwari   | 34.978383  | 43.5412   |
| SD6          | Biji-alishetehe  | 34.949254  | 43.50763  |
| SD7          | Biji-alhanshi    | 35.021586  | 43.57791  |
| SD8          | Biji-alshat      | 34.933493  | 43.51394  |
| SD9          | Biji-b'i'ajji     | 34.917269  | 43.51662  |
| SD10         | Biji-almazra'a   | 34.855359  | 43.53805  |
| SD11         | Tikrit-hajaj     | 34.778133  | 43.5824   |
| SD12         | Tikrit-mahzam    | 34.662442  | 43.67389  |
| SD13         | Tikrit-qarawardi | 34.670019  | 43.66819  |
3. Materials and Procedures

In the year 2020, thirty water samples were collected from eight sectors from Tigris river in the Salah Al-Din Governorate in Iraq. The samples were prepared by drying each water sample using an heater at 100°C until a constant weight was achieved. The samples dried up from 3 liters to 1 litter. Water samples stored in a sealed morinli beaker for 30 days to achieve the secular equilibrium between radon and its decay products[11]. The activity concentration of (226Ra, 232Th and 40K) in water samples were determined using NaI(Tl) (3x3) scintillation detector coupled to PC-MCA (4096 channel) and related accessories based on a high efficiency gamma spectrometry device with an overall efficiency of 60% and resolution of (6.5- 8.5) were used.

A multi radionuclides stander source with energies of (59.53, 88.34, 661.7, and 1333,1) keV for 214Am, 109Cd, 137Cs, and 60Co was put in front of the detector for a time of 1080 seconds to test the detector’s performance and energy calibration.

3.1. Specific activity of radionuclides

The following equation was used to calculate the precise concentrations of activity of radionuclides in water samples:[12]

\[
A = \frac{\text{Net area under the photo peak at energy (E)} - \text{B.G}}{M \times I(E) \times \epsilon(E) \times T}
\]

Where,
A: The specific activity concentration of radionuclide (Bq/L).
M: Volume of the water sample (L).
I (E): is the abundance at energy (E).
\(\epsilon(E)\): The efficiency at energy (E).
T: The time of measurement which is equal to (2h).

3.2 Evaluation of radiological hazard effects
- Radium equivalent activity (Raeq)

The definition of radium equivalent operation (Raeq) allows a single index or number to classify the gamma contribution from various mixtures of 238U, 232Th, and 40K in water samples from various
locations. Raeq was determined using the following formula [12,13]:

\[ \text{Raeq} = AU + 1.43 ATh + 0.07 AK \]  

(2)

The basic operation of $^{238}$U, $^{232}$Th, and $^{40}$K (Bq/L) is represented by AU, ATh, and AK, respectively. The gamma dose rate is assumed to be the same for 370 Bq/L of $^{238}$U, 259 Bq/L of $^{232}$Th, and 4810 Bq/L of $^{40}$K. Raeq is linked to radon and its daughters’ external-dose and internal-dose effects.

- **Absorbed gamma dose rate ($D_\gamma$)**

Based on UNSCEAR guidance, the absorbed gamma dose thresholds related to gamma radiations in air at 1 m above the ground surface for the uniform distribution of naturally occurring radionuclides ($^{238}$U, $^{232}$Th, and $^{40}$K) were determined [14]. The conversion factors for calculating the absorbed gamma dose rate ($D_\gamma$) in air per unit specific operation in Bq/L are as follows: 0.462 nGy h$^{-1}$ for $^{238}$U, 0.604 nGy h$^{-1}$ for $^{232}$Th and 0.042 nGy h$^{-1}$ for $^{40}$K. Therefore, $D_\gamma$ can be determined using the following formula [15]:

\[ DR(nGy/h) = 0.462AU + 0.604 AT + 0.042AK \]  

(3)

- **Annual Effective Doses Equivalent**

The annual effective dose equivalent (AEDE) of the member was calculated using a factor of 0.7 SvGy$^{-1}$ to convert the absorbed dose rate to human effective dose equivalent with an outdoor of 20% and an indoor of 80%. The annual effective doses equivalent outdoor and indoor is calculated using equations [16]:

\[ Outdoor \ (mSv/y) = AD\ (nGy/h) \times 8760h \times 0.2 \times 0.7 \text{SvGy/y} \times 0.000001 \]  

(4)

\[ Indoor \ (mSv/y) = AD\ (nGy/h) \times 8760h \times 0.8 \times 0.7 \text{SvGy/y} \times 0.000001 \]  

(5)

- **Radiation hazard indices**

The external and internal hazard indexes are calculated using the (Raeq) expression on the assumption that the permitted maximum value (equal to unity) corresponds to Raeq’s upper limit (370 Bq/L). The (Hex) external hazard index and internal hazard index (Hin) are then [17]:

\[ H_{ex} = \frac{AU}{370Bq/L} + \frac{ATh}{259Bq/L} + \frac{AK}{4810Bq/L} \]  

(6)

\[ H_{in} = \frac{AU}{185Bq/L} + \frac{ATh}{259Bq/L} + \frac{AK}{4810Bq/L} \]  

(7)

In order for the radiation hazard to be trivial, this index value must be less than unity.

- **Excess Lifetime Cancer Risk (ELCR)**

Excess Lifetime Cancer Risk (ELCR) is a value that represents the amount of extra cancers predicted in a given number of people on exposure to a carcinogen at a given dose, and we can measure (ELCR) using Eq. (8) if we regard (70) years as the average lifespan of a human being[18]

\[ ELCR = AEDE \times DL \times RF \]  

(8)

RF stands for risk factor (Sv1), which is the lethal cancer risk per Sievert, where AEDE stands for Annual Effective Dose Equivalent, DL stands for normal Quality of Life (estimated to be 70 years), and DL stands for average Duration of Life (estimated to be 70 years). ICRP 60 uses 0.05 for public exposure for low dose background radiations that are thought to have stochastic effects [16]. We can deduce the equation above from this value-free unit since it represents the likelihood of cancer incidence.
4 RESULTS AND DISCUSSION

Table 2 shows the activity concentrations of radionuclides in 30 water samples obtained from Tigris river in Salah Al-Din governorate. The results show that the highest concentration of $^{226}$Ra was (805.6 Bq/L) found in SD23 (Ishaqi-raqah2) higher than the concentration of specific activity of $^{238}$U global limit which is equal to (35 Bq/L) [19], while the lowest concentration (0.056 Bq/L) was found in SD13 (Tikrit-qarawardi) lower than global limit. The average concentration of $^{238}$U was (292.8 Bq/L) higher than the global limit as shown in Fig. 2.

The highest concentration of $^{212}$Pb was 75.1 Bq/L found in SD23 (Ishaqi-raqah2) higher than the specific activity concentration of $^{232}$Th global limit which is equal to (30 Bq/L) [12], while the lowest concentration (0.7 Bq/L) was found in SD25 (Ishaqi-qaban2) lower than global limit. The average concentration of $^{232}$Th was (30.8 Bq/L) near to the global limit as shown in Fig. 3.

The highest concentration of $^{40}$K was 1149.4 Bq/L found in SD4 (Biji-Mahzam) higher than the specific activity of global limit which is equal to 400 Bq/L [12], while the lowest specific activity 105.23 Bq/L was found in SD29 (Alhatamiah-Dour) lower than global limit. The average concentration of $^{232}$Th was (509.2 Bq/L) higher than the global limit as shown in Fig. 4.

The highest concentration of $^{137}$Cs was 27.58 Bq/L found in SD23 (Ishaqi-raqah2) higher than the concentration of specific activity of global limit which is equal to (14.8 Bq/L) [20], while the lowest concentration (0.15 Bq/L) was found in SD21 (Samarra-Qala'h) lower than global limit. The average concentration of $^{232}$Th was (12.04 Bq/L) lower than the global limit as shown in Fig. 5.
| Sample ID | $^{226}$Ra (Bq/L) | $^{212}$Pb (Bq/L) | $^{137}$Cs (Bq/L) | $^{40}$K (Bq/L) |
|-----------|------------------|------------------|------------------|----------------|
| SD1       | 5.959            | 2.218            | 4.426            | 321.3          |
| SD2       | 697.9            | 58.34            | 23.77            | 259.7          |
| SD3       | 296.4            | 18.22            | 2.728            | 342.9          |
| SD4       | 583.1            | 51.54            | 13.25            | 1149           |
| SD5       | 640.1            | 52.54            | 10.81            | 506.7          |
| SD6       | 184.7            | 5.500            | 23.98            | 592.1          |
| SD7       | 222.1            | 13.69            | 7.116            | 503.4          |
| SD8       | 6.426            | 9.617            | 5.341            | 405.3          |
| SD9       | 249.4            | 16.39            | 19.01            | 848.0          |
| SD10      | 246.3            | 42.53            | 9.526            | 546.1          |
| SD11      | 271.4            | 23.87            | 4.947            | 818.2          |
| SD12      | 639.1            | 69.38            | 11.11            | 818.2          |
| SD13      | 0.057            | 24.04            | 4.198            | 207.8          |
| SD14      | 5.414            | 0.806            | 14.57            | 597.7          |
| SD15      | 426.0            | 34.97            | 10.71            | 781.5          |
| SD16      | 160.4            | 13.53            | 5.801            | 802.8          |
| SD17      | 342.0            | 35.43            | 20.57            | 265.7          |
| SD18      | 147.0            | 12.07            | 24.58            | 515.1          |
| SD19      | 181.9            | 16.78            | 10.86            | 653.6          |
| SD20      | 423.5            | 40.63            | 11.18            | 536.2          |
| SD21      | 332.9            | 25.12            | 0.151            | 411.5          |
| SD22      | 19.01            | 1.292            | 17.38            | 452.1          |
| SD23      | 805.6            | 75.11            | 27.58            | 869.0          |
| SD24      | 2.339            | 1.955            | 6.830            | 373.1          |
| SD25      | 38.99            | 0.702            | 11.83            | 505.4          |
| SD26      | 697.1            | 59.54            | 19.97            | 773.3          |
| SD27      | 411.2            | 61.41            | 6.739            | 307.0          |
| SD28      | 538.0            | 48.71            | 6.695            | 358.9          |
| SD29      | 728.9            | 71.63            | 3.085            | 105.1          |
| SD30      | 452.3            | 37.11            | 4.520            | 128.2          |
| A.V.      | 325.2            | 30.81            | 11.44            | 525.2          |
Table 3 shows that the highest value of radium equivalent activity (Raeq) was found in (Ishaqiaqah2) sectors which was equal to (805.6 Bq/L) higher than the global limit which is equal to (370 Bq/L) [15], while the lowest value found in (Tikrit-Qarawardi) region which equal to (0.056 Bq/L), with an average (315.6 Bq/L) shown in Fig.6. The present results have shown that values of average radium equivalent activity in Salah Al-Din governorate were lower than the value of global limit which equal to (370 Bq/L).
The highest value of absorbed gamma dose rate ($D_\gamma$), of outdoor annual effective dose rate ($AED_{out}$), indoor annual effective dose rate ($AED_{in}$), external hazard index ($H_{out}$), internal hazard index ($H_{in}$) and Excess Lifetime Cancer Risk (ELCR) were found in (Ishaqi-raqaq2) sectors equal to (454.1 nGy/h, 0.56, 2.23 mSv/y, 2.64, 4.8, 1.95x10^{-3}) respectively, while the lowest value of absorbed gamma dose rate ($D_\gamma$), of outdoor annual effective dose rate ($AED_{out}$), indoor annual effective dose rate ($AED_{in}$), external hazard index ($H_{out}$), internal hazard index ($H_{in}$) and (ELCR) Excess Lifetime Cancer Risk were found in (AlSherqat-kosom) sectors equal to (17.4 nGy/h0.02, 0.086 mSv/y, 0.091, 0.098, 0.075x10^{-3}) respectively. The average values of the absorbed gamma dose rate ($D_\gamma$), of outdoor annual effective dose rate ($AED_{out}$), indoor annual effective dose rate ($AED_{in}$), internal hazard index ($H_{in}$), external hazard index ($H_{out}$) and (ELCR) Excess Lifetime Cancer Risk were (185.6 nGy/h, 0.23, 0.91 mSv/y, 2.04, 2.9, 0.8x10^{-3}) respectively. The present results have shown that the average values of absorbed gamma dose rate ($D_\gamma$) and the internal hazard index ($H_{in}$) in Salah Al-Din governorate were higher than the a worldwide limit which equal to ( 55 nGy/h and 1 mSv/y).

The average values of indoor annual effective dose rate ($AED_{in}$), outdoor annual effective dose rate ($AED_{out}$), external hazard index ($H_{out}$) and ELCR Excess Lifetime Cancer Risk in Salah Al-Din governorate were higher than the value of the a worldwide limit which equal to ( 1 mSv/y, 1, 1, ). [20].
### TABLE 3: Radium Equivalent Activity (Ra eq), Absorbed Gamma Dose Rate (Dγ), Annual Effective Dose Rate External (AE Dout) and Internal (AE Din), Hazard Indices (Hin), (Hex) and Excess Lifetime Cancer Risk (ELCR) for Water Samples in Salah Al-Din Governorate.

| Sample ID | Ra eq (Bg/L) | Absorbed Dose Rate (nGy h⁻¹) | The Annual Effective Dose (mSv/y) | Hazard Indices | ELCR×10⁻⁵ |
|-----------|--------------|-------------------------------|----------------------------------|----------------|-----------|
|           |              |                               | Outdoor | Indoor | Hex | Hin |          |
| SD1       | 33.90        | 17.40                         | 0.02    | 0.09   | 0.09 | 0.11 | 0.07     |
| SD2       | 800.4        | 368.4                         | 0.45    | 1.81   | 2.16 | 4.05 | 1.59     |
| SD3       | 348.9        | 162.2                         | 0.20    | 0.80   | 0.90 | 1.70 | 0.70     |
| SD4       | 745.3        | 348.5                         | 0.42    | 1.71   | 2.01 | 3.60 | 1.50     |
| SD5       | 754.2        | 348.8                         | 0.40    | 1.71   | 2.04 | 3.80 | 1.50     |
| SD6       | 238.1        | 113.1                         | 0.14    | 0.60   | 0.64 | 1.10 | 0.50     |
| SD7       | 280.4        | 131.7                         | 0.16    | 0.65   | 0.76 | 1.30 | 0.57     |
| SD8       | 51.30        | 25.70                         | 0.03    | 0.13   | 0.13 | 0.16 | 0.11     |
| SD9       | 338.1        | 160.3                         | 0.20    | 0.79   | 0.90 | 1.59 | 0.69     |
| SD10      | 349.1        | 162.6                         | 0.20    | 0.80   | 0.94 | 1.61 | 0.70     |
| SD11      | 368.6        | 173.9                         | 0.21    | 0.80   | 0.99 | 1.72 | 0.74     |
| SD12      | 801.3        | 371.7                         | 0.45    | 1.82   | 2.16 | 3.89 | 1.60     |
| SA13      | 50.43        | 23.60                         | 0.03    | 0.12   | 0.14 | 0.14 | 0.10     |
| SA14      | 52.59        | 27.70                         | 0.03    | 0.14   | 0.14 | 0.15 | 0.12     |
| SD15      | 536.2        | 250.5                         | 0.31    | 1.23   | 1.45 | 2.60 | 1.08     |
| SD16      | 241.5        | 115.6                         | 0.14    | 0.57   | 0.65 | 1.08 | 0.50     |
| SD17      | 413.1        | 190.7                         | 0.23    | 0.94   | 1.11 | 2.04 | 0.82     |
| SD18      | 203.9        | 96.60                         | 0.12    | 0.47   | 0.55 | 0.95 | 0.42     |
| SD19      | 256.1        | 121.3                         | 0.15    | 0.59   | 0.69 | 1.18 | 0.52     |
| SD20      | 522.9        | 242.7                         | 0.29    | 1.19   | 1.41 | 2.55 | 1.04     |
| SD21      | 400.5        | 186.1                         | 0.22    | 0.9    | 1.08 | 1.98 | 0.80     |
| SD22      | 55.66        | 28.30                         | 0.03    | 0.14   | 0.15 | 0.20 | 0.12     |
| SD23      | 979.9        | 454.1                         | 0.56    | 2.23   | 2.64 | 4.82 | 1.95     |
| SD24      | 33.86        | 17.70                         | 0.02    | 0.09   | 0.09 | 0.09 | 0.07     |
| SD25      | 78.91        | 39.30                         | 0.04    | 0.19   | 0.21 | 0.31 | 0.16     |
| SD26      | 841.8        | 390.5                         | 0.48    | 1.92   | 2.27 | 4.15 | 1.68     |
| SD27      | 522.6        | 240.5                         | 0.3     | 1.20   | 1.40 | 2.50 | 1.01     |
| SD28      | 635.3        | 293.2                         | 0.35    | 1.44   | 1.71 | 3.17 | 1.20     |
| SD29      | 839.4        | 385.0                         | 0.48    | 1.90   | 2.27 | 4.24 | 1.66     |
| SD30      | 515.3        | 237.0                         | 0.29    | 1.16   | 1.39 | 2.62 | 1.02     |
| A.V       | 397.4        | 185.6                         | 0.23    | 0.91   | 2.04 | 2.90 | 0.80     |
5 CONCLUSIONS
The specific activity for $^{226}\text{Ra}$, $^{212}\text{Pb}$, $^{137}\text{Cs}$ and $^{40}\text{K}$ radionuclides in water samples were measured covering eight sectors in Tigris river in Salah Al-Din Governorate. The highest values of $^{226}\text{Ra}$ which belongs to $^{238}\text{U}$ series were found in (Ishaqi-Raqah2) sectors higher than the global limite and the lowest value found in (Tikrit-Qarawardi) sectors. The average value of $^{238}\text{U}$ in Salah Al-Din governorate was less than the global limite. The highest values of $^{212}\text{Pb}$ which belongs to $^{232}\text{Th}$ series were found in (Ishaqi-raqah2) sectors higher than the global limite and the lowest value found in (Ishaqi-qaban2) sectors. The average value of $^{232}\text{Th}$ in Salah Al-Din governorate was less than the global limite. The highest values of artificial nuclide $^{137}\text{Cs}$ was found in (Ishaqi-raqah2) sectors higher than the global limite and the lowest value found in (Samarra-qala’h) sectors. The average value of $^{137}\text{Cs}$ in Tigris river in Salah Al-Din governorate was less than the global limite. The highest values of $^{40}\text{K}$ nuclide was found in (Biji-Mahzam) sectors higher than the global limite and the lowest value found in (Alhatamiah-Dour) sectors. The average value of $^{40}\text{K}$ in Salah Al-Din governorate was higher than the global limite. The average of absorbed dose rate, the hazard index outdoor and the hazard index indoor in Salah Al-Din governorate were higher than the global limite.
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