Activity Concentration of Natural Radionuclides in Sediment of Tigris River in the City of Mosul, Iraq

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Abstract: Ten samples were studied from sediments collected from the Tigris River in the city of Mosul, and gamma ray spectroscopy NaI(Tl) was used in order to detect and calculate the content of natural radionuclides for all samples collected. The results of the samples analyzed for the specific activity of ²²⁶Ra ranged from 6.30±0.319 Bq/kg to 13.73±0.411 Bq/kg with mean of 9.86±0.385 Bq/kg, and for ²³²Th from 13.39±0.626 Bq/kg to 29.84±0.923 Bq/kg and with mean of 23.05±0.838 Bq/kg, while for ⁴⁰K, it ranged from 166.83±6.456 Bq/kg to 275.96±7.601 Bq/kg and at mean of 232.91±6.456 Bq/kg. The results of the study were within the range of the recommended global values. Therefore, it can be said that the study area is safe and does not pose a threat to the residents near it. Statistical data such as skewness and kurtosis were calculated, and box plot, were applied in order to assess the distribution of radiological parameters.

Keywords: Tigris River, sediments, natural radioactivity, gamma spectroscopy.

1, Introduction

Humans are generally and permanently exposed to natural radiation resulting from the concentration of elementary radionuclides, ²³⁸U, ²²⁶Ra, ²³²Th and ⁴⁰K, which are found in the earth's crust, water, air and food, as well as in building materials and the human body [1]. The natural radioactivity spreads in the earth's environment on a large scale and is also found in geological formations such as soil, sediments, rocks, plants, air and water [2-5]. The decay products of the ²²⁶Ra and ²³²Th series exist in the Earth’s crust in parts per million (ppm) level [6,7]. ⁴⁰K is a single natural radionuclide and makes up 0.0118% of the total potassium present in the crust. ²²⁶Ra, ²³²Th, and ⁴⁰K concentrations in the soil vary because their concentration level depends on the soil and the nature of the rocks [8]. In marine sediments, natural radionuclides dissolve in the water over time, and move to humans, animals and plants. Knowledge of the distribution and concentration of natural radionuclides is very important, where the level of radioactivity concentration affects human exposure to radiation. In the literature, a number of studies have been conducted regarding natural radioactivity [9-14]. Gamma rays are released from naturally occurring radionuclides, which are always known as background radiation produced from the earth, and are responsible for the main external source of exposure to the human body [15]. The terrestrial radiative background is related to the types of rocks that make up the soil, so the geographical and geological conditions are considered among the basic factors on which the radioactivity depends [16]. The level of natural radioactivity of river sediments results from the presence of natural radionuclide concentrations in soil and rock [17].

The degree of exposure to natural nuclides...
varies depending on the site. Often, artificial opportunity with artificial sources [18,19]. Natural radiation often comes from the $^{238}$U and $^{232}$Th series radionuclides and their hydrolyzed products, and from potassium $^{40}$K, as this radiation affects human safety [20]. This research aims to measure the natural activity in sediments of the Tigris River in the city of Mosul, northern Iraq, using gamma spectroscopy with a detector of thallium-activated sodium iodide. This study is considered the first to measure the activity concentrations of natural radionuclides in sediments in the city of Mosul - Nineveh governorate in northern Iraq.

2, Materials and Methods

2.1, Study Area

Nineveh governorate is an Iraqi governorate located in the north of Iraq, located 402 km from the capital Baghdad, the center of Nineveh governorate is the city of Mosul, where the Tigris River in the city of Mosul was chosen as a study area. The astronomical location of the city is between latitude 36 north and longitude 43 east. The area of the city is 180 km$^2$, and its population is about three million seven hundred thousand people, and it is the second largest city in Iraq. As for the administrative borders of Nineveh governorate, it is bordered from the north by Dohuk governorate, from the south by Salah al-Din governorate, on the east by Erbil and Kirkuk governorate, and to the west by the Syrian Arab Republic.

2.2, Sample Collection

In this study, Ten samples were collected from sediments of the Tigris River in the city of Mosul, and they were collected from random sites along the river, as shown in the figure(2). The mechanism for collecting each sample was to determine an area of $0.5 \times 0.5$ m$^2$ and remove debris and obstructions to a depth of 5-10 cm[21]. Where three samples were collected for each site from different points and mixed well in order to obtain a uniform sample covering the whole site. The masses of samples collected while wet ranged between 1.5 – 2 kg. The coordinates of the study samples were determined according to the Global Site Map program as shown Figure (2). Table (1) shows the coordinates of the samples sites for the studied areas.

Table (1): illustrates the names, symbols and coordinates of the samples sites from the Tigris River sediments in the city of Mosul.

| Sample No. | Sample ID | Sample Location       | Latitude N  | Longitude E |
|------------|-----------|-----------------------|-------------|-------------|
| 1          | RS1       | Mushirifa             | 36° 23 37.39| 43° 03 54.54|
| 2          | RS2       | Mosul Water Project   | 36° 23 47.19| 43° 04 47.19|
| 3          | RS3       | Fourth Church         | 36° 23 42.88| 43° 05 14.59|
| 4          | RS4       | Church Container      | 36° 23 34.55| 43° 06 06.34|
| 5          | RS5       | The Victory Bridge    | 36° 23 22.05| 43° 06 54.49|
| 6          | RS6       | Church Container2     | 36° 22 19.44| 43° 06 20.61|
| 7          | RS7       | The Third Bridge      | 36° 21 39.62| 43° 06 49.57|
| 8          | RS8       | Atomic Medical Hospital| 36° 21 35.77| 43° 06 55.42|
| 9          | RS9       | Republic Hospital     | 36° 21 29.62| 43° 07 02.93|
| 10         | RS10      | Pashtabiya Castle     | 36° 21 20.18| 43° 07 20.33|
2.3, Sample preparation

The sediment samples were prepared well and dried by exposing them to sunlight for 7 days and then placed in an oven at 105 °C, after which they were crushed by an electric grinder. They were also sifted using a clamp with holes of 0.75 µm in diameter to obtain homogeneous patterns. The samples were weighed and put them in a 500 gm Marinelle container, to be then stored in this container for at least 28 days in order to achieve the radiative balance of natural radionuclides and their offspring [22].

2.4, Gamma-Ray Spectrometry

In the study, SPECTCH UCS-20 gamma ray spectroscopy was used with a crystal of thallium activated sodium iodide (TI) detector of dimensions (3.8 * 2.5 cm), and the detector crystal was surrounded by a lead shield to reduce the radiation background, where the detector is connected to the system. It consists of a primary, a main amplifier and a high-voltage power supply that equips the detector with the necessary voltage, and the voltage used in this research is (600) Volt, which is within the range of the detector operating voltage and a multi-channel analyzer, then it is connected with a computer in order to operate and display the resulting spectrum, and before starting the process of spectrophotometry, the energy calibration process and the efficiency of the detector were also performed using reference source, by using the energy barium source $^{133}$Ba (356) keV, the cesium source $^{137}$Cs with energy (661.6) keV and the energy cobalt source $^{60}$Co (1332.5) keV for the purpose of conducting the energy calibration of the detector. As energy calibration is one of the most important factors that should be taken into account before starting the analysis process in order to obtain accurate results, due to the fact that the interpretation of the gamma spectrum depends on radionuclides and energy instead of voltage and channel number [23]. After that, the efficiency calibration was performed using a standard source with known energies, if the isotope urmium-152 ($^{152}$Eu) was used, which contains a number of energies ranging from (1408.0-121.8) keV placed in a Marnelli Baker's vessel.
2.5, Activity Measurement

Before any measurement of the radiation effectiveness of a model, the radiation background must be measured for the possible presence of contaminated materials or radioactive sources that become a source of radiation. The radiation background was measured by placing an empty half-kilogram Marnelli Baker vessel below the detector, the same vessel used to measure the radiative effectiveness of the models. The time period for the assembly of a full spectrum on the computer screen was (18000) seconds, the same time period used to measure sample models. As well as knowing the space below the curve for the purpose of projecting this number of recorded readings of the models and of the energies themselves. Activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K have been calculated using the following equation\cite{24,25}:

$$A = \frac{N - B}{\varepsilon I t m}$$

Whereas
A: Specific Activity.
N: The area under the curve for each sample.
B: The radiological background of the laboratory.
$\varepsilon$: The detector efficiency for a specific gamma ray.
I: The relative intensity.
t: Spectrum collection time in units of second.
m: The mass of samples in units of kilograms.

The gamma-ray lines of 295.22 keV from $^{214}$Pb and the 609.31 keV from $^{214}$Bi was to the determine the activity concentration of $^{226}$Ra in the sediment samples. The activity concentration of $^{232}$Th was evaluated using gamma-ray peak at 338.32 keV and 911.2 keV for $^{228}$Ac a. The activity concentration of $^{40}$K was determined using gamma-ray peak at 1460.83 keV.

3. Result and discussion

The activity concentrations for Radium-226, Thorium-232, and potassium-40 in sediment samples of the Tigris River are mentioned in the table (2), Figure (3). It represents the comparative activity concentrations between $^{226}$Ra, $^{232}$Th and $^{40}$K in the studied sediment samples.

The activity concentration for $^{226}$Ra in sediment samples recorded lowest value 6.30 Bq/kg in sample RS2 (Mosul Water Project), and the highest value 13.73 Bq/kg in sample RS10 (Pashtabiya Castle) with a mean 9.86 Bq/kg. The average level of radioactivity of $^{238}$U nuclide in sediment samples are well below the recommended global limits 33 Bq/kg \cite{26}.

The lowest value of the activity concentration for $^{232}$Th was equal to 13.39 Bq/kg in the sample RS1 (Mushirifa), while the highest value was equal to 29.84 Bq/kg in the sample RS2 (Mosul water project) with a mean of 23.05 Bq/kg. Where the mean radioactivity of $^{232}$Th nuclides in the river sediments samples was less than the global permissible limit of 45 Bq/kg \cite{26}.

Also, the lowest value of the activity concentration for $^{40}$K was recorded in the RS4 (church container) sample, which is 166.83 Bq/kg, while the highest value was equal to 275.96 Bq/kg with a mean of 232.91 Bq/kg. Where the mean radioactivity of nuclide $^{40}$K in the sediment samples studied was less than the global permissible limit of 420 Bq/kg\cite{26}.

The concentration of $^{40}$K accounted for approximately 87% of the total gamma activity of the sediment samples from the Tigris River. The study shows that the specific activity due to $^{40}$K is the largest contributor to the total activity for all the samples. Figure (4) It represents contributions of radionuclides $^{226}$Ra, $^{232}$Th and $^{40}$K are normal at the sampled sites in the study.

The activity concentrations of radium-226, thorium-232 and potassium-40 in sediment samples in the studied areas were compared with other studies for different countries of the world, and the results are presented in table (3) and figure (5). The comparison shows that the normal
radioactivity values of the studied samples are very low compared with the results of other studies in neighboring and non-neighboring countries to Iraq, as well as compared with local studies conducted in Iraq. It was found that the average value of the concentration of $^{226}$Ra activity in the current study was close to the results reported in Ghana, Saudi Arabia and Nigeria, while the average concentration of Ra activity in this study was less than what was reported in Wasit, Basra and Dhuluiya in Iraq. As well as Egypt, Turkey, India, Syria and Iran. It was also found that the activity concentration rate for $^{232}$Th was close to the results recorded in Dhi-Qar and Wasit in Iraq, as well as in Syria, India, Iran and Nigeria, and the activity concentration rate for Th in this study was less than the results recorded in Basra Governorate in Iraq and Turkey, and higher than those results were recorded in Egypt, Saudi Arabia and Ghana. When comparing the rate of $^{40}$K activity concentration in our study with other studies, we find that the average of $^{40}$K activity concentration in Wasit, Basra and Dhi-Qar in Iraq was similar to the results of our study, and it was less than the average of the results obtained in Turkey, Iran and Ghana.

The geological and geographical conditions, so physical and chemical difference of earth of the region are the factors on which the specific activity of different countries of the world depends [1].

**Table (2):** The activity concentration of natural radionuclides $^{226}$Ra, $^{232}$Th and $^{40}$K in sediments of Tigris River of Mosul City, Iraq

| Sample ID | Activity concentration (Bq/Kg) |
|-----------|-------------------------------|
|           | $^{226}$Ra | $^{232}$Th | $^{40}$K |
| RS1       | 10.43±0.404 | 13.39±0.626 | 243.86±7.145 |
| RS2       | 6.30±0.319  | 20.15±0.895 | 275.96±7.601 |
| RS3       | 10.09±0.251 | 29.84±0.923 | 208.31±6.604 |
| RS4       | 12.89±0.405 | 28.61±0.909 | 166.83±6.456 |
| RS5       | 10.30±0.369 | 29.38±0.911 | 241.37±6.358 |
| RS6       | 8.56±0.334  | 24.20±0.830 | 241.15±6.358 |
| RS7       | 9.38±0.349  | 16.72±0.689 | 240.15±6.355 |
| RS8       | 6.53±0.291  | 22.24±0.898 | 235.91±6.286 |
| RS9       | 10.40±0.722 | 22.99±0.820 | 203.90±5.844 |
| RS10      | 13.73±0.411 | 23.05±0.882 | 271.69±6.746 |
| Ava.      | 9.86±0.385  | 23.05±0.838 | 232.91±6.456 |
| Max.      | 13.73±0.411 | 29.84±0.923 | 275.96±7.601 |
| Min       | 6.30±0.319  | 13.39±0.626 | 166.83±6.456 |
| World Ave.| 33            | 45           | 420         |
Figure 2: Comparison of radioactivity concentrations between $^{226}$Ra, $^{232}$Th and $^{40}$K in different sediment samples for all sites.

Figure 3: The relative contribution of radionuclides from total natural radiation in the studied samples.
Table (3): Comparison of the activity concentrations of the studied Tigris river sediment samples with the results of various previous studies from the world.

| Country             | Mean activity concentration (Bq/kg) | Reference |
|---------------------|-------------------------------------|-----------|
|                     | $^{226}\text{Ra}$ | $^{232}\text{Th}$ | $^{40}\text{K}$ |
| Egypt               | 16.30                 | 12.94      | 200.21       | [27] |
| Saudi Arabia        | 11.68                 | 6.21       | 169.40       | [28] |
| Ghana               | 7.31                  | 6.91       | 379.94       | [29] |
| Turkey              | 37                    | 40         | 667          | [30] |
| India               | 41                    | 29         | 400          | [1]  |
| Syria               | 23                    | 20         | 270          | [1]  |
| Iran                | 28                    | 22         | 640          | [1]  |
| Nigeria             | 7.8                   | 29.4       | 229.4        | [31] |
| Iraq/ Thi-Qar       | 29.2                  | 22.7       | 304.6        | [32] |
| Governorate         |                       |            |              |      |
| Iraq/ Wassit        | 19.42                 | 18.487     | 204.266      | [33] |
| Governorate         |                       |            |              |      |
| Iraq/ Dhuluiya      | 15.48                 | 8.36       | 418.47       | [34] |
| City                |                       |            |              |      |
| Iraq/ Basra         | 46.548                | 40.325     | 165.599      | [35] |
| Governorate         |                       |            |              |      |
| Iraq/ Mosul         | 9.86                  | 23.05      | 232.91       | Present Study |
| City                |                       |            |              |      |

Figure 4: Shows a comparison between the activity concentrations of $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in samples from current study with local studies, neighboring countries and global ones.

4. Statistical approach

By the descriptive statistical program (SPSS 25.0), descriptive statistical data such as the mean, median, standard deviation, skewness and kurtosis for assessed parameters in sediment samples were calculated as shown in the Table (3). A positive skewness of (0.018) was found with respect to $^{226}\text{Ra}$, while a skewness was found for $^{232}\text{Th}$ with (-0.396) negative, and also for
potassium-40 with a negative (-0.758) ratio. Where information about the asymmetric distribution was obtained through the values of the skewness, whether positive or negative. Positive values for the skewness of $^{226}$Ra indicate that the peak of the distribution lies is right of the average value, While the negative values for the skewness of $^{232}$Th and $^{40}$K indicate that the peak of the distribution goes to the left of the mean value. The information that we obtain about the degree of the peakedness of the probability distribution is done by kurtosis, where a negative (-0.246) kurtosis was found for $^{226}$Ra, which means that the distribution is somewhat flat. Kurtosis of $^{232}$Th of (-0.420) was found negative, which also means that the distribution is relatively flat. A positive K-40 (0.733) kurtosis was found. Whereas, positive kurtosis indicates that the distribution has reached a relative peak. Figure (6,7,8) shows the box diagram for the activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K in units of Bq/ kg, and respectively. In order to obtain information about how the values in the data are spread, we use a box diagram for the activity concentration. As Figure (6.8) shows that the median is closer to the top of the box for $^{226}$Ra and $^{40}$K, and this means that the distribution is negatively skewed. As for Figure (7), it shows that the median of the box diagram for $^{232}$Th is closer to the bottom of the box, and this means that the distribution is positively skewed.

**Table(4):** Descriptive statistical data for the measured parameters in the sediments of the Tigris River in the city of Mosul

| Variable         | $^{226}$Ra | $^{232}$Th | $^{40}$K |
|------------------|------------|------------|----------|
| Mean             | 9.861      | 23.057     | 232.913  |
| Median           | 10.195     | 23.020     | 240.650  |
| Standard deviation | 2.252     | 5.107      | 30.808   |
| Variance         | 5.070      | 26.086     | 949.129  |
| Kurtosis (Fisher) | -0.246   | -0.420     | 0.737    |
| Skewness (Fisher)| 0.018      | -0.396     | -0.758   |
| Minimum          | 6.300      | 13.390     | 166.830  |
| Maximum          | 13.730     | 29.840     | 275.960  |
| Range            | 7.430      | 16.450     | 109.130  |
5, Conclusion

Ten samples were collected from the sediment of the Tigris River in the city of Mosul, and the radioactivity of these samples was determined. All the values of the activity concentrations of radionuclides $^{226}\text{Ra}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in the sediment of the Tigris River in the studied areas were less than the adult global average values (33, 45, 420) Bq/kg respectively recommended by the united nations scientific committee on sources and effects on ionizing radiation [26]. Therefore, we conclude that the area under study is safe for the residents close to it, as well as fishermen and tourist. From through statistical analysis, we found that both of $^{232}\text{Th}$ and $^{40}\text{K}$ were leading to an increase in the radioactivity in the sediments. This study can be used as a baseline for future researches and the data obtained in this study may be useful for radioactivity mapping. Information obtained from the study was intended to help in the determination of radionuclide sources and radionuclide distribution of Tigris River in city of Mosul.
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