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## Heat Production Rate and Radiation Hazard Indices from Radioactive Elements in Different Types of Natural Water in Nineveh Governorate, Iraq.

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### Abstract:

The current study sheds light on the measurement and estimation of the radioactivity of radionuclides ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) in natural waters of different regions of Nineveh Governorate in Iraq. 15 samples were collected from different sources of natural waters, where gamma-ray spectroscopy was used using NaI(Tl) sodium iodide detector to determine the concentration of radioactivity in the samples. According to the results, the radioactivity concentration in the tested water sample were ranged from  $0.36 \pm 0.04$ - $1.57 \pm 0.09$  with an average value of  $0.69 \pm 0.06$  Bq/l for  $^{238}\text{U}$ , and  $2.9 \pm 0.02$ - $0.88 \pm 0.03$  with an average value of  $0.65 \pm 0.03$  Bq/l for  $^{226}\text{Ra}$  Bq/l, and  $0.48 \pm 0.04$ - $1.36 \pm 0.06$  with an average value of  $0.88 \pm 0.05$  Bq/l for  $^{232}\text{Th}$ , while for  $^{40}\text{K}$   $13.00 \pm 0.69$ - $36.89 \pm 1.12$  with an average value of  $25.1 \pm 0.95$  Bq/l, respectively. The results obtained from the water samples are below the safe and standard limits established by UNSCEAR. In addition to calculating the radiological hazard indicators that included Radium equivalent ( $R_{\text{eq}}$ ), air absorbed dose rate ( $D_{\text{r}}$ ), effective annual equivalent dose rate (AEDE), indoor and outdoor radiation hazard (H) indices, lifetime cancer risk (ELCR), gonadotropin equivalent dose (AGDE), and ideal level index of gamma rays ( $I_{\gamma}$ ) has been calculated. To verify its deleterious character. On the other hand, the results showed that the rate of heat production values ranged between  $0.006$ - $0.0015$   $\mu\text{W}/\text{m}^3$ , which indicates a low rate of heat production and does not affect the temperature of the Earth's crust. Finally, In addition to physicochemical parameters such as PH, dissolved solids TDS, and electrical conductivity Ec. All tested data are within the permissible limit of WHO standards. The results of the current study can be used to provide essential baseline data for future epidemiological investigations and surveillance programs in the areas under study.

**Keywords:** Cancer Risk (ELCR), Gamma-ray spectroscopy, Heat production rate, NaI(Tl) detector, Physicochemical parameters.

### Introduction:

People are naturally and permanently exposed to natural radiation due to the concentrations of the basic radionuclides  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and,  $^{40}\text{K}$  found in the earth's crust, water, air and food, as well as building materials and the human body <sup>1</sup>. Radioactive pollution is one of the most dangerous types of environmental pollution. When radioactive materials reach the cells of the body, external and internal damages occur that may lead to human death. And that radioactive pollution occurs from natural sources such as rays emanating from outer space and radioactive gases rising from the earth's crust, or industrial sources that occur by humans, such as

atomic reactors, nuclear power plants, and radioactive isotopes used in agriculture, medicine and industry <sup>2</sup>. The isotopes involved in radioactive or radiogenic heat production are referred to as primordial or primeval radioactive elements. In geophysics, primordial isotopes are nuclides that are abundant on Earth and have existed since the Earth's formation <sup>3</sup>. An essential factor in the Earth's surface heat flux is the quantity of naturally radioactive materials found in the planet's crust. The measurement of radioactive heat sources is a fundamental aim of heat-flow investigations, especially for the lithosphere of the continents, which has a complicated composition compared to

the oceanic lithosphere<sup>4</sup>. The natural decay of atoms through the natural process known as radioactivity is a process that releases heat that increases the dissipation of energy associated with the slow cooling of the planet. Surface heat flux in continental regions, where the crust is typically thicker, can result mainly from radioactive decay 60%, a relevant contribution to heat dissipation from the core and mantle 40%. Geothermal energy, which is the extraction of heat from the Earth's interior, is widely used by humans to heat areas and produce electricity, usually in areas of the world where heat flow is much higher than the global average, such as in active volcanic regions<sup>5</sup>. However, the use of geothermal energy has been successfully extended in the past decades to other geological settings where heat flow is not very intense, but geothermal reservoirs can be created at higher depths through engineering techniques. This is the case, for example, in the deep geothermal projects in Stoltz and Landau, where reservoirs in California are located at a depth of 5 km. Both are characterized by the presence of granite, the rocks are usually very rich in radioactive elements, and the heat flux values are moderately higher than normal<sup>6</sup>. It is not only the heat content of the young Earth that supplies the main internal source of heat, but also the radioactive decay of the unstable isotopes of uranium ( $^{235}\text{U}$ ;  $^{238}\text{U}$ ), thorium ( $^{232}\text{Th}$ ), and potassium ( $^{40}\text{K}$ )<sup>7</sup>. The Tahir, & Alaamer<sup>8</sup> results of a study that included using Gamma-ray spectroscopy to determine the concentrations of natural radionuclides such as ( $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{k}$ ) in groundwater samples in Pakistan, have used the NaI(Tl) detector. As well as calculating the annual effective dose (AEDE) and physiochemical parameters (PH, TDS, and Ec), revealed that all values are less than the World Health Organization's recommended values. AL-Ubaidi et al<sup>9</sup>; Harb et al<sup>10</sup>, Some radioactive elements for  $^{137}\text{Cs}$ ,  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  were identified from different water samples using Gamma-ray spectroscopy in conjunction with the hazard indicator. The results show that the concentrations of these elements were less than the global limit. Alam et al<sup>11</sup>. In Kirkuk, the pH, TDS, and EC of nine tap water samples and 20 bottled water samples were measured. Each of these values was found to be within the appropriate WHO range. Amin & Jassim<sup>12</sup>, has used the NaI(Tl) detector to examine and analyze drinking water samples for radionuclide levels and determined the yearly effective dose (AED) and total (AED) for all specimens that were less than the global standard value of 0.1mSv/y Alseroury et al<sup>13</sup> One of the researchers used HPGe to assess the concentrations of natural radioactive elements in groundwater in

the Makkah region and found that the average values of the specific activity concentrations of these elements were less than the global limit. There is a survey conducted in Nigeria, Osun State by Oluyide et al<sup>14</sup> by using the NaI(Tl) detector, to determine the radioactivity of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{k}$ . For 38 water samples conducted that there are indications of radiological hazards. The results show that the values of concentration of these elements were less than the global limit. The researcher Parhoudeh et al<sup>15</sup> observed the values of pH 8.12, TDS 285 ppm, and EC 446.19  $\mu\text{s}/\text{cm}$ . Since the values of the parameters were above the recommended range, it was determined that Balad city tap water is unsafe. Al-Khashab et al<sup>16</sup> measured the pH, TDS, and EC and discovered that they were 7.7-8.7, 226-302 mg/L, and 330-405  $\mu\text{s}/\text{cm}$ , respectively, and that all the values are within the recommended ranges. Salman et al<sup>17</sup> were able to carry out a comprehensive radioactivity of  $^{232}\text{Th}$ ,  $^{238}\text{U}$ , and  $^{40}\text{k}$ . The NaI(Tl) detector was used to ascertain this. The researchers found that the lifetime risk of cancer was much lower than what the ICRP had determined, which means the samples are safe and healthy. Kurnaz et al<sup>18</sup>, there is a group of researchers who have estimated some of the radioactive elements  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{k}$  in samples of drinking water belonging to the Kastamonu region of the Black Sea in western Turkey using HPGe detector technology, researchers evaluated the concentration the values of these radioactive elements were consistent with the values allowed by the organization The World Health Organization's with the exception of  $^{228}\text{Ra}$  was higher than the concentration recommended by WHO. The aim of the study is to estimate the concentration of radionuclides ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{k}$ ), using gamma-ray spectroscopy by NaI(Tl) detector, alongside the measuring of the heat production rate and radiation hazard indices in different types of natural waters in Nineveh Governorate, Iraq. In addition to measuring some physicochemical parameters.

## Methodology

### Description of study areas

Nineveh Governorate was selected as a study site in this work. It is located in northwestern Iraq, and its center is the city of Mosul, 465 kilometers from Baghdad, the country's capital. With a population of nearly three million, Nineveh is the second-largest governorate after Baghdad. The province lies between longitudes of 36 degrees and latitudes of 43 degrees. The Tigris River runs through the province and divides Mosul into two

coasts, right and left, with major towns and villages located on either side.

### Techniques for collecting and preparing samples

In the Nineveh Governorate, fifteen samples of natural water were taken from various sources and used as drinking water. Samples can be distributed as follows: 6 samples are taken from different purification projects from Nineveh, 7 water samples are taken from wells from different regions and with different depths ranging from 15 to 25 m, and two samples are taken from tap water from different regions as shown in Fig.1, 1-liter polyethylene Marinelli cups were used. Packages were cleaned before use, cleaned with dilute hydrochloric acid, and washed with distilled water.

Every beaker is entirely full, and the pressurized beaker is closed with a tight lid until all air is emptied. The water samples were kept in polyethylene canisters overnight to permit the suspension to precipitate. And each sample was tested. The transparent supernatant was filtered from each sample, and then the transparent supernatant was isolated. Additionally, by adding 0.5 mL of concentrate, the pure solution was acidified. To keep microorganisms at bay, use HNO<sub>3</sub>/L to prevent radium isotope loss around the walls of the container. The vibration was used to fully standardize water and samples. Table 1: Identification, types, and locations of water samples in Nineveh Governorate, as well as longitude and latitude coordinates.

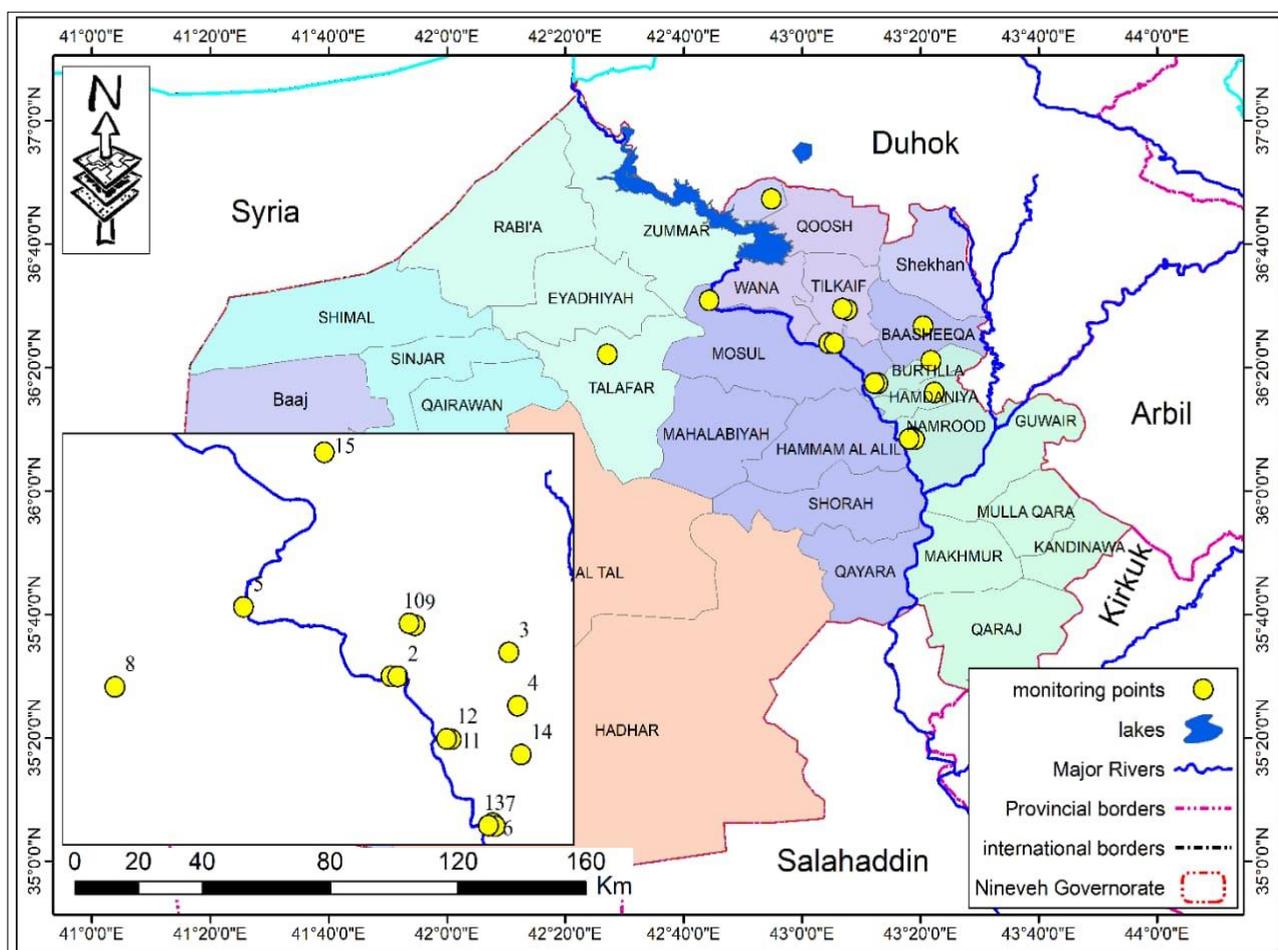


Figure 1. GPS coordinates were used to identify the location from which water samples were collected.

**Table 1. The latitude and longitude, sample code, and the names of the selected samples from the Nineveh governorate.**

Sample code	Sample Type	Location	Longitude-X	Latitude-Y
Ds1	Raw water	AL-Rashidiya water project	43° 4' 29.645" E	36° 23' 57.942" N
Ds2	Pure tap water	AL-Rashidiya water project	43° 5' 26.094" E	36° 23' 56.543" N
Ds3	Cold well water	Qas-jaber-Bashiqa	43° 20' 28.410" E	36° 26' 42.106" N
Ds4	Cold well water	Bartella	43° 21' 47.033" E	36° 21' 6.711" N
Ds5	Cold well water	Old city of mosul	42° 44' 16.754" E	36° 30' 54.298" N
Ds6	Raw water	Al-Salamiyah water project	43° 18' 39.428" E	36° 8' 41.901" N
Ds7	Pure tap water	Al-Salamiyah water project	43° 19' 0.674" E	36° 8' 22.623" N
Ds8	Cold well water	Tal Afar	42° 27' 6.144" E	36° 22' 8.111" N
Ds9	Pure tap water	Talkef	43° 7' 38.404" E	36° 29' 22.562" N
Ds10	Cold well water	Talkef	43° 6' 50.012" E	36° 29' 33.255" N
Ds11	Raw water	Yarmja water project	43° 12' 50.009" E	36° 17' 26.525" N
Ds12	Pure tap water	Yarmja water project	43° 12' 12.177" E	36° 17' 28.680" N
Ds13	Cold well water	Al-Salamiyah	43° 18' 4.846" E	36° 8' 26.286" N
Ds14	Pure tap well	AL-Hamdaniyah	43° 22' 21.317" E	36° 15' 58.087" N
Ds15	Cold well water	Fayda	42° 54' 49.426" E	36° 47' 21.831" N

### Gamma-Ray Spectrometry

SPECTCH UCS-20 gamma-ray spectroscopy was used with a crystal of thallium-activated sodium iodide (TI) detector with dimensions 3.8 \* 2.5 cm. the detector is installed on a lead surrounded by a holder for the purpose of shielding and reducing the background radiation. The spectrum collection system consists of a basic amplifier, the main amplifier, and a high-voltage power source that supplies the detector with the necessary voltage, and the voltage used in this research is 600 volts, which is in the range of the detector's operating voltage. And a multi-channel analyzer, then connected to a computer to operate and display the output spectrum, before starting the spectrophotometric process, the energy efficiency calibration of the detector was also carried out with a reference source, using barium <sup>133</sup>Ba 661.6 Kev and 60 Kev power source. They must be taken into account before starting the analysis process in order to obtain accurate results, since the interpretation of the gamma spectrum depends on the radionuclides. The second energy is in place of the voltage and channel number. After which an efficiency calibration was performed using a standard source with known energies of the (<sup>152</sup>Eu) isotope was used, which has a number of energies ranging from 1408.0, 121.8 Kev at the same experiment conditions (Marinelli vessel).

### Calculation of Activity Concentration

The natural water samples collected from different regions were left by placing one liter of it in a sealed Marinelli vessel for 28 days, in order to reach the ideal balance between the parent nuclide and its daughter. The detector crystal is inserted

quietly into the same container so that it is facing the sample to be examined. To prevent external radiation from reaching the detector, all of this is surrounded by sheets of lead 5 cm thick. And then the spectrum of gamma-rays emitted from the water sample is collected for a period of 18,000 seconds. By calculating the area under the gamma spectrum curve, the concentration of the radionuclide <sup>226</sup>Ra, <sup>232</sup>Th, and <sup>40</sup>K content in the samples are calculated using the radioactivity relationship as in the following formula 1 <sup>19</sup>. It should be mentioned that the radiation background was measured for the same time period and its value is subtracted to get the actual radioactivity generated by the samples <sup>20</sup>.

$$A = \frac{(N-B) \pm \sqrt{N-B}}{\epsilon_{\gamma} I_{\gamma} t m} \quad 1$$

And A denotes the radioactivity in question in unit Bq/l N is the all area underneath the radioactive isotope energy's optical peak, B is the laboratory background radiation,  $\epsilon_{\gamma}$  is the detector's efficiency at a specific energy of the measured nuclide's gamma line,  $I_{\gamma}$  is the percentage severity of a gamma-ray emitted by the radioactive element, m, is indeed the sample volume mass in L, and t recording the time of the spectrum counting in seconds.. The second term preceded by  $\pm$ S.E sign in the above equation represents the percentage error in the spectrum counting. Table 1: indicates different types and locations of water samples collected in various regions of Nineveh province. Following the determination of the activity concentration levels of <sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K in samples, the activity concentration levels of radionuclides calculated by (Bq/l) are converted to the initial concentration (ppm, percent) of radionuclides using the conversion transactions described below <sup>21</sup>:

1 ppm of <sup>238</sup>U is equal to 12.35 Bq/l.

1 ppm of  $^{232}\text{Th}$  is equal to 4.06 Bq/l.  
1 percent of  $^{40}\text{K}$  equals 313 Bq/l.

### Effects of radiological hazards are assessed.

To determine the amount of radioactive hazard in the selected water samples, several risk indicators were computed, including:

#### Radium Equivalent ( $Ra_{eq}$ ):

The equivalent activity of radium is defined as a radiation factor using the uniform distribution of natural radionuclides represented by  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , and it is measured in units of Bq/l, and Radium equivalent can be calculated through the following equation:

$$Ra_{eq} \text{ (Bq/l)} = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \quad 2$$

Where  $A_{Ra}$ ,  $A_{Th}$ , and  $A_K$  are the specific activity of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  in units of Bq/l. The maximum universally permitted value of equivalent radium activity ( $Ra_{eq}$ ) is 370 Bq/l <sup>22</sup>.

#### Absorbed Dose Rate in Air ( $D_\gamma$ )

The rate of absorbed dose of gamma rays in the air at one meter 1m above the ground level can be calculated using the specific activity of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , and it can be calculated through the following equation<sup>23</sup>:

$$D_\gamma \text{ (nGy/h)} = 0.462 A_{Ra} + 0.604 A_{Th} + 0.0417 A_K \quad 3$$

$D_\gamma$ : Absorbed dose rate in nGy/h.

$A_{Ra}$  and  $A_{Th}$  and  $A_K$  represent the specific activity of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in Bq/l unit. The conversion factors used to calculate the absorbed dose of gamma rays in air correspond to 0.462 nGy/h for  $^{226}\text{Ra}$ , 0.604 nGy/h for  $^{232}\text{Th}$  and 0.0417 nGy/h for  $^{40}\text{K}$ .

#### Annual Effective Dose Equivalent (AEDE)

The annual equivalent dose means that the radiological factor is used to judge the extent of the health effects resulting from the absorbed dose, and it is measured in units mSv/y. Effective as well as by using the external occupancy factor 0.2 and the internal occupancy factor 0.8. The annual effective dose equivalent (indoor) can also be calculated using the following equation <sup>23</sup>:

$$(AEDE)_{in} \text{ mSv/h} = D_\gamma \text{ nGy/h} \times 10^{-6} \times 8760 \text{ h/y} \times 0.8 \times 0.7 \text{ Sv/Gy} \quad 4$$

The annual effective dose equivalent (outside the home) can be calculated through the following equation

$$(AEDE)_{out} \text{ mSv/h} = D_\gamma \text{ nGy/h} \times 10^{-6} \times 8760 \text{ h/y} \times 0.2 \times 0.7 \text{ Sv/Gy} \quad 5$$

The number 8760 denotes the amount of hours in a year.

#### Hazard Index (H)

A Hazard guide is a radiological parameter used to identify and evaluate external and internal radiation hazards. The external hazard index ( $H_{ext}$ ) and the internal hazard index ( $H_{int}$ ) are calculated through the following equations <sup>24</sup>:

$$H_{ext} = \frac{A(Ra)}{370} + \frac{A(Th)}{259} + \frac{A(k)}{4810} \leq 1 \quad 6$$

$$H_{int} = \frac{A(Ra)}{185} + \frac{A(Th)}{259} + \frac{A(k)}{4810} \quad 7$$

To get the gamma index ( $I_\gamma$ ), we use the following equation <sup>25</sup>:

$$I_\gamma = \frac{A(Ra)}{150} + \frac{A(Th)}{100} + \frac{A(k)}{1500} \leq 1 \quad 8$$

And it should be  $\leq 1$ ; the internationally agreed-upon limit.

#### Life time cancer risk (ELCR)

The Excess Lifetime cancer risk (ELCR) was calculated using the following equation <sup>26</sup>.

$$ELCR_{out} = AEDE_{out} * DL * RF \quad 9$$

Where AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor ( $\text{Sv}^{-1}$ ), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public.

#### Annual gonadal dose equivalent (AGDE)

The gonads, the bone marrow and the bone surface cells are considered organs of interest by UNSCEAR (2000) because of their sensitivity to radiation. An increase in AGED has been known to affect the bone marrow, causing the destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. The AGED for the resident using such material for building by evaluated by the following equation <sup>27</sup>.

$$AGDE(\mu\text{Sv/y}) = 3.09 A_U + 4.18 A_{Th} + 0.314 A_K \quad 10$$

Where,  $A_{Ra}$ ,  $A_{Th}$ , and  $A_K$  are the radioactivity concentration of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in water samples.

#### Heat Production Rate (HPR):

The estimation of the number of radioactive elements, the main internal heat source of the Earth. Has been the focus of various research over the last few decades due to its importance in modeling the thermal evaluation of natural waters. The radioactive isotopes  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  contribute the majority of the terrestrial heat flux. Those elements are essential for understanding the mantle and crust of the earth <sup>28</sup>, as well as their heat-generating potential, by considering the heat generation constant (amount of heat released per

gram  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  per unit time) it is possible to determine the rate of heat production rate using the values given in the following equation <sup>29</sup>.

$$A (\mu\text{Wm}^{-3}) = 10^{-5}\rho(9.52A_{\text{U(ppm)}} + 2.56A_{\text{Th(ppm)}} + 3.48A_{\text{K(\%)}}) \quad 11$$

Where A denotes the heat production rate in  $\mu\text{Wm}^3$ ,  $\rho$  is the sample density in  $\text{kg/M}^3$ ,  $A_{\text{U}}$  and  $A_{\text{Th}}$  denote the  $^{238}\text{U}$  and  $^{232}\text{Th}$  concentrations in ppm unit, and  $A_{\text{K}}$  denotes the total potassium concentration in percent%.

### Results and Discussion:

The results showed that the concentration level of radioactive elements ranged between  $0.36\pm 0.04 - 1.57\pm 0.09$  Bq/l, with an average value

of  $0.69\pm 0.06$  Bq/l for  $^{238}\text{U}$  all values were within the permissible limits  $10 \text{ Bq/l}^{30}$ . and from  $2.9\pm 0.02 - 0.88 \pm 0.03$  Bq/l with an average value of  $0.65\pm 0.03$  Bq/l for  $^{226}\text{Ra}$  It showed that it was within the permissible and estimated global rates  $1\text{Bq/l}^{30}$ , and was between  $4.85\pm 0.4 - 1.36\pm 0.06$  Bq/l with an average value of  $0.88\pm 0.05$  Bq/l for  $^{232}\text{Th}$  the average concentrations of radionuclides appeared which is less than the globally permissible value, which should not exceed  $1\text{Bq/l}^{30}$ , while the level concentration of radioelements of  $^{40}\text{k}$  was higher and appeared to range between  $13.00\pm 0.69 - 36.89\pm 1.12$  Bq/l with an average value of  $25.1\pm 0.95$  Bq/l in all samples was found to be lower than the recommended general mean limits  $400 \text{ Bq/l}^{31}$ .

**Table 2. The total concentrations of radioactive elements ( $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{226}\text{Ra}$ , and  $^{40}\text{K}$ ) Bq/l, in addition to the Physiochemical parameters in natural water samples in Nineveh Governorate.**

Sample Code	Activity Concentrations in Bq/l				Physiochemical parameters		
	$^{238}\text{U}$	$^{226}\text{Ra}$	$^{232}\text{Th}$	$^{40}\text{k}$	PH	Ec $\mu\text{s/cm}$	TDS ppm
Ds1	0.74±0.06	0.72±0.03	0.77±0.05	18.96±0.84	7.78	2.04	156
Ds2	0.42±0.04	0.62±0.03	1.24±0.06	19.38±0.85	8.03	2.5	165
Ds3	0.48±0.05	0.52±0.02	0.79±0.04	33.40±1.12	8.07	25	1003
Ds4	0.77±0.06	0.79±0.03	0.53±0.04	26.77±1.00	7.43	9.09	655
Ds5	0.78±0.06	0.78±0.03	0.48±0.04	25.80±0.98	7.41	14.28	913
Ds6	0.36±0.04	0.39±0.02	0.65±0.04	14.59±0.74	7.87	2.32	211
Ds7	1.57±0.09	0.29±0.02	1.02±0.08	13.00±0.69	7.55	2.63	160
Ds8	0.50±0.05	0.56±0.02	0.96±0.05	33.86±1.12	7.74	0.45	165
Ds9	0.85±0.06	0.88±0.03	1.36±0.06	19.34±0.85	7.62	2.32	204
Ds10	0.64±0.05	0.64±0.03	1.17±0.06	36.89±1.11	7.91	2.22	174
Ds11	0.79±0.06	0.82±0.03	0.60±0.04	33.06±1.11	8.01	14.2	982
Ds12	0.52±0.05	0.53±0.02	1.10±0.06	29.52±1.05	7.53	2.38	193
Ds13	0.51±0.05	0.55±0.02	0.82±0.05	33.48±1.12	7.40	52.63	2011
Ds14	0.76±0.06	0.79±0.033	0.85±0.05	19.15±0.84	7.59	2.85	195
Ds15	0.74 ±0.06	0.78±0.03	0.87±0.05	18.80±0.84	7.51	3.57	223
Min.	0.36±0.04	0.88±0.03	0.48±0.04	13.00±0.69	7.40	2.5	156
Max.	1.57±0.09	2.9±0.02	1.36±0.06	36.89±1.12	8.07	52.63	2011
Mean	0.69±0.06	0.65±0.03	0.88±0.05	25.1±0.95	7.69	9.23	493.6

One can be noticed that the concentration of  $^{40}\text{k}$  dominate over  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ , and  $^{232}\text{Th}$ , which is what normally happens in all different samples of soils, air, and water, because it's high in Natural potassium As in the following Fig. 2 and Table 2: The concentration levels of Natural radioactive elements in water samples tested for  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{k}$  in Bq/l units are shown. The Physiochemical parameters, as well as the geological composition of the Earth, cause changes in the levels of radioactive concentrations of  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  from one sample to another. Regarding the physical and chemical hazards, total dissolved solids (TDS), conductivity (Ec), and (pH)

were measured as the pH levels of natural water samples from 7.40 - 8.07, with An average value of 7.69 The pH level expressed in all water samples from the study area was found to be within the safe limit recommended by the World Health Organization 6.5-8.5 in 1971, the electrical conductivity (Ec) ranged between of 2.5-52.63  $\mu\text{s/cm}$  with an average value of (9.23) the maximum permissible limit of 1.500  $\mu\text{s/cm}$  recommended By the LOCA <sup>32</sup>, and the dissolved solids (TDS) ranged between 156 – 2011 ppm with a mean value of 493.6 ppm All values are within the permissible range 500 ppm recommended By the WHO, As represented in table 2.

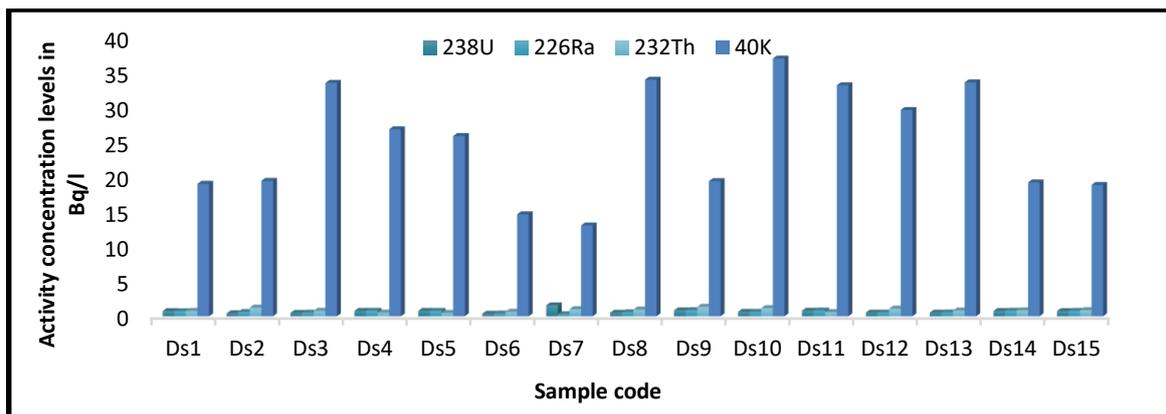


Figure 2. the radioactivity concentration for ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) according to selected sample of natural sources.

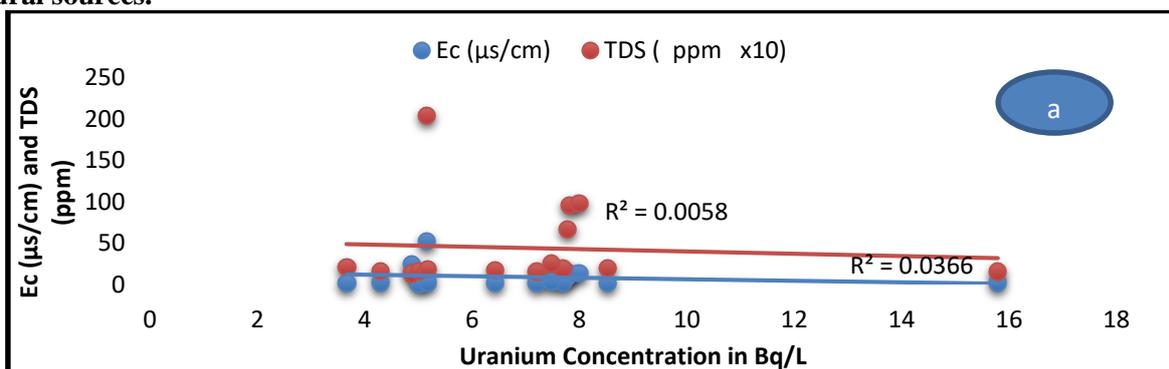


Figure 3-a. The correlation coefficient of uranium ( $^{238}\text{U}$ ) with electrical conductivity (Ec) and the dissolved solids (TDS)

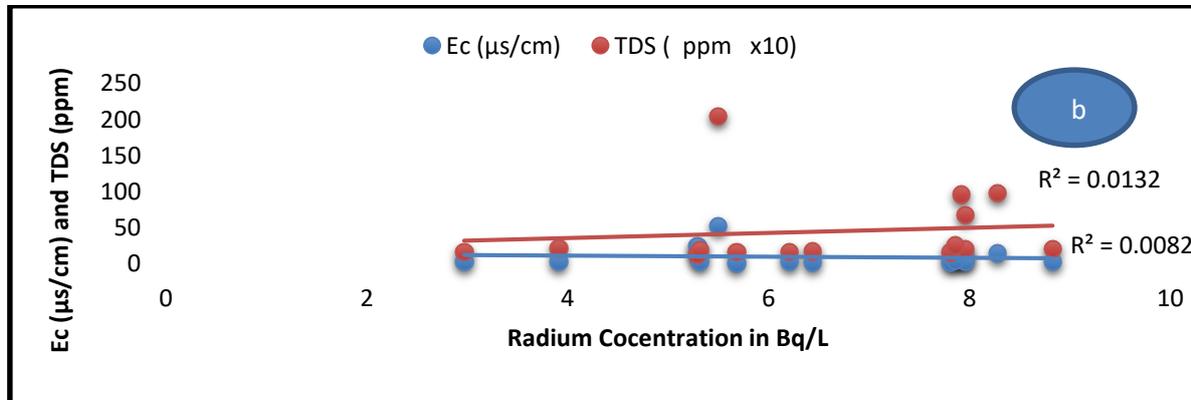


Figure 3-b. the correlation coefficient of Radium ( $^{226}\text{Ra}$ ) with electrical conductivity (Ec) and the dissolved solids (TDS).

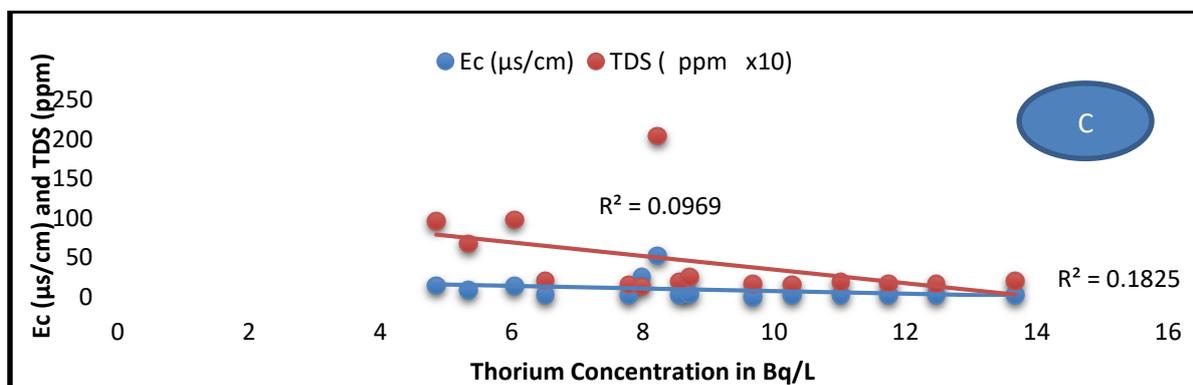


Figure 3-c. the correlation coefficient of Thorium ( $^{232}\text{Th}$ ) with regard to electrical conductivity (Ec) and dissolved solids (TDS).

There was no correlation discovered between uranium, radium, thorium, and pH in this research. However, the concentration levels of  $^{238}\text{U}$ ,  $^{226}\text{Ra}$ , and  $^{232}\text{Th}$  in water samples decrease as the pH increases. Natural water contains a high concentration of TDS, a positive correlation was observed between the radioactive elements and TDS, indicating that the movement of the radioactive elements in the water was significantly affected and controlled by TDS, Fig. 3- a, b, and c. The general rule is that the greater the TDS (or EC), It can be concluded in general from these correlation relations that most of the elements are

positively correlated with each other, a direct relationship (the ratio of an increase leads to an increase in the other). The greater the radioactivity. This study's data may be useful in determining natural radionuclide background levels in drinking water, as well as in initiating safety standards for preserving radioactive materials by relevant authorities and providing clean drinking water to the general public. The concentrations of activity of natural radionuclides of concern in water samples from the current investigation were compared to levels reported for different locations of Iraq and the world in the Table. 3.

**Table 3. Comparison of radionuclide elements concentration with other studies.**

Country	$^{238}\text{U}$ Bq/l	$^{226}\text{Ra}$ Bq/l	$^{232}\text{Th}$ Bq/l	$^{40}\text{K}$ Bq/l	References
Egypt	0.23	0.971–1.6	0.21–1.1	0.97–23	33
Iran	--	0.53	2.08	7.17	34
Jordan	--	3.7	2.41	24.20	35
Pakistan	--	0.00175	0.00235	0.04708	36
Yemen	0.41	3.47	2.02	15.05	37
Turkey	--	0.72	0.53	2.40	38
Iraq (Nineveh Governorate)	0.69	0.65	0.88	25.1	Present work

**Table 4. the radiation hazard indicator values.**

Sample Code	$R_{\text{aeq}}$ Bq/L	$D_{\gamma}$ nGy/h	AEDE Indoor* $10^3$ $\mu\text{Sv/y}$	AEDE Outdoor* $10^3$ $\mu\text{Sv/y}$	$H_{\text{in}}$ * $10^2$	$H_{\text{ex}}$ * $10^3$	$I_{\gamma}$ * $10^2$	ELCR out* $10^3$	AGDE
Ds1	3.22	1.45	1.7	6.2	10.6	8.9	2.3	6.9	10.09
Ds2	3.30	1.59	1.9	6.8	10.9	10.4	2.5	7.8	11.58
Ds3	3.88	1.84	2.2	7.9	12.1	11.3	2.9	9.0	12.56
Ds4	4.22	2.11	2.5	9.0	12.8	9.7	3.3	7.7	15.27
Ds5	3.60	1.80	2.2	7.7	11.8	9.1	2.8	7.4	13.00
Ds6	3.40	1.70	2.0	7.3	11.1	6.5	2.6	5.0	12.61
Ds7	2.44	1.18	1.4	5.0	0.76	7.4	1.8	5.5	8.41
Ds8	2.75	1.29	1.5	5.5	0.82	12.2	2.0	9.6	13.2
Ds9	4.54	2.25	2.7	9.6	13.7	11.6	3.5	8.7	16.18
Ds10	4.31	2.03	2.4	8.7	14.0	13.9	3.2	10.9	14.38
Ds11	5.15	2.54	3.1	10.9	15.6	11.4	4.0	9.1	18.45
Ds12	4.22	2.11	2.5	9.0	13.6	11.8	3.3	9.3	15.32
Ds13	4.37	2.14	2.6	9.2	13.2	10.5	3.4	9.2	15.50
Ds14	4.28	2.13	2.7	9.1	13.0	9.4	3.4	7.2	15.47
Ds15	3.49	1.68	2.0	7.2	11.5	9.3	2.7	7.1	11.91
Min	2.44	1.18	1.4	5	0.76	6.5	1.8	5	8.41
Max	5.15	2.54	3.1	10.9	15.6	13.9	4	10.9	18.45
Average	3.81	1.85	2.22	7.94	11.03	10.22	2.91	8.02	13.59

The radium equivalent value ( $R_{\text{aeq}}$ ) of the examined water samples varied from 2.44-5.15 Bq/l with an average of 3.81 Bq/l, which is fewer than 370 Bq/l as illustrated in Fig. 4. The absorbed dose ratio varies from 1.18-2.54 nGy/h with a mean of 1.85 nGy/h as illustrated in Fig. 5. It is also fewer than the globally suggested minimum 55 nGy/h. Moreover, the annual efficacy value of the dose equal to indoor exposure (AEDE<sub>in</sub>) in the water samples ranged between 1.4-3.1\* $10^3$   $\mu\text{Sv/y}$  and the

overall mean is 2.22\* $10^3$   $\mu\text{Sv/y}$ . As shown in Fig. 6, this value is less than the globally acceptable value of 0.1  $\mu\text{Sv/y}$ . The annual outdoor exposure dose value (AEDE<sub>out</sub>) in the water samples was 5-10.9\* $10^3$   $\mu\text{Sv/y}$ , and the total average 7.94\* $10^3$   $\mu\text{Sv/y}$  as shown in Fig. 6, which is less than the universally permissible limit of 0.1  $\mu\text{Sv/y}$ <sup>38</sup>. The internal hazard index value was smaller than the internationally permitted value, and it varied from 0.76-15.6\* $10^2$  with an average of 11.03\* $10^2$ , as seen

in Fig. 7. The external hazard index value for all samples of analysis water is much lower than the permissible global average, ranging between  $6.5-13.9 \times 10^3$ , with a mean of  $10.22 \times 10^3$ , as shown in Fig. 7 the gamma index ranges from  $1.8-4 \times 10^2$  with an average of  $2.91 \times 10^2$ . Fig. 8 shows the values that are less than the permissible global value and should not exceed  $0.1 \mu\text{Sv/y}$ . The calculated value of ELCR varies from  $5-10.9 \times 10^3$  mSv with an

average of  $8.02 \times 10^3$  mSv as seen in Fig. 9. The ELCR obtained values from water samples tested are lower than the global average  $0.29 \mu\text{Sv}$  the Table 4. Shows the AGDE calculated values in this study, and they vary from  $8.41-18.45 \mu\text{Sv/y}$ , with a mean value of  $13.59 \mu\text{Sv/y}$ , indicating that the AGDE values of all water samples tested are less than the global average of  $300 \mu\text{Sv/y}$  <sup>32</sup> as seen in Fig.10.

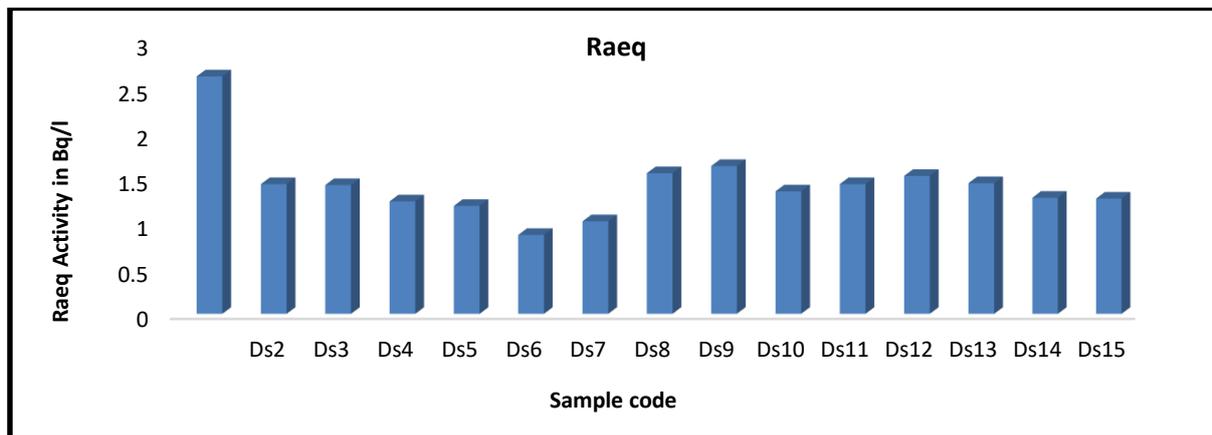


Figure 4. Equivalent levels of radium activity (Raeq) in water samples in Nineveh province, Iraq.

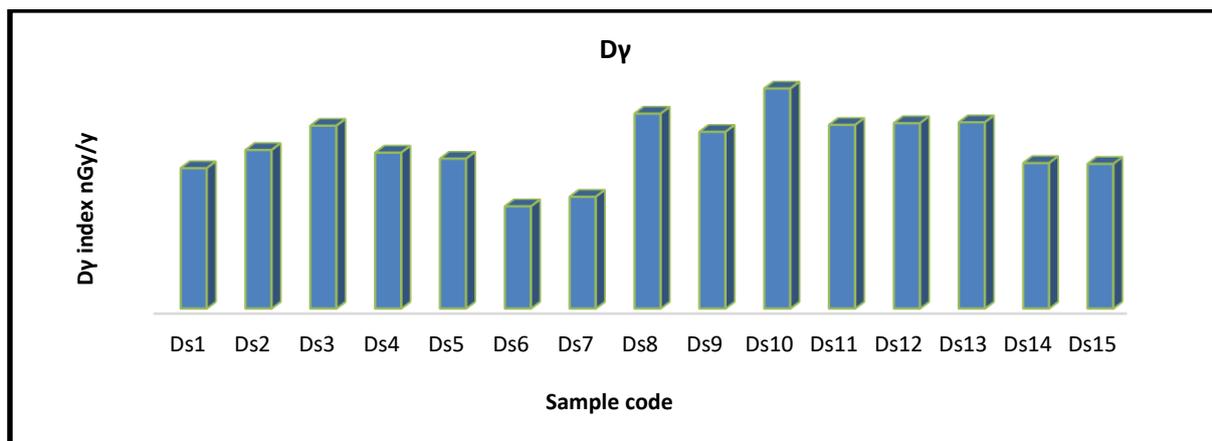


Figure 5. Levels Absorbed dose rate in air (Dy) in water samples in Nineveh province, Iraq.

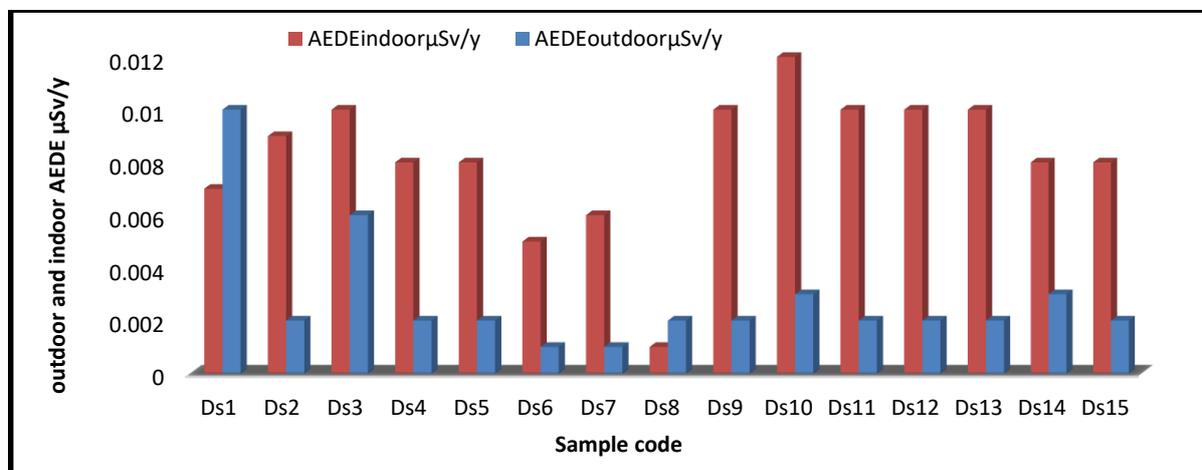


Figure 6. Annual effective dose equivalent rate of internal and external exposure (AEDE indoor) (AEDE outdoor) levels in water samples in Nineveh province, Iraq.

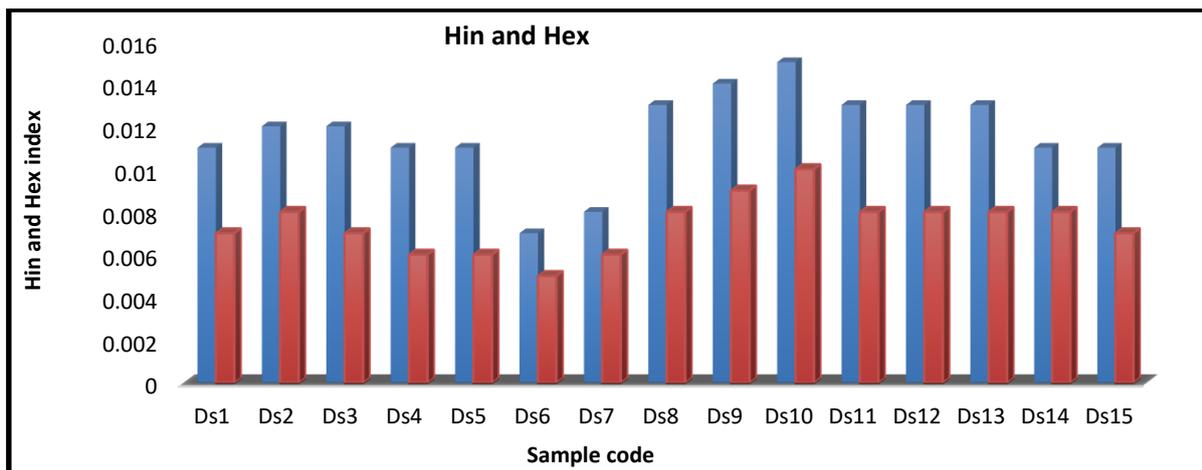


Figure 7. External and internal hazard index levels in water samples from Nineveh province, Iraq.

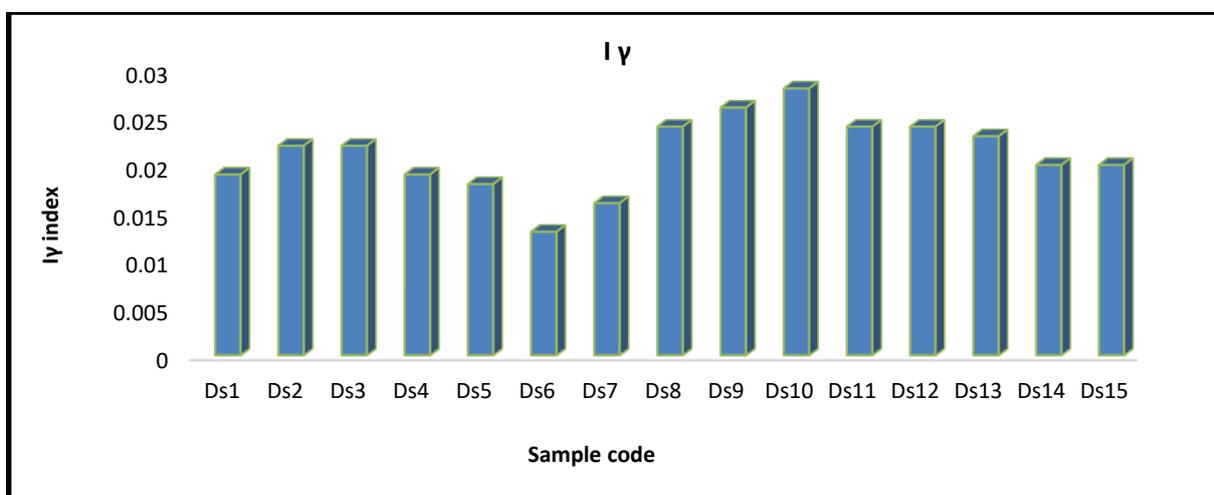


Figure 8. Levels of gamma radiation hazard index in water samples in Nineveh province, Iraq.

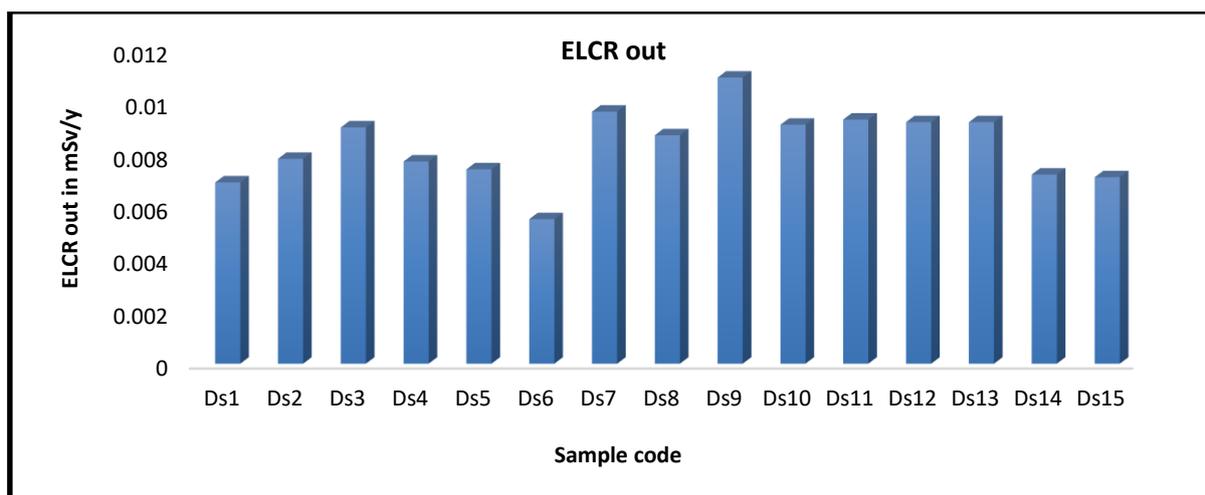


Figure 9. Lifetime cancer risk (ELCR) for various sites of selected samples.

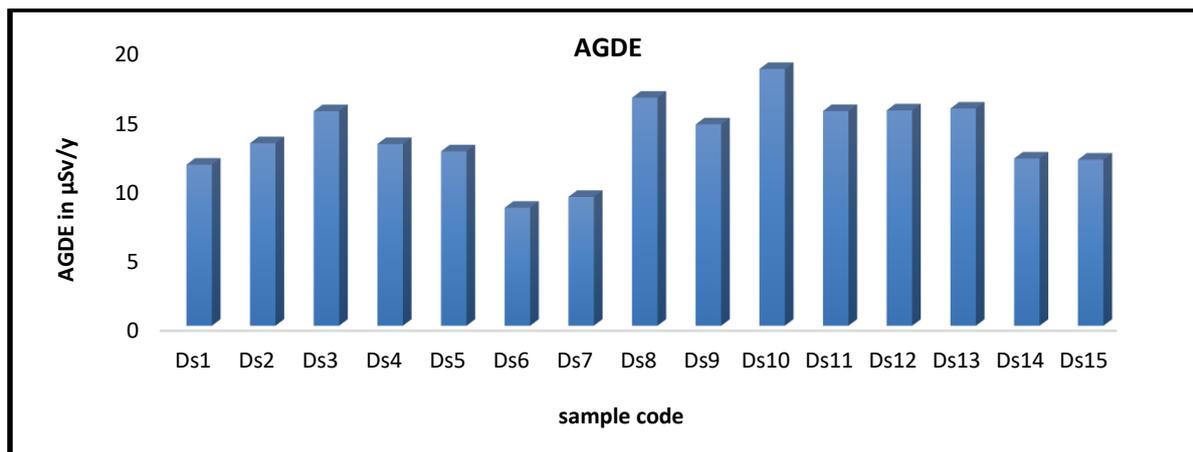


Figure 10. The annual gonadotropin equivalent dose (AGDE) at various locations from the chosen water samples.

Table 5. Activity Concentrations levels of <sup>238</sup>U, <sup>232</sup>Th, and <sup>40</sup>K in Selected Water Samples in (ppm), Plus Heat Production rate.

Sample Code	Activity Concentrations			Heat Production (µW/m <sup>3</sup> )			A µW/m <sup>3</sup>
	<sup>238</sup> U	<sup>232</sup> Th	<sup>40</sup> K	<sup>238</sup> U	Th <sup>232</sup>	K <sup>40</sup>	
	ppm	ppm	%				
Ds1	0.059	0.192	0.060	0.569	0.492	0.211	0.011
Ds2	0.033	0.310	0.062	0.323	0.793	0.215	0.013
Ds3	0.038	0.197	0.106	0.369	0.505	0.371	0.011
Ds4	0.062	0.132	0.085	0.593	0.339	0.298	0.010
Ds5	0.063	0.120	0.082	0.600	0.307	0.287	0.009
Ds6	0.029	0.162	0.046	0.277	0.416	0.162	0.006
Ds7	0.127	0.255	0.041	1.209	0.652	0.144	0.008
Ds8	0.040	0.240	0.108	0.385	0.614	0.377	0.013
Ds9	0.068	0.340	0.061	0.654	0.870	0.215	0.014
Ds10	0.051	0.292	0.118	0.492	0.748	0.410	0.015
Ds11	0.063	0.150	0.105	0.608	0.384	0.368	0.011
Ds12	0.042	0.275	0.094	0.400	0.704	0.328	0.013
Ds13	0.041	0.205	0.107	0.392	0.524	0.372	0.012
Ds14	0.061	0.212	0.061	0.585	0.544	0.213	0.006
Ds15	0.059	0.217	0.060	0.569	0.556	0.209	0.006
Min.	0.029	0.120	0.041	0.277	0.307	0.162	0.006
Max.	0.127	0.340	0.118	1.209	0.793	0.410	0.015
Mean	0.056	0.220	0.080	0.535	0.563	0.279	0.010

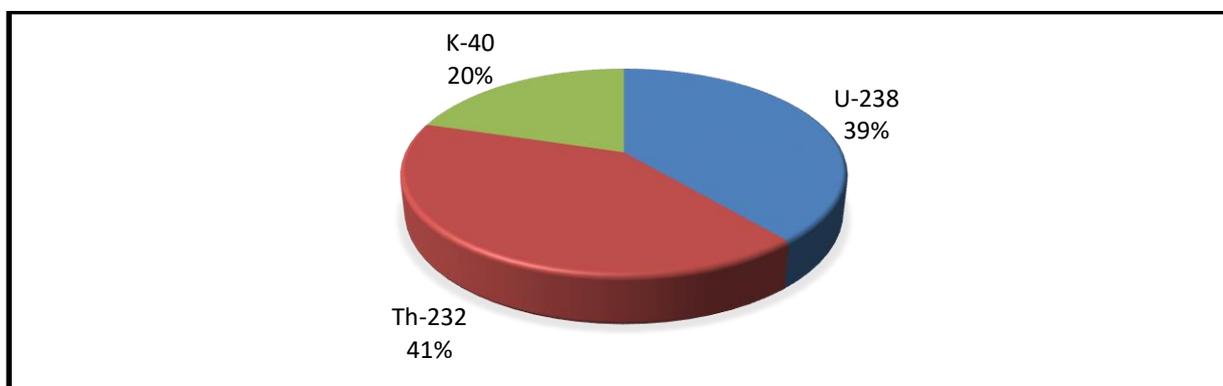


Figure 11. Heat produced by radioactive elements (%)

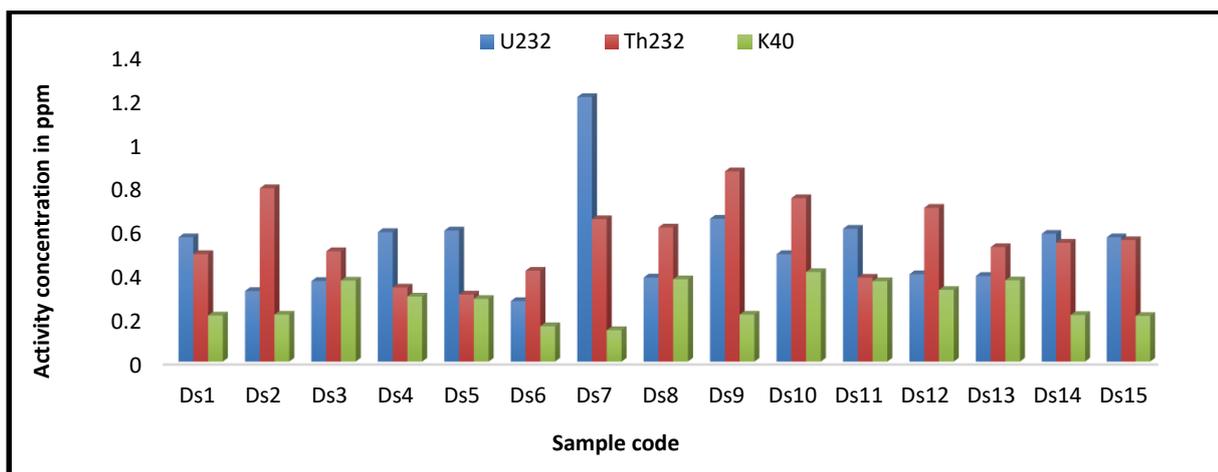


Figure 12. the radioactivity concentrations in units (ppm) of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and (%)  $^{40}\text{K}$  in the natural water samples of Nineveh Governorate.

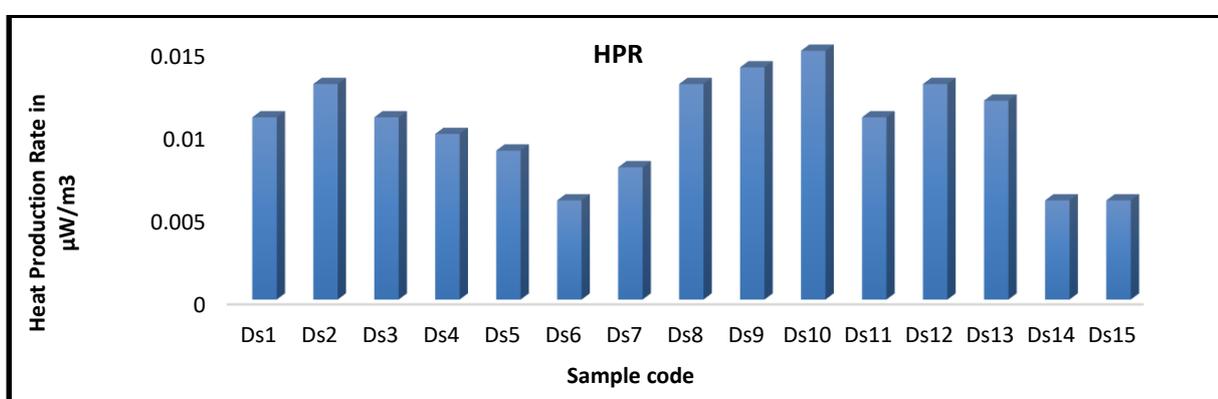


Figure 13. Distribution of heat production rates (HPR) for radioactive element from natural water samples.

The natural radionuclide activity concentrations ( $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) in the selected water samples were examined. The results showed the concentration of  $^{238}\text{U}$  ranged between 0.029-0.127 ppm, with an average value of 0.056 ppm, as for  $^{232}\text{Th}$ , the activity concentrations ranged between 0.120-0.340 ppm with a mean value of 0.220, According to the findings, the concentration level of  $^{40}\text{K}$  varied of between 0.041-0.118% with a mean value of 0.080 %. Although the mean activity concentration value of  $^{232}\text{Th}$  in all samples studied is higher than the mean activity concentration values for  $^{238}\text{U}$  and  $^{40}\text{K}$ , as shown in Table 5, Where the contributions to the average radiant heat production in natural water samples were mostly  $^{232}\text{Th}$  followed by uranium  $^{238}\text{U}$  and then potassium  $^{40}\text{K}$  with a contribution of 41%, 39%, and 20%, respectively as seen in the Fig. 11 and Table 5. This is due to the fact that the thorium element  $^{232}\text{Th}$  is poorly soluble in water and reacts with water at a temperature of 100 C°. Fig. 12 shows the distribution of heat production rates for radioactive elements from natural water samples. And the heat of production rate ranged between 0.006-0.015  $\mu\text{W}/\text{m}^3$  with an average 0.010  $\mu\text{W}/\text{m}^3$ . The

calculated total heat production rate (HPR) at the sites was less than  $1\mu\text{W}/\text{m}^3$  <sup>28</sup>. this indicates that the total heat production in the natural water samples has a low heat production capacity (HPR). Although high radiative concentrations of radioactive elements in a particular location may not always mean a high contribution to the rate of radiant heat production as in Fig.13 And due to the scarcity of data for studies of the rate of radiant heat production for water samples in this region and in Iraq in general, and as a result, they are basic data for the characteristics of the rate of heat production for the study area, as well as a basis for future research on the effect of heat on this site.

### Conclusion:

The possibility of employing gamma-ray spectroscopy by using a sodium iodide detector doped with thallium NaI(Tl) to determine the heat of production rate resulting from the decay of radioactive elements represented by ( $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ). The values of the concentrations of radioactive elements showed that they are within the acceptable and safe limits estimated by the

international organization 10, 1, and 400 Bq/l respectively. These values were reflected in the heat production rates, which in turn were at a rate compatible with the permissible limits of less than 1  $\mu\text{w}/\text{m}^3$ . And the radiological hazard indicators showed that there are no abnormal values that negatively affect human life and health on those who drink or deal with these natural waters. We can confirm that the contribution of the  $^{232}\text{Th}$  nuclide was it has a large percentage in the heat of production rate, followed by the two nuclides of  $^{238}\text{U}$  and  $^{40}\text{K}$ .

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### Authors' Declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Mosul.

### Authors' Contributions Statement:

D. S. M. contributed preparation and design of the study. The data for it was prepared and analyzed by measuring the concentrations of the elements. [D. S. M. Al. and F. M. A. Al.] They contributed to the design and implementation of the research and writing the manuscript.

### References

1. UNSCEAR S. effects of Ionizing Radiation. United Nations, New York. 2000; 453-87. <https://www.unscear.org>.
2. Gómez M, Suursoo S, Martin-Sanchez N, Vaasma T, Leier M. Natural radioactivity in European drinking water: A review. *Crit Rev Environ Sci Tec*. 2022 Feb; 26: 1-8. <https://doi.org/10.1080/10643389.2022.2041975>.
3. Hoffman DC, Lawrence FO, Mewherter JL, Rourke FM. Detection of plutonium-244 in nature. *Nature*. 1971 Nov; 234(5325): 132-4.
4. Martin A, Harbison S, Beach K, Cole P. An introduction to radiation protection. 7th Edition. Boca Raton. CRC Press. 2018 Oct 25. <https://doi.org/10.1201/9780429444104>
5. Zhao X, Luo D. Driving force of rising renewable energy in China: Environment, regulation and employment. *Rev renew sust energ rev*. 2017 Feb 1; 68: 48-56.
6. Abbady AG, Al-Ghamdi AH. Heat production rate from radioactive elements of granite rocks in north and southeastern Arabian shield Kingdom of Saudi Arabia. *J. Radiat Res Appl Sci*. 2018 Oct 1; 11(4): 281-90.
7. Hasterok D, Webb J. On the radiogenic heat production of igneous rocks. *Geosci. Front*. 2017 Sep 1; 8(5): 919-40.
8. Szabo Z, Zapecza OS. Relation between natural radionuclide activities and chemical constituents in ground water in the Newark Basin, New Jersey. In *Radon, radium, and other radioactivity in ground water*; 1st Edition. eBook Published. 2020; p. 562. CRC Press. <https://doi.org/10.1201/9781003069836>.
9. Ubaidi KH, Nasri SK, Saudany ZA. Natural radionuclides and hazards in water and sediment samples of Tigris River in Al-Amara City-Maysan-Iraq. *Adv J Theor Appl Phys*. 2015; 44: 117-22.
10. Salahel Din K, Ali K, Harb S, Abbady AB. Natural radionuclides in groundwater from Qena governorate, Egypt. *Environ Forensics*. 2021 Apr 3; 22(1-2):48-55.
11. Alam I, ur Rehman J, Ahmad N, Nazir A, Hameed A, Hussain A. An overview on the concentration of radioactive elements and physicochemical analysis of soil and water in Iraq. *Rev Environ Health*. 2020 Jun 1; 35(2): 147-55.
12. Amin SA, Jassim AA. Radium Isotopes Levels in Drinking-Water Samples. *J Eng Technol*. 2017 Jan 28; 35(1 Part B): 46-9.
13. Alseroury FA, Almeelbi T, Khan A, Barakata MA, Al-Zahrani JH, Alali W. Estimation of natural radioactive and heavy metals concentration in underground water. *J Radiat Res Appl Sci*. 2018 Oct 1; 11(4): 373-8.
14. Oluyide SO, Tchokossa P, Orosun MM, Akinyose FC, Louis H, Ige SO. Natural radioactivity and radiological impact assessment of soil, food and water around iron and steel smelting area in Fashina Village, Ile-Ife, Osun State, Nigeria. *J Appl Sci Environ. Ma*. 2019 Feb 15; 23(1): 135-43.
15. Parhoudeh M, Khoshgard K, Zare MR, Ebrahiminia A. Natural radioactivity level of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  radionuclides in drinking water of residential areas in Kermanshah province, Iran using gamma spectroscopy. *Iran J Med Phys*. 2019; 16(1): 98-102.
16. Alkhashab Y, Daoud R, Majeed M, Yasen M. Drinking water monitoring in mosul city using IoT In2019. *Int Conf Comp Inf Sci Technol App*. 2019 Mar 3; (p. 1-5). IEEE.
17. Salman AY, Kadhim SA, Alaboodi AS, Alhous SF. Study the contamination of Radioactivity levels of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in (water) Iraq and their potential radiological risk to human population. *IOP Conf Ser: Mater Sci Eng C*. 2020 Nov 1; 928 (7): 72-80.
18. Kurnaz A, Turhan Ş, Alzaridi FM, Bakır TK. Radiological and physicochemical properties of drinking waters consumed in the Western Black Sea Region of Turkey. *J Radioanal Nucl Chem*. 2021 Jun; 328(3): 805-14.
19. Taher AA, Mohammad K. Natural Radioactivity in

- Underground Waters In Tallafar Distract In Iraq. IOP Conf Se: Mater Sci Eng .2020 Nov 1; 928 (7): 72-79.
20. Darko EO, Tetteh GK, Akaho EH. Occupational radiation exposure to norms in a gold mine. Radiat. Prot Dosim. 2005 Jun 28; 114(4): 538-45.
21. Sedara SO, Adelowo A. Assessment of radiogenic heat production in soil samples around Ife steel rolling mill site in Southwestern Nigeria. Int J Innov Sci Res. 2015; 13(1):249-56.
22. Najam LA, Wais TY. Radiological Hazard Assessment of Radionuclides in Sediment Samples of Tigris River in Mosul city, Iraq. AJNSA. 2022 Jan 1; 55(1): 45-52.
23. Salih NA, AL-Bakhat YM, Abd ulmajeed, Al-Rahmani A, Murbat OM, Ameen NH, et al. Assessment of Radiological Air Contamination for Selected Places at Al-Tuwaita Nuclear Site during winter and spring. Baghdad Sci J. 2018; 15(3): 278-286.
24. Najam LA, Muhammad KA, Mohammed FM. Evaluation of the Natural Radioactivity of Samples of Some Types of Field Crops in Different Areas of Tikrit, Iraq. Iran. J. Sci. Technol. Trans. A. 2021 Dec;45(6):2241-7.
25. Hameed BS, Fzaa WT. Concentrations and Radiation Hazard Indices of Naturally Radioactive Materials for Flour Samples in Baghdad Markets. Baghdad Sci J. 2021 Sep 1; 18(3): 0649.
26. Marzaali AA, Al-Shareefi MA, Abojassim AA.  $^{222}\text{Rn}$ ,  $^{226}\text{Ra}$  and  $^{238}\text{U}$  concentration in water samples for some marshes in Dhi-Qar governorate, Iraq. Water Supply. 2022 Jan; 22(1): 1035-46.
27. Avwiri GO, Ononugbo CP, Nwokeoji IE. Radiation Hazard Indices and Excess Lifetime cancer risk in soil, sediment and water around mini-okoro/oginigba creek, Port Harcourt, Rivers State, Nigeria Environ Earth Sci. 2014; 3(1): 38-50.
28. Ojha L, Karunatilake S, Karimi S, Buffo J. Amagmatic hydrothermal systems on Mars from radiogenic heat. Nat Commun. 2021 Mar 19; 12(1): 1-1.
29. Hasterok D, Webb J. On the radiogenic heat production of igneous rocks. Geosci. Front. 2017 Sep 1; 8(5): 919-40.
30. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 1996 Report: Report to the General Assembly, with Scientific Annexes. United Nations. New York; 1996 Nov 7: p.86. <https://www.unscear.org>.
31. Annex D, United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Investigation of United Nation. New York,. 2000; 1: 2-17. <https://inis.iaea.org>.
32. Stein R. Water Law in a Democratic South Africa: A County Case Study Examining the Introduction of a Public Rights System. Tex L Rev. 2004; 83: 2167.
33. Arabi AE, Ahmed NK, Salahel Din K. Natural radionuclides and dose estimation in natural water resources from Elba protective area, Radiat Prot Dosim. 2006 Dec 1; 121(3): 284-92.
34. Parhoudeh M, Khoshgard K, Zare MR, Ebrahiminia A. Natural radioactivity level of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  radionuclides in drinking water of residential areas in Kermanshah province, Iran using gamma spectroscopy. Iran J Med Phys. 2019; 16(1): 98-102.
35. Kashparov VA, Lundin SM, Khomutinin YV, Kaminsky SP, Levchuk SE, Protsak VP, et al. Soil contamination with  $^{90}\text{Sr}$  in the near zone of the Chernobyl accident. J Environ Radioact. 2001 Jan 1; 56(3): 285-98.
36. Ahmad N, Khan A, Ahmad I, Hussain J, Ullah N. Health implications of natural radioactivity in spring water used for drinking in Harnai, Balochistan. Int J Environ Anal Chem. 2021 Jul 15; 101(9): 1302-9.
37. Abd El-Mageed AI, El-Kamel AE, Abbady AE, Harb S, Saleh II. Natural radioactivity of ground and hot spring water in some areas in Yemen. Desalination. 2013 Jul 15; 321: 28-31.
38. Kurnaz A, Turhan Ş, Alzaridi FM, Bakır TK. Radiological and physicochemical properties of drinking waters consumed in the Western Black Sea Region of Turkey. J Radioanal Nucl Chem. 2021 Jun; 328(3): 805-14.

## معدل إنتاج الحرارة ومؤشرات مخاطر الإشعاع من العناصر المشعة في أنواع مختلفة من المياه الطبيعية في محافظة نينوى، العراق

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قسم الفيزياء، كلية العلوم، جامعة الموصل، موصل، العراق.

### الخلاصة:

تلقي الدراسة الحالية الضوء على قياس وتقدير النشاط الإشعاعي للعناصر المشعة ( $^{238}\text{U}$ ,  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ ) في المياه الطبيعية لمناطق مختلفة من محافظة نينوى في العراق، تم جمع 15 عينة من مصادر مختلفة من المياه الطبيعية. حيث تم استخدام التحليل الطيفي لأشعة كاما باستخدام NaI(Tl) لتحديد تراكيز النشاط الإشعاعي في العينات. وبحسب النتائج، تراوحت تراكيز النشاط الإشعاعي في عينة الماء المختبرة من  $0.36\pm 0.04$  Bq/l -  $1.57\pm 0.09$  Bq/l بمتوسط قيمة  $0.69\pm 0.06$  Bq/l لـ  $^{238}\text{U}$ ، و  $0.88\pm 0.03$  Bq/l -  $2.9\pm 0.02$  Bq/l بمتوسط قيمة  $0.65\pm 0.03$  Bq/l لـ  $^{226}\text{Ra}$ ، و  $0.48\pm 0.04$  Bq/l -  $1.36\pm 0.06$  Bq/l بمتوسط قيمة  $0.88\pm 0.05$  Bq/l لـ  $^{232}\text{Th}$ ، بينما لـ  $^{40}\text{K}$   $0.69\pm 1.12$  -  $13.00\pm 36.89$  Bq/l بمتوسط قيمة  $25.1\pm 0.95$  Bq/l على التوالي. النتائج التي تم الحصول عليها من عينات المياه أقل من الحدود الآمنة والمعيارية التي وضعتها لجنة UNSCEAR. بالإضافة إلى حساب مؤشرات الخطر الإشعاعي التي شملت مكافئ الراديوم (Raeq)، ومعدل الجرعة الممتصة في الهواء ( $D\gamma$ )، ومعدل الجرعة السنوية المكافئة الفعالة (AEDE)، ومؤشرات مخاطر الإشعاع الداخلي والخارجي (H)، ومخاطر الإصابة بالسرطان مدى الحياة (ELCR)، تم حساب الجرعة المكافئة للغدد التناسلية (AGDE)، ومؤشر المستوى المثالي لأشعة كاما ( $I\gamma$ ). للتحقق من طابعها الضار. من ناحية أخرى أظهرت النتائج أن معدل إنتاج الحرارة تتراوح بين (0.0015- $0.006\ \mu\text{W}/\text{m}^3$ ) وبمعدل ( $0.010\ \mu\text{W}/\text{m}^3$ ) مما يدل على انخفاض معدل إنتاج الحرارة ولا يؤثر على درجة حرارة القشرة الأرضية. أخيراً، بالإضافة إلى المعلمات الفيزيائية والكيميائية مثل PH والمواد الصلبة الذائبة TDS والموصلية الكهربائية EC. جميع البيانات المختبرة ضمن الحد المسموح به لمعايير منظمة الصحة العالمية. يمكن استخدام نتائج الدراسة الحالية لتوفير بيانات أساسية للتحقيقات البوابة المستقبلية وبرامج المراقبة في المناطق قيد الدراسة.

**الكلمات المفتاحية:** مخاطر الإصابة بالسرطان (ELCR)، التحليل الطيفي لأشعة كاما، معدل إنتاج الحرارة (HPR)، كاشف NaI(Tl)، المعلمات الفيزيوكيميائية.