Estimation of Radionuclides Elements for Natural Water Resources in Nineveh Province, Iraq Using Gamma Ray Spectroscopy

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ABSTRACT

The present study is intended to analyze and evaluate the radioactivity level of radioactive nuclides namely, [26]Ra, [232]Th, and [40]k of different kinds of natural waters for various regions of the Nineveh Province in Iraq. To achieve the objective of the study, 30-samples of natural water were taken from various sources. The water samples were distributed in three types: 8 samples of surface raw water, 13 samples of tap water, 5 samples of cold well (underground) water, 3 samples of mineral spring water, and one rainwater sample. Gamma-ray spectroscopy using a NaI (TI) scintillation detector attached to a software multi-channel analysis tool was used to determine the radioactivity concentrations in the samples. In the investigated samples of natural water, the radioactivity concentrations of [226]Ra, [232]Th, and [40]k ranged between (4.67± 0.26 - 22.95 ± 0.58) Bq/l for [226]Ra, and between (4.44±0.38– 1.85 ±0.07) Bq/l for [232]Th, while [40]k ranged between (7.24±0.52 -38.49±1.20)Bq/l, respectively. The results obtained from the samples of water were below the safe and standard limits established by UNSCEAR, with the exception of one site due to their geological nature. Radium activity equivalents (Ra_{eq}), Absorbed dose rate in the air (Dγ), effective dose rate per year, and the gamma radiation level index (Iγ) were calculated to investigate their harmful characters. Radiological hazard indicators appeared to be below the international permissible rate. The current study's findings can be used to provide essential basic data for future epidemiological investigations and surveillance programs in the study area.

1. INTRODUCTION

Radiation is a vital part of existence that cannot be avoided. We exist in a world where radiation naturally prevails and permeates all aspects of life. The radiation comes in food and water mainly through the [238]U, [232]Th series, and [40]k radionuclides that have been naturally present since the universe's starting [1]. Natural sources account for more than 96% of all human radiation exposure [2], while human-made sources account only for 4% [3]. Water plays a significant part because of its everyday use through living beings and its capacity for contaminant transport, it is used in environmental research. When natural radionuclides are present in drinking water, they pose a health risk if consumed [4]. The greatest external source of human body irradiation is the gamma radiation emitted from these radionuclides, which may be regarded as the most contribution to the external dosage taken by the world's population [5].

[226]Ra, [232]Th, and [40]k are three key natural radionuclides that significantly contribute to the radiation dosage humans get [6]. There was a slight increase in the level of radium in mineral water samples and in underground wells compared to surface water samples (raw, pure), because the samples that contain some minerals that may contain radium, or the sources of these samples are in the depths of the earth. Groundwater moves through rocks and soil containing radioactive elements. This shows that the effectiveness of radium increases approximately with increasing depth from the surface of the earth, and this explains the increase in the proportion of radium in water samples taken from great depths below the surface of the earth. [7]. The researchers [8,9,10] identified some radioactive elements for ^{137}Cs, [238]U, [232]Th, and [40]K from different samples of water using Gamma-ray spectroscopy alongside the hazard indicator. The results show that the values of concentration of these elements were less than the global limit. Amin & Jassim[11] have

used the NaI (TI) 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.

Some local researchers [12] measured the concentration of natural elements radioactivity in the groundwater in Mecca (Makkah Al Mukarramah) region as ^{226}Ra, ^{232}Th, and ^{40}k elements using HPGe, and the results showed that the values of the concentrations of these elements were less than the global limit. Other researchers [13] have conducted a study that included measuring the levels of some radioactive elements (^{222}Rn, ^{226}Ra) in various water sources in Erbil Province, Kurdistan Region, Iraq, using two techniques, including RAD7 and a NaI (TI) detector. The study revealed concentrations of radium and radon in water samples. This is except for Par saline and Hogarth wells which are fewer than the US National Environmental Agency's recommended maximum contamination. There is a survey study that has conducted in Nigeria, Osun State [14] using the NaI(TI) detector, determined the radioactivity of ^{238}U, ^{232}Th, and ^{40}k. (38) Water samples. They 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. Salman and his group [15] were able to carry out comprehensive radioactivity levels of ^{232}Th, ^{238}U, and ^{40}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 that the samples are safe and healthy. Another work [16] have studied some of the radioactive elements ^{226}Ra, ^{232}Th, and ^{40}k in drinking water samples. ^{226}Ra, ^{232}Th, and ^{40}k belong to the Kastamonu district in western Turkey's Black Sea regionwere studied using Gamma-ray spectroscopy utilizing the HPGe detector. The values of these radioactive elements were consistent with the values allowed by the World Health Organization (WHO) with the exception of ^{228}Ra which was higher than the concentration recommended by WHO. The aim of the current work is to estimate the concentration levels of some radioisotopes such as ^{232}Th, ^{226}Ra, and ^{40}k in various types of natural and drinking water in Mosul city, and the districts and countryside located outside the Mosul city in Nineveh province. The concentration measurement of the radioactive nuclides is based on Gamma-ray spectroscopy by means of a NaI (TI) detector. The present study also aims to identify the danger indicators of the radioactive isotopes and their influence on the life of the population as a result of daily water consumption.

2. MATERIALS AND METHODS OF PREPARATION

2.1 Studying location

In this paper, Nineveh province has been selected as a study site. It is located in the northwest of Iraq and its center is the city of Mosul, which is of a faraway distance of 465 km from the capital, Baghdad. Nineveh is the second largest province after Baghdad, with a population of nearly three million people. The province is located between 36º degrees longitude and 43º degrees latitude. The Tigris River passes through the province and divides the city of Mosul into two coasts, right and left, where many cities and villages of the province are located on both sides of it. The study of radioactivity levels in this city can be considered important because of the environmental neglect that the province and its center suffer from, the city of Mosul, as a result of the bombing and destruction that the city was subjected to during the war, which had a significant impact on the components of the environment, especially water. The Tigris River, which passes through the city, is the primary supply of drinking water and other daily necessities, and also agricultural and irrigation usage.

2.2 Sample Collection and Preparation

Water samples were taken in the province of Nineveh in August 2021. The samples included most of the water purification projects in the province center in the city of Mosul and the nearby areas, the Mosul dam on the Tigris River (downstream, power intakes, guard gate), underground wells that feed most of the districts in areas far from the province center and the Tigris River, a number of minerals Springs, as well as the city's rainwater. The administrative structure of the Nineveh Province, and the places where the water samples were collected, are shown in Fig. (1). Three samples were collected from each place. Three samples were brought from each site and mixed together and one sample was taken from the mixture with a capacity of 5 liters. The samples included natural raw water for purification projects and Mosul Dam from depths of 3-4 meters below the surface of the river, while the depths of wells ranged from (30-180) meters. Table (2) lists the sites from which samples were taken. 5-liter plastic bottles were used after being thoroughly washed with dilute hydrochloric acid to preserve the water samples.

The acid has the benefit of minimizing radionuclide absorption on the walls of the container, while also preventing the formation of algae. The water is filtered to remove any suspended particles in the samples before being filled into containers. The openings of the containers are closed tightly with paraffin tape and left

for at least 28 days to acquire the ideal (or secular) irradiated equilibration of radioactive elements and their daughters. After that, the water samples were examined by placing (1) One liter of water in a Marinelli's vessel to collect the spectrum of gamma rays emitted from the radionuclide content in the samples. Radioisotope concentrations including ^{226}Ra, ^{232}Th, and ^{40}k were estimated using a spectroscopic study of these rays using a NaI (Tl) detector connected to a multichannel analyzer and a personal computer (pc).

2.3 Gamma -Ray Spectrometry

To detect the radioactivity in the studied water samples, the authors have utilized Gamma-ray spectroscopy using a Thallium-doped sodium iodide detector NaI (TI) (Oak Ridge, TN 37830, USA) of 3.8 cm radius and 2.5 cm thickness. The detector is installed on a lead-coated holder where the lead works to decrease the recorded background radiation. The detector is connected through a primary amplifier to a multichannel analyzer which is linked via a USB cable to a PC computer to display the radionuclides gamma spectrum using the installed software "SPECTCH UCS-20". It is known that the spectrum of gamma rays depends on the radionuclides as well as the energy. The authors have experimentally calibrated and verified the energy using the standard sources ^{133}Ba,^{137}Cs, and ^{60}Co having the gamma lines at 356 Kev, 661.6 Kev, and (1332.5, 1173.2) Kev respectively, by collecting the gamma spectrum of these isotopes for 180 seconds so as to get the energy value for each channel (Kev/channel). Moreover, the detector's effectiveness was calibrated using Europium as a standard source, which has a huge variety of known energies ranging from (121.8-1408) Kev. The calibration was done under the same conditions of measuring the water samples by placing the source in a Marinelli's vessel and collecting its gamma spectrum for the same period of time, which is 18000 s, and using the radioactivity relation given in Eq.1. Figure (2) shows the calibration curve for the NaI (TI) detector efficiency. Thus, according to this Figure, the percentage efficiency, and ^{226}Ra, ^{232}Th, and ^{40}k for their own gamma lines and energies were found. The water samples under study were examined by taking one liter of water (1kg) in a container similar to the Marinelli baker, and the emitted gamma spectrum was collected for a period of 18000 s to compute the concentrations of radioactivity in the samples.
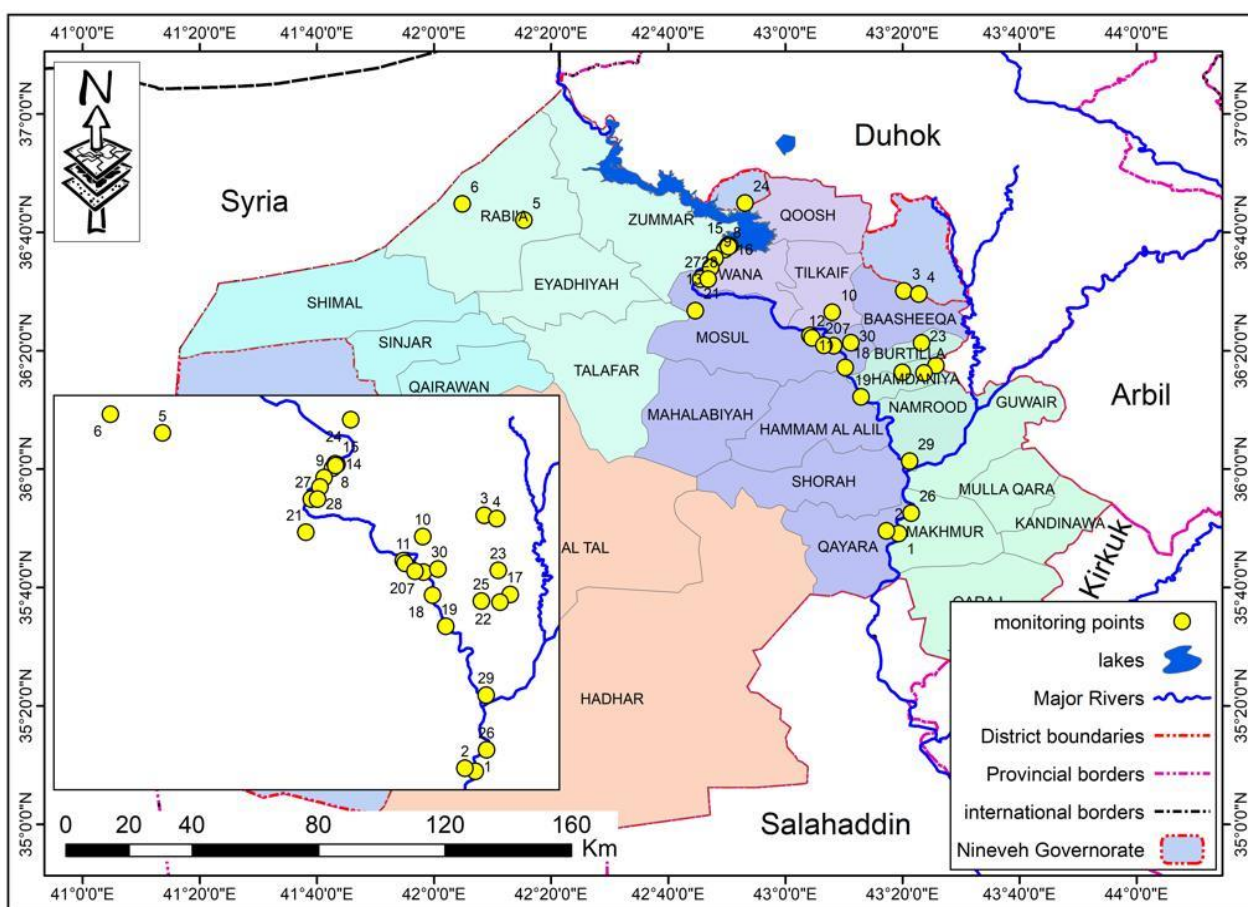

Fig. (1): GPS coordinates were used to determine the locations from which water samples were collected

It is worth mentioning that the radioactive background was measured for the same time period and its value was subtracted to get the real radioactivity resulting from the samples [16].

2.4 calculation of Activity concentration

The water samples understudy that were brought from various regions of Nineveh province were examined by placing one liter (1 L) of water, which has been subjected to a pre-radiological balance, in a container similar to the Marinelli's vessel, then the detector crystal was inserted quietly into the same container so that it was facing the sample to be examined. To prevent external radiation from reaching the detector, all samples were surrounded by sheets of lead (5 cm thick). Then the spectrum of gamma-ray emitted from the water sample was collected for a period of 18,000 seconds. By calculating the area under the gamma spectrum curve, the concentrations of the radionuclides ^{226}Ra, ^{232}Th, and ^{40}K content in the samples are calculated using the radioactivity relationship

as in the following formula [17]. 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 [16].

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

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, ε_γ is the detector's efficiency at a specific energy of the measured nuclide's gamma line, I_γ is the percentage severity of a gamma-rays 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) reveals different types and locations of water samples collected in various regions of Nineveh province.
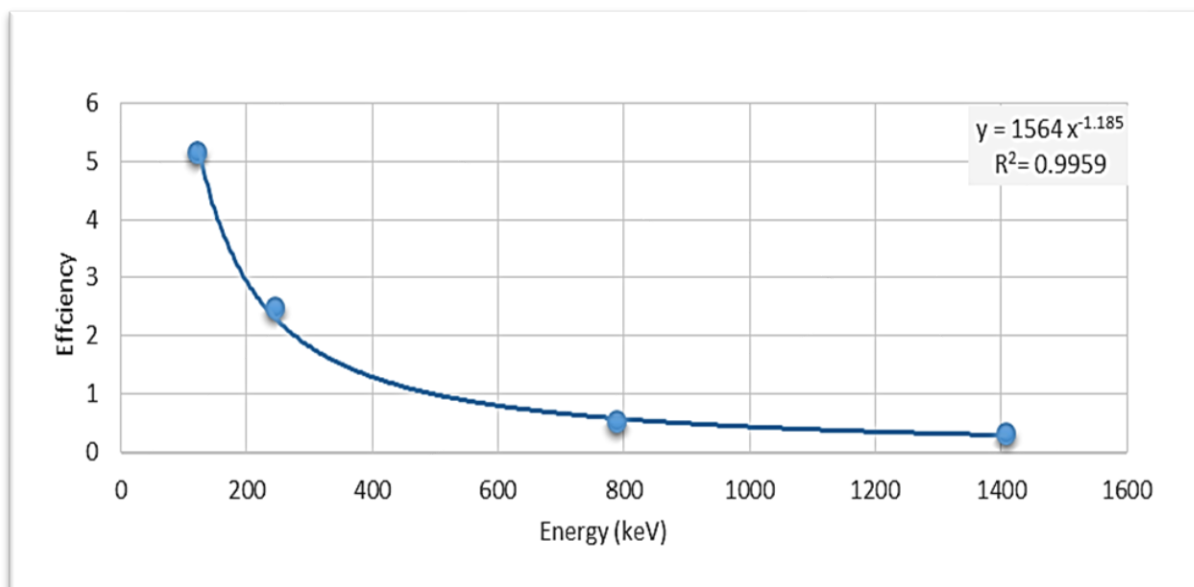

Fig. (2): the efficiency calibration for NaI (TI) detector

Table (1): indicates the latitude and longitude, samples ID; and names of samples for different regions of Nineveh Province

No. of sample	Sample Type	Location	(X-Y) Coordinate
W01	Raw water	Qayara water Project	(43˚.32ʹ 21 80ʺ , 35˚.81ʹ 89 29ʺ)
W02	Pure tape water	Qayara water Project	(43˚.28ʹ 75 49ʺ , 35˚.82ʹ 64 12ʺ)
W03	Cold well water	Ras Al-Ein- Bashiqa	(43˚.33 ʹ72 52ʺ , 36˚.50ʹ 18 17ʺ)
W04	Cold well water	Abu Jarboua- Bashiqa	(43˚.37ʹ 96 49ʺ , 36˚.49ʹ 32 44ʺ)
W05	Cold well water	Rabia	(42˚.25ʹ 60 19ʺ , 36˚.70ʹ 12 38ʺ)
W06	Pure tap water	Rabia	(42˚.08ʹ 01 36ʺ , 36˚.74ʹ 69 60ʺ)
W07	Mineral spring water	Ein Kabreet-Mosul	(43˚.13ʹ 79 70ʺ , 36˚.34ʹ 74 06ʺ)
W08	Raw water	Mosul Dam Project	(42˚.82ʹ 75 55ʺ , 36˚.61ʹ 88 97ʺ)
W09	Pure tap water	Mosul Dam Project	(42˚.80ʹ 01 55ʺ , 36˚.59ʹ 37 18ʺ)
W010	Cold well water	Al-Qusiyat-Mosul	(43˚.13ʹ 36 51ʺ , 36˚.44ʹ 21 14ʺ)
W011	Raw water	Right water project	(43˚.07ʹ 00 72ʺ , 36˚.37ʹ 66 00ʺ)
W012	Pure tap water	Right water Project	(43˚.07ʹ 62 31ʺ , 36˚.36ʹ 95 43ʺ)
W013	Pure tap water	Badoush- Hamidat	(42˚.78ʹ 74 29ʺ , 36˚.56ʹ 79 99ʺ)
W014	Raw water/ Down stream	Mosul Dam Project/	(42˚.84ʹ 26 47ʺ , 36˚.62ʹ 92 48ʺ)
W015	Raw water/ Power intake	Mosul Dam Project	(42˚.83ʹ 62 20ʺ , 36˚.63ʹ 07 06ʺ)
W016	Raw water/ Guard gate	Mosul Dam Project	(42˚.83ʹ 79 87ʺ , 36˚.62ʹ 65 49ʺ)
W017	Pure tap water	Karamlees	(43˚.50ʹ 36 08ʺ , 36˚.29ʹ 69 14ʺ)
W018	pure tap water	Albusayf	(43˚.17ʹ 04 03ʺ , 36˚.28 ʹ63 22ʺ)
W019	Mineral spring water	Hamam Al-Alil	(43˚.21ʹ 57 51ʺ , 36˚.20ʹ 36 71ʺ)
W020	Pure tap water	old City of Mosul	(43˚.10ʹ 98 37ʺ , 36˚.34ʹ 90 97ʺ)
W021	Pure tap water	Al kasak	(42˚.74ʹ 38 40ʺ , 36˚.44ʹ 66 27ʺ)
W022	Pure tap water	Qaraqosh-Baghdida	(43˚.46ʹ 99 22ʺ , 36˚.27ʹ 58 40ʺ)
W023	Pure tap water	Bartella	(43˚.46ʹ 27 91ʺ , 36˚.36ʹ 05 83ʺ)
W024	Pure tap water	Faidah	(42˚.88ʹ 48 99ʺ , 36˚.74ʹ 94 59ʺ)
W025	Cold Well water	Al Hamdaniyah	(43˚.33ʹ 26 61ʺ , 36˚.27ʹ 29 66ʺ)
W026	Raw water/River side	Qayara	(43˚.35ʹ 48 07ʺ , 35˚.87ʹ 66 50ʺ)
W027	Raw water	Wana Project	(42˚.75ʹ 90 14ʺ , 36˚.53ʹ 55 08ʺ)
W028	Pure tap water	Wana Project	(42˚.78ʹ 00 56ʺ , 36˚.53ʹ 55 20ʺ)
W029	Mineral spring water	Namrud	(43˚.35ʹ 40 53 ʺ , 36˚.02ʹ 25 03ʺ)
W030	Rain water	Mosul city	(43˚.18ʹ 64 88ʺ , 36˚.35ʹ 62 76ʺ)

3. Evaluation of Radiological hazards Effect

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

3.1 Radium Equivalent (Ra_{eq}):

It is described as the sum of the ratios of the radioactive concentration of the radionuclides ^{226}Ra, ^{232}Th, and ^{40}k, which are calculated using the following formula:

$$Ra_{eq} \text{ (Bq/l)} = A_{Ra} + 1.43\,A_{Th} + 0.077Ac._k \qquad (2)$$

Denote the activity levels of ^{226}Ra, ^{232}Th, and ^{40}k in Bq/l considering radium activity, its maximum possible value is 370 Bq/l [18].

3.2 Absorbed Dose Rate in the Air $(D\gamma)$

In Gray unit (Gy), the amount of energy soaked up in joules for every kilogram of irradiated material is determined. The following equation is used to compute it [19]:

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

Where $A_{Ra,Th,and\,k}$ are the specific activities of the ^{226}Ra, ^{232}Th, and ^{40}K in Bq/l, respectively, and D is the rate absorbed dose in nGy/h. ^{226}Ra, ^{232}Th, and ^{40}K have conversion coefficients of 0.462, 0.604, and 0.0417 nGy/h , respectively.

3.3 Internal $(H_{in.})$ and External $(H_{ex.})$ risk Indices, and Ideal Level Index for Gamma Rays (I_γ)

Internal and external exposure, therefore the gamma index, are measured using specified relations. The total ratio is obtained by dividing the three-level concentration radioelement ^{226}Ra, ^{232}Th, and ^{40}K by the degree of Hazard determined by a particular value for that element, and these values are related to the maximum allowable hazard level for each element or dosage. External or internal exposure is permissible for a certain time period. The external and internal risk levels $(H_{ex.}$ & $H_{in.})$ Are calculated using the following equations [18]

$$H_{ex.} = \frac{A(Ra)}{370} + \frac{A(Th)}{259} + \frac{A(k)}{4810} \qquad \leq 1 \qquad (4)$$

$$H_{in.} = \frac{A(Ra)}{185} + \frac{A(Th)}{259} + \frac{A(k)}{4810} \qquad\qquad (5)$$

To get the gamma index (Guide) (Iγ), the following equation is used:

$$I_\gamma = \frac{A(Ra)}{150} + \frac{A(Th)}{100} + \frac{A(k)}{1500} \qquad \leq 1 \qquad (6)$$

And it should be ≤ 1 ; the internationally agreed-upon limit [19].

4. RESULTS AND DISCUSSION

To achieve the aim of this study, the level concentration of radioelements for ^{226}Ra is varying from (0.46 ± 0.02) Bq/l in sample W_{028} and (2.29 ± 0.05) Bq/l in sample W0$_3$. Furthermore, the values of ^{226}Ra in all samples were found to be lower than the recommended general mean limits (1Bq/L).WHO, with the exception of one sample (W_{03}). This is due to the high level of ^{226}Ra in mineral water samples and in underground wells compared to surface water samples (raw, pure), because samples that contain some minerals that may contain radium, or the sources of these samples are deep under the surface. Water passes through rocks as it flows. This shows that the effectiveness of radium increases approximately with increasing depth from the surface of the earth, and this explains the increase in the proportion of radium in water samples taken from great depths below the surface of the earth and for ^{232}Th was between (0.44 ± 0.03) Bq/l in W_{08} and (1.85 ± 0.07) Bq/l in W_{023}, while level concentration of radioelements of ^{40}k was higher and appeared to range between (7.24 ± 0.52) Bq/l in W_{030} and (38.49 ± 1.20) Bq/l in W_{05}, The average activity concentrations of ^{40}K were higher than those of all the other radionuclides in all the samples. Table (2) and Fig. (3) showed that is is generally not considered in assessing the radiological hazards on health from radionuclides in drinking water because potassium is a key element in regulating many body functions and the potassium content of the body is retained constant by a range of physiological processes. The chemical and physical properties as well as the geological composition of the earth cause changes in the levels of radioactive concentrations of ^{226}Ra, ^{232}Th, and ^{40}K from one sample to another. Despite the discrepancy in the concentrations of radionuclides in the models used, the average concentrations of radionuclides appeared less than the internationally permissible average limits, as shown in Table (2).

Table (2): The concentration levels of Natural radioactive elements in water samples tested for ^{226}Ra, ^{232}Th, in Bq/l units

| No. of sample	Level concentrations of radioelements (Bq /l)		
	^{226}Ra	^{232}Th	^{40}K
W01	1.13 ± 0.04	1.46 ± 0.06	35.59 ± 1.15
W02	0.76 ± 0.03	0.99 ± 0.05	33.14 ± 1.11
W03	2.29 ± 0.05	0.60 ± 0.06	28.62 ± 1.03
W04	0.49 ± 0.02	0.89 ± 0.08	33.37 ± 1.12
W05	0.98 ± 0.03	1.09 ± 0.05	38.49 ± 1.20
W06	0.98 ± 0.03	1.11 ± 0.05	27.23 ± 1.01
W07	1.36 ± 0.04	1.24 ± 0.06	29.30 ± 1.05
W08	0.80 ± 0.03	0.44 ± 0.03	29.64 ± 1.05
W09	0.47 ± 0.02	0.84 ± 0.05	31.03 ± 1.08
W010	0.83 ± 0.03	1.06 ± 0.06	35.25 ± 1.15
W011	0.82 ± 0.03	0.91 ± 0.05	26.25 ± 0.99
W012	0.70 ± 0.03	0.70 ± 0.05	28.17 ± 1.03
W013	0.87 ± 0.03	1.02 ± 0.05	31.97 ± 1.09
W014	0.67 ± 0.03	0.83 ± 0.07	33.18 ± 1.11
W015	0.69 ± 0.03	0.73 ± 0.11	30.47 ± 1.07
W016	0.57 ± 0.02	1.07 ± 0.11	32.80 ± 1.11
W017	0.69 ± 0.03	1.22 ± 0.05	22.97 ± 0.93
W018	0.75 ± 0.03	0.76 ± 0.49	18.84 ± 0.84
W019	1.11 ± 0.03	1.23 ± 0.06	18.22 ± 0.82
W020	1.04± 0.03	0.64 ± 0.04	18.07 ± 0.82
W021	0.66 ± 0.03	0.63 ± 0.04	17.63 ± 0.81
W022	1.13 ± 0.04	0.74 ± 0.04	30.92 ± 1.07
W023	0.77 ± 0.03	1.85 ± 0.07	24.89 ± 0.48
W024	0.71 ± 0.03	0.84 ± 0.05	17.51 ± 0.81
W025	0.79 ± 0.03	0.62 ± 0.04	28.88 ± 1.04
W026	0.54 ± 0.02	0.60 ± 0.04	16.49 ± 0.78
W027	0.74 ± 0.03	0.80 ± 0.05	18.87 ± 0.84
W028	0.46 ± 0.02	1.07 ± 0.06	18.20 ± 0.82
W029	0.69 ± 0.03	0.68± 0.04	14.41 ± 0.73
W030	0.72 ± 0.03	1.36 ± 0.06	7.24 ± 0.52
Min.± S.E	0.46± 0.02	0.44 ± 0.03	7.24 ± 0.52
Max.± S.E	2.29 ± 0.05	1.85 ± 0.07	38.49 ± 1.20
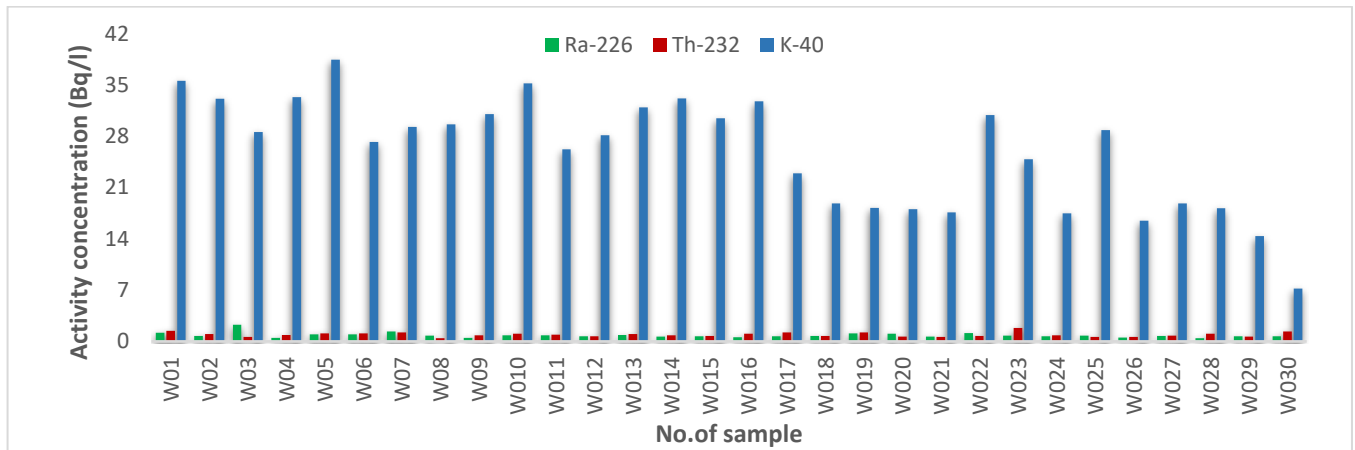
Fig. (3): The radioactivity concentration for ^{226}Ra, ^{232}Th, and ^{40}K according to selected sample of natural sources

Table (3): the values of radiation hazard indicators

No. of sample	Ra$_{eq.}$ Bq/l	D $_\gamma$ nGy/h	H$_{in}$	H$_{ex}$	I$_\gamma$
W01	6.015	2.914	0.019	0.016	0.046
W02	4.742	2.337	0.014	0.012	0.037
W03	5.361	2.617	0.020	0.014	0.040
W04	4.340	2.159	0.013	0.011	0.034
W05	5.515	2.721	0.017	0.014	0.043
W06	4.661	2.257	0.015	0.012	0.035
W07	5.409	2.608	0.018	0.014	0.041
W08	3.725	1.877	0.012	0.010	0.029
W09	4.078	2.026	0.012	0.011	0.032
W010	5.070	2.497	0.015	0.013	0.039
W011	4.151	2.027	0.013	0.011	0.032
W012	3.879	1.924	0.012	0.010	0.030
W013	4.807	2.358	0.015	0.012	0.037
W014	4.428	2.201	0.013	0.011	0.035
W015	4.082	2.031	0.012	0.011	0.032
W016	4.637	2.282	0.014	0.012	0.036
W017	4.212	2.017	0.013	0.011	0.032
W018	3.293	1.594	0.010	0.008	0.025
W019	4.283	2.020	0.014	0.011	0.031
W020	3.366	1.629	0.011	0.009	0.025
W021	2.927	1.424	0.009	0.007	0.022
W022	4.573	2.260	0.015	0.012	0.035
W023	5.348	2.518	0.016	0.014	0.040
W024	3.275	1.572	0.010	0.008	0.024
W025	3.911	1.948	0.012	0.010	0.030
W026	2.685	1.307	0.008	0.007	0.020
W027	3.347	1.616	0.011	0.009	0.025
W028	3.407	1.624	0.010	0.009	0.026
W029	2.781	1.334	0.009	0.007	0.021
W030	3.230	1.459	0.010	0.008	0.023
Min	2.685	1.307	0.008	0.007	0.020
Max	6.015	2.914	0.020	0.016	0.046

The radium equivalent value (Ra_{eq}) of the examined water samples varying from (2.685) Bq/l in the sample (W_{026}) and (6.015) Bq/l in the sample (W_{01}) with an average of (4.184) Bq/l, which is fewer than (370) Bq/l as shown in Figure (4). The absorbed dose rate is varying from (1.307) nGy/h in sample (W_{026}) and (2.914) nGy/h in the sample (w_{01}) with an average of (2.038) nGy/h as shown in Figure (5). It is also fewer than the globally suggested minimum (55) nGy/h. recommended by the WHO. The internal hazard index value was smaller than the internationally permitted value, and it is varying from (0.008) in the sample (W_{026}) and (0.020) in the sample (W_{03}) with an average of (0.013), as seen in the Figure (6). The external hazard index value for all analysis water samples is much less than the global allowable average, ranging between (0.007) in the sample (W_{026}) and (0.016) in the sample (W_{02}, W_{029}), with an average of (0.010), as seen in Figure (6). The obtained results are less than unity which shows that there is no radiation hazard for the body. The gamma index ranges from (0.020) in the sample ($W026$) to (0.046) in the sample (W_{01}), with an average of (0.031). Figure (7) shows that these values are within the safe limits.

The concentrations of activity and radiological hazard of natural radionuclides of concern in water samples from the current investigation was compared to levels reported for different locations in Iraq and the world as in Table (4).

Table (4): a comparison of radionuclide elements concentrations with other studies

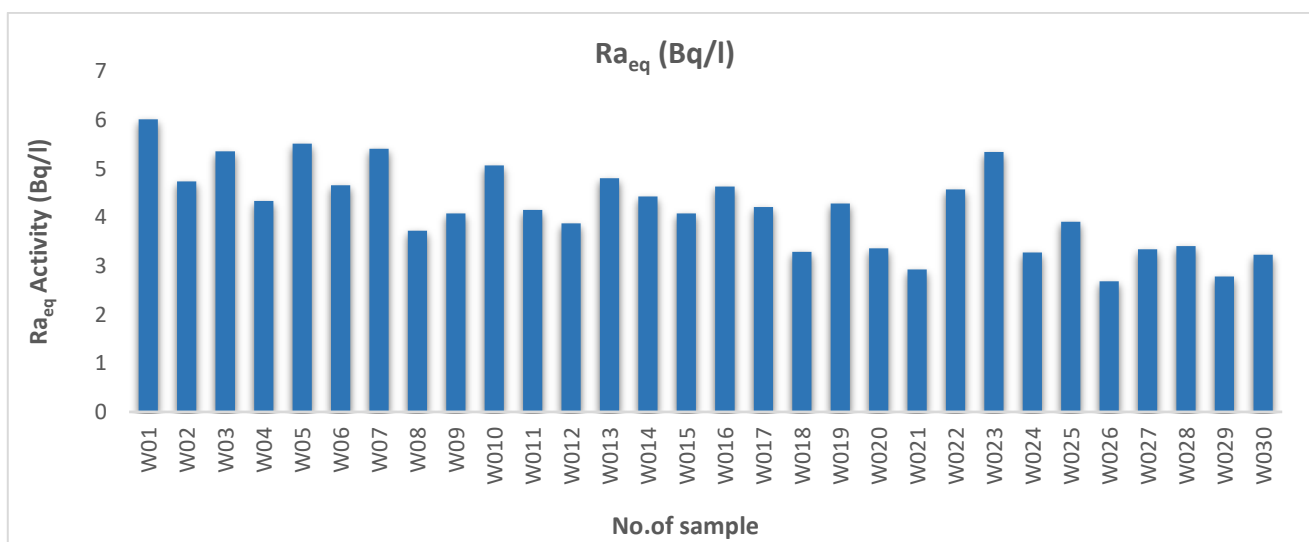| Country	^{226}Ra	^{232}Th	^{40}K	References
Egypt	0.971– 1.6 Bq/l	0.21– 1.1 Bq/l	0.97–23 Bq/l	[20]
Iran	0. 53 Bq/l	2.08 Bq/l	7. 17 Bq/l	[21]
Jordon	3. 7 Bq/l	2.41 Bq/l	24. 20 Bq/l	[22]
Pakistan	0.00175 Bq/l	0.00235 Bq/l	0.04708 Bq/l	[23]
Yemen	3. 47 Bq/l	2.02 Bq/l	15. 05 Bq/l	[24]
Turkey	0. 72 Bq/ 1	0. 53 Bq/l	2. 40 Bq/l	[25]
Iraq(Nineveh provice)	0.842 Bq/l	0.93 Bq/l	25.92 Bq/l	Present work

Fig. (4): Equivalent levels of radium activity (Raeq) in water samples in Nineveh province, Iraq
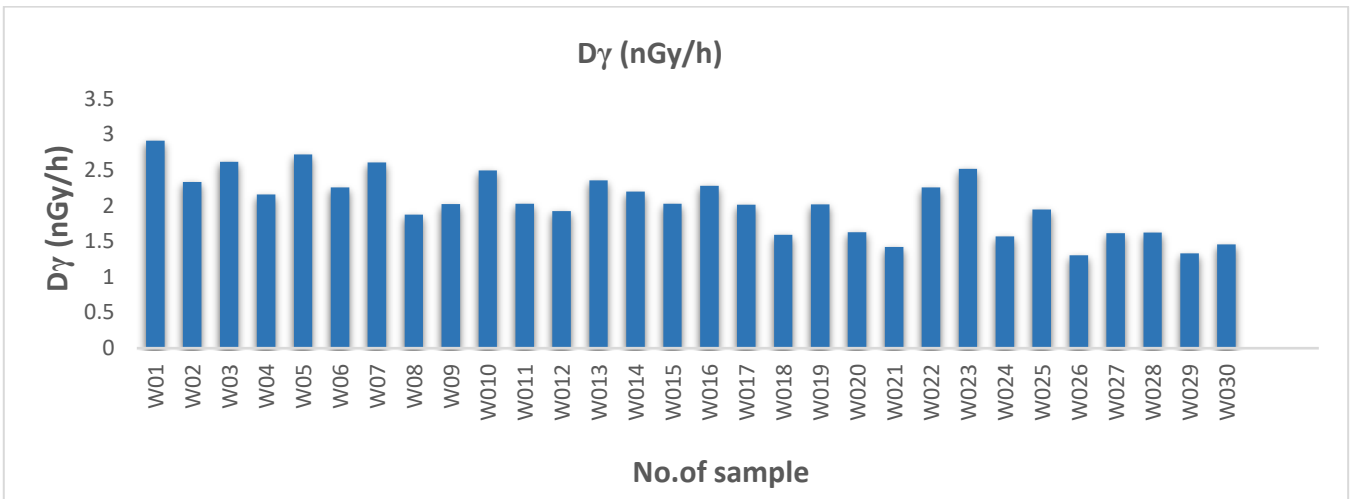
Fig. (5): Levels of air absorbed dose (Dɣ) in water samples in Nineveh province, Iraq
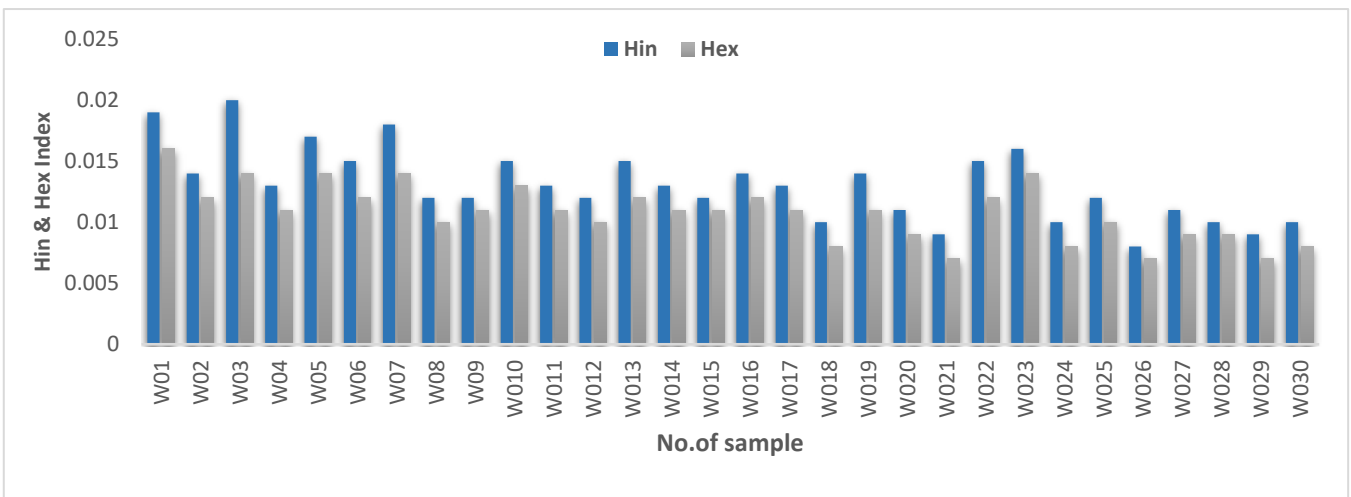

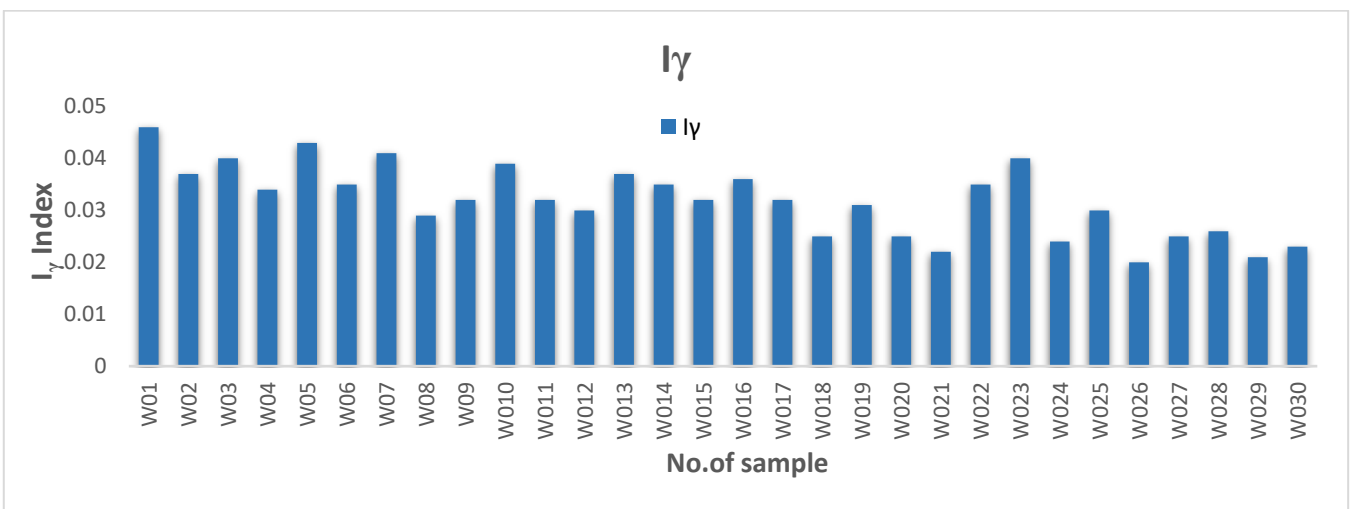**Fig. (6): Levels of external and internal hazard index in water samples in Nineveh province, Iraq**

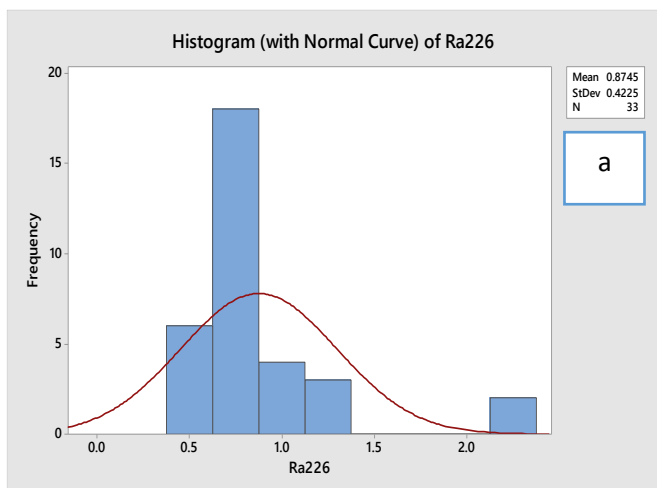**Fig. (7): Levels of gamma radiation hazard index in water samples in Nineveh province, Iraq**

Fig. (8, a) the level concentration of radioelement of
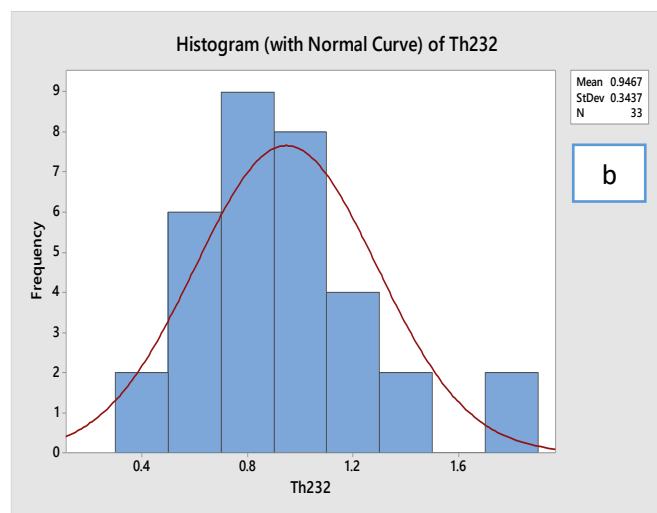^{226}Ra in (Bq/l)

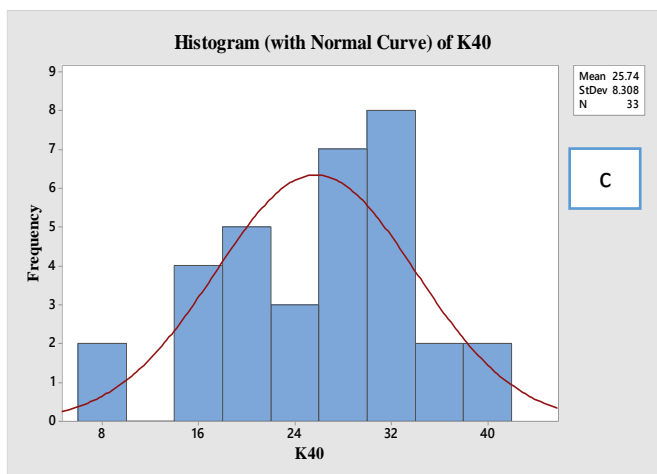Fig. (8, b) the level concentration of radioelement of
^{232}Th in (Bq/l)

Fig. (8, c) the level concentration of radioelement of ^{40}K
in (Bq/l)

Fig. (8) (a,b,c) reveals the frequency distribution of Ra^{226}, Th^{232} and ^{40}K.

The measured activities of concentrations for all radionuclides studied, as shown in Tables (2 and 3) show the presence of a normal distribution and they are practically symmetrical. This is also supported by the symmetrical figures in Fig. 8a, b, and c, which were fitted to a polynomial model.
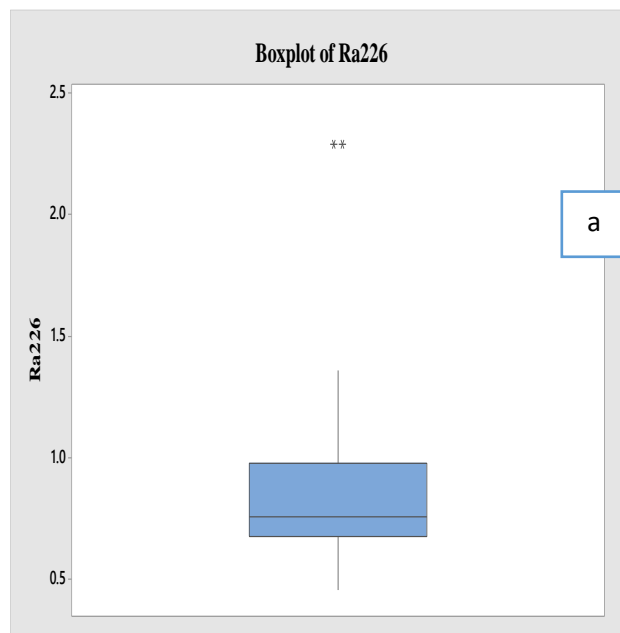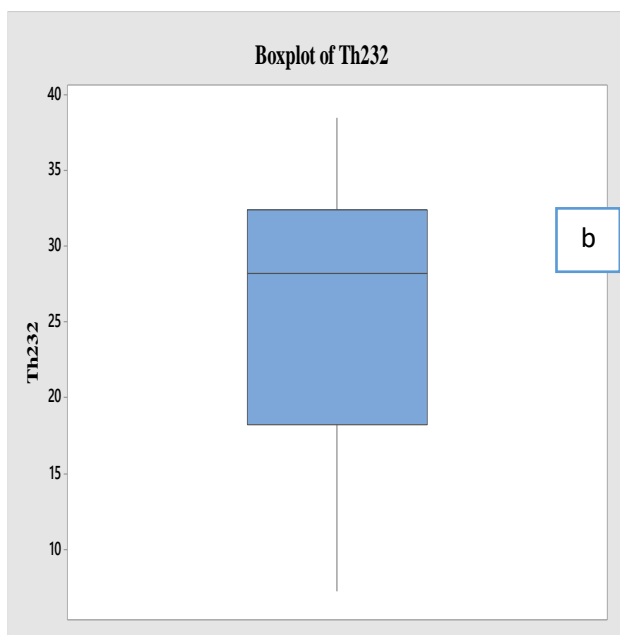

Fig. (9,a) Box plot of Radium (^{226}Ra)
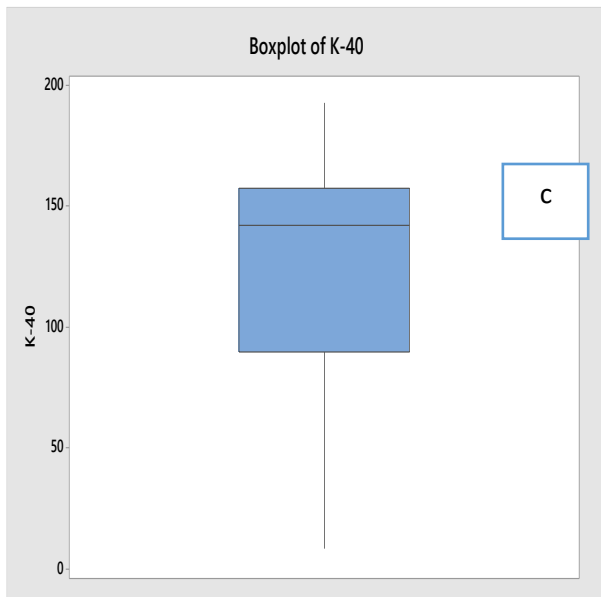

Fig. (9,b) Box plot of thorium (^{232}Th)

Fig. (9,c) Box plot of potassium (^{40}k)

Fig. (9): a Box plot of Radium (^{226}Ra), b Box plot of Thorium (^{232}Th), and c Box plot of potassium (^{40}k), respectively

Box plots (9 a,b,c) show the level concentrations of radioelements of ^{226}Ra,^{232}Th,and ^{40}K in units of Bq/l, respectively. An activity focus box plot is used to learn about how the values are divvied up in the data The median of ^{226}Ra, ^{40}K is nearer to the box's top as shown in Figures (9 a and c), indicating that the distribution is skewed in the opposite direction (negatively). The median of the box plot for ^{232}Th is nearer to the box's bottom, indicating a positively skewed distribution, as shown in Figure (9 b).

3. CONCLUSIONS

The health risks of radioactivity are associated with ^{226}Ra, ^{232}Th, and ^{40}K for thirty samples examined in water specimens from Nineveh Province, northern Iraq, using a NaI (TI) scintillation detector. This study presents the basic levels of radioactivity in the chosen samples of water. Furthermore, the values of ^{226}Ra in all samples were found to be lower than the recommended general mean limits (1Bq/L) of the WHO, with the exception of sample (W$_{03}$,). This is due to their geological nature. Additionally, the study indicates that the averages value of radium equivalents (Raeq) is less than the allowable limits of 370 Bq/l. Absorbed does rate in the air is smaller than the allowable values of the permissible rates. The results of calculating the external and internal hazard indicators showed that they were

within the internationally permissible rate, as the where the value did not exceed one did not exceed one, and that the average value of the gamma radiation level indicator for those areas did not exceed one, which is also less than the internationally permissible rates. Similarly, we conclude that all studied areas are safe for human consumption.

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