PERIÓDICO TCHÊ QUÍMICA
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RADIOATIVIDADE NA ÁGUA SUBTERRÂNEA A OESTE DE BASRA, IRAQUE, USANDO ESPECTROSCOPIA DE RAIOS GAMA

RADIOACTIVITY IN GROUNDWATER WEST OF BASRA, IRAQ, USING GAMMA-RAY SPECTROSCOPY

النشاط الإشعاعي في المياه الجوفية غرب البصرة، العراق، باستخدام مطيافية أشعة كاما

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RESUMO

Introdução: A água subterrânea, encontrada nos vazios das rochas abaixo da superfície da terra, é uma fonte crucial de água para consumo, irrigação e, em menor grau, para usos industriais. A água é essencial para a vida e para todas as atividades econômicas, sendo utilizada nos setores residencial, industrial e agrícola. Obter água suficiente com a qualidade e quantidade adequadas é fundamental para manter a saúde. Fornecer água potável de alta qualidade é vital para a prevenção de doenças e para melhorar a qualidade de vida. O consumo de água aumentou devido ao crescimento da população e das atividades. A água subterrânea é particularmente importante para o desenvolvimento regional, especialmente para usos humanos, agrícolas e industriais. **Objetivos:** O objetivo deste estudo é avaliar e analisar os níveis de radioatividade de Th-232, U-238 e K-40 em água subterrânea em diferentes áreas de Zubair, na cidade de Basra, Iraque, e realizar o cálculo dos indicadores de risco de radiação. **Métodos:** Utilizou-se um detector de cristal de iodeto de sódio dopado com tálio para realizar a análise do espectro de raios gama. **Resultados:** As concentrações de radioatividade dos radionuclídeos de U-238 variaram entre (0,025-1,612) Bq/L e Th-232 (0,001-1,282) Bq/L e K-40, (1,208-39,473) Bq/L, respectivamente. Além disso, foram calculados indicadores de risco de radiação, como a atividade de rádio (Ra), que varia entre 0,641 e 3,857 Bq/L. A faixa da dose média absorvida do ar (D) foi entre 0,345 e 2,016 nGy/h. Os resultados do índice gama (Iγ) variaram entre 0,0055 e 0,03183, o índice de risco interno (Hin) variou entre 0,00179 e 0,01211, e o índice de risco externo (Hex) variou entre 0,00173 e 0,01041. **Discussão:** Todos os resultados obtidos com o reagente de iodeto de sódio dopado com tálio para U-238 e Th-232 estão dentro dos limites recomendados pela OMS e não colocam em risco a saúde pública. No entanto, foi observada uma discrepância nos resultados devido às variações geológicas de uma região para outra. Além disso, há uma variação e aumento na concentração de K-40 em diferentes regiões, principalmente devido às atividades agrícolas e ao uso de fertilizantes, que elevam os níveis de K-40. Apesar desse aumento, não representa um risco significativo para o público geral. **Conclusões:** Com base nos valores obtidos, podemos inferir que não há risco para a população geral. Exceto pelas amostras (WK02 e WK014), ambas são adequadas para uso na construção e na agricultura.

Palavras-chave: *água subterrânea, Radioatividade, Espectrometria de raios gama, Detector NaI (Tl), Radionuclídeos naturais*.

ABSTRACT

Background: Groundwater, found in the voids of rocks below the surface of the earth, is a crucial source of water for drinking, irrigation, and, to a lesser extent, industrial uses. Water is essential for life and every economic activity, and it is used across residential, industrial, and agricultural sectors. Obtaining sufficient water of the appropriate quality and quantity is crucial for maintaining health. Providing fresh, high-quality water is vital for disease prevention and improving the quality of life. Water consumption has risen due to the increase in population and activities. Groundwater is particularly important for regional development, especially for human, agricultural, and industrial uses. **Aims**: The purpose of this study is to assess and analyze the radioactivity levels of Th-232, U-238, and K-40 in groundwater.In different areas of Zubair in Basra city, Iraq, the calculation of radiation hazard indicators is performed. **Methods**: A thallium-doped sodium iodide crystal detector was used to do the gamma-ray spectrum analysis. **Results**: The radioactivity concentrations of the radionuclides of U-238 ranged between (0.025-1.612) Bq/L and Th-232(0.001-1.282) Bq/L and K-40, (1.208-39.473) Bq/L, respectively. Furthermore, markers of radiation hazard were computed, such as the activity of radium (Ra), which varies between 0.641 to 3.857 Bq/L. The range of the average dose absorbed from the air (D) was between 0.345 to 2.016 nGy/h. The results of the gamma (Iγ) index were between 0.0055 and 0.03183, the internal hazard index (Hin) was between 0.00179 to 0.01211, and the external hazard index (Hex) was between 0.00173 and 0.01041. **Discussion**: All results obtained with a sodium iodide reagent doped with thallium for U-238 and Th-232 are within the WHO's recommended limits and do not endanger public health. However, there is a noted discrepancy in the results due to the geological variations from one region to another. Additionally, there is a variation and increase in the concentration of K-40 in different regions, primarily due to agricultural activities and the use of fertilizers, which raise the K-40 levels. Despite this increase, it does not pose a significant risk to the general public**.** **Conclusions**: Based on the obtained values, we may infer that there is no risk to the general population. Except for the sample (WK02 and WK014), both are appropriate for use in construction and agriculture.

Keywords: *groundwater, Radioactivity, Gamma-ray spectrometry, NaI (TI) detector, Natural Radionuclides*.

خلاصة

الخلفية: المياه الجوفية ، الموجودة في فراغات الصخور تحت سطح الأرض ، هي مصدر مهم للمياه للشرب والري ، وبدرجة أقل ، الاستخدامات الصناعية. المياه ضرورية للحياة وكل نشاط اقتصادي ، ويتم استخدامها في القطاعات السكنية والصناعية والزراعية. يعد الحصول على كمية كافية من المياه بالجودة والكمية المناسبة أمرا بالغ الأهمية للحفاظ على الصحة. يعد توفير المياه العذبة عالية الجودة أمرا حيويا للوقاية من الأمراض وتحسين نوعية الحياة. ارتفع استهلاك المياه بسبب الزيادة في عدد السكان والأنشطة. تعتبر المياه الجوفية مهمة بشكل خاص للتنمية الإقليمية ، خاصة للاستخدامات البشرية والزراعية والصناعية. **الأهداف**: الغرض من هذه الدراسة هو تقييم وتحليل مستويات النشاط الإشعاعي من الثوريوم-232 ، اليورانيوم-238 ، و البوتاسيوم-40 في المياه الجوفية. في مناطق مختلفة من الزبير في مدينة البصرة ، العراق ، يتم حساب مؤشرات الخطر الإشعاعي. **الطرق**: تم استخدام كاشف بلورة يوديد الصوديوم المطعم بالثاليوم لإجراء تحليل طيف أشعة كاما. **النتائج**: تراوحت تركيزات النشاط الإشعاعي للنويدات المشعة لليورانيوم-238 بين (1.612-0.025) بيكريل/لتر و الثوريوم-232(1.282-0.001) بيكريل/لتر و البوتاسيوم-40 ، (39.473-1.208) بيكريل/لتر ، على التوالي. وعلاوة على ذلك ، تم حساب مؤشرات خطر الإشعاع ، مثل نشاط الراديوم (Ra) ، الذي يتراوح بين 0.641 إلى 3.857 بيكريل/لتر. وكان نطاق متوسط الجرعة الممتصة من الهواء (D) بين 0.345 إلى 2.016 نانوغرام/ساعة.وكانت نتائج مؤشر كاما (Iγ) بين 0.0055 إلى 0.03183 ، وكان مؤشر الخطر الداخلي (Hin) بين 0.00179 إلى 0.01211 ، وكان مؤشر الخطر الخارجي (Hex) بين 0.00173 إلى 0.01041. **مناقشة**: جميع النتائج التي تم الحصول عليها من كاشف يوديد الصوديوم المطعم بالثاليوم ل اليورانيوم-238 و الثوريوم-232 هي ضمن الحدود الموصى بها من قبل منظمة الصحة العالمية ولا تعرض الصحة العامة للخطر. ومع ذلك ، هناك تباين ملحوظ في النتائج بسبب الاختلافات الجيولوجية من منطقة إلى أخرى. بالإضافة إلى ذلك ، هناك تباين وزيادة في تركيز البوتاسيوم-40 في مناطق مختلفة ، ويرجع ذلك أساسا إلى الأنشطة الزراعية واستخدام الأسمدة ، مما يرفع مستويات البوتاسيوم-40. على الرغم من هذه الزيادة ، إلا أنها لا تشكل خطرا كبيرا على عامة الناس. **الاستنتاجات**: بناء على القيم التي تم الحصول عليها ، قد نستنتج أنه لا يوجد خطر على عامة السكان. باستثناء العينة (WK02و WK014) ، وكلاهما مناسب للاستخدام في البناء والزراعة.

الكلمات المفتاحية: المياه الجوفية ، النشاط الإشعاعي ، مطيافية أشعة كاما ، كاشف يوديد الصوديوم المطعم بالثاليوم ، النويدات المشعة الطبيعية.

1. INTRODUCTION:

Groundwater is a vital component of human life and is valued greatly in dry and semi-arid areas. The world's water needs have significantly increased due to factors such as growing populations, intensifying urban, industrial, and agricultural activities, and Earth's temperature rising due to natural climate change. These changes have had a substantial impact on surface and groundwater resources (Al-Mallah *et al.*, 2022). As economic development accelerates and public health awareness develops, people's concerns about radioactive contaminants in the environment, especially in groundwater, and their potential consequences on human health are growing (Zhaoxuan *et al.*, 2023). We cannot completely avoid radiation; it is an inevitable part of life. Radiation is a natural part of our environment and affects every aspect of our existence. Food and water contain radionuclides such as K-40, Th-232 series, and U-238, which have been present in the universe naturally from the beginning of time. Around 96% of the radiation that humans are exposed to comes from natural sources, with only 4% coming from man-made sources (Alsofy & Al-jomaily, 2022). According to UNSCEAR, the population's effective dosage is derived from natural sources at a rate of 2.4 mSv annually, of which 0.29 is attributable to food and water intake (Pintilie-Nicolov *et al.*, 2020). The groundwater can have different concentrations of dissolved minerals and radioactive elements resulting from the interaction between minerals and water in soils and rocks. The physicochemical features of the region most likely have an impact on naturally occurring radionuclide concentrations in water(Alseroury *et al*., 2018).

Given that most radionuclides are heavy nuclei and some of them are soluble in water, it is expected that one will find them in sediments and groundwater. In groundwater, radionuclides are soluble and mobile, significantly impacting water quality(Al-Battat & Subber, 2022). In the EU, groundwater supplies 310 million people with drinking water, which makes up around half of the world's total water supply(Borrego-Alonso *et al*., 2023). The danger of radionuclides depends on various criteria, including levels of radioactivity and the type of radiation produced(Ioannidis *et al*., 2023). Groundwater contains a variety of natural alpha nuclides (U-234, U-238, Th-232, Ra-226, Rn-222, and Po-210) and beta nuclides (K-40, Ra-228, and Pb-210), where these nuclides' concentrations range from undetectable levels to accumulations that could be hazardous to human health (Baják *et al*., 2023). Some man-made activities may lead to increased concentrations of radionuclides, for instance, mineral processing oil and gas extraction, and mining(Faanu *et al*., 2024). The isotope U-235 can emit gamma, beta, and alpha radiation. When radically active nuclei produce alpha particles, the majority of those particles have energy between 4 and 10 MeV. Its isotope U-238 is 0.07% of its basic counterpart. The nucleus also emits large alpha particles due to its short half-life (Potrous, 2020). Research suggests that groundwater may contain many radionuclides, for instance, the presence of radiological ions has been studied in several countries. In Brazil, Ra was studied by Chirinos and Jesus (2011), while Salikova *et al*. (2020) investigated the presence of U, Th, Ra, and Pb in the waters of Kazakhstan. Groundwater may enter due to interactions between water and rocks, exposing users to radiation (Akuo-ko *et al*., 2023).

The earth's crust contains ionizing radiation that humans are constantly exposed to, primarily from uranium, thorium, and its derivatives (Subber *et al*., 2017). The numerous oil extraction operations led to an increase in the concentration of natural radioactivity, which in turn produced an increase in cancer cases across Iraq, including Basra City. Because of the various geological compositions found in different places, some parts of the earth have significant natural radiation rates (Shanoon *et al*., 2018).

Gamma-ray spectroscopy is a commonly used technique in laboratories worldwide for the detection and identification of radionuclides, both natural and man-made, for radioactive measurements such as environmental sample analysis and activation testing. Numerous detector types, including high-purity germanium (HPGe) and thorium-activated sodium iodide (NaI(Tl) detectors, can be used for this process. HPGe detectors provide precise quantitative results in radiation testing due to their superior resolution; nevertheless, they also need elaborate cooling systems and long counting times. Nevertheless, NaI(Tl) detectors are a preferable choice for radioactive measurements since they operate at room temperature, employ large-area detectors that significantly reduce measurement times, and have a higher detection efficiency than HPGe detectors(El-Gamal *et al*., 2019).

This study's objectives are to:

- Assess the degree of radioactive contamination in groundwater and any potential dangers related to radionuclide concentrations of Th-232, U-238, and K-40.
- Conducting a comparative study of normal and abnormal levels of radiation in these models, comparing them with other local and global studies.
- In addition, several radiation risk indicators will be computed.

2. MATERIALS AND METHODS:

2.1. Study Area

The study area, which is in west Basra city and its environs in the western and southwestern part of Iraq, was selected by the latitudes between (29 -30) and the length lines between (46 -48). The areas included in the study include the western part of the city of Basra, which includes the Zubair. In the western half of the study area, groundwater is regarded as one of the most significant sources of water because surface water is scarce and lacks large superficial water. In this context, the use of groundwater has increased significantly recently in West Basra city. The Zubair Desert is a region that relies heavily on groundwater as a basic source of irrigation for crops due to the dry and desert character of the climate in this region, which is characterized by a lack of annual rainfall. Hence, the researcher was motivated to highlight the issue of radiation pollution in groundwater because of the increase in the use of groundwater and the increasing pressure on this water resource.

2.2. Materials

Materials used in the sample preparation process:

- plastic bottles
- Marinelli containers
- diluted hydrochloric acid
- standard sources Cs-137 and Co-60

The apparatus utilized in the experiment was a thallium-doped sodium iodide crystal (3*3) gamma-ray spectrometer.

2.3. Methods

2.3.1. Gathering and Preparing Samples

Samples of groundwater were gathered in west Basra city, from Zubair, in August 2023. Fifteen samples were gathered in unused 1L plastic bottles from various locations Figure 1, for the specimen's safety, it was cleaned with diluted hydrochloric acid before use (Alsofy & Al-jomaily, 2022). Radionuclide absorption on the container walls is reduced thanks to the acid. The GPS device was used to determine the location of each well, with well depths ranging from 18 to 30 meters Table 1. Marinelli containers of 1L capacity were utilized after washing them with diluted hydrochloric acid and rinsing for sample safety (Taher & Mohammad, 2020). To attain radioactive equilibrium for the radioactive elements, a 0.5L volume from each sample was employed in each container for a minimum of 45 days.

2.3.2. Efficiency Calibration and Gamma-Ray Spectrometry, or the data collection methods

Groundwater samples were analyzed to detect radionuclides using a gamma-ray spectrometer of sodium iodide crystal (3*3) doped with thallium, enclosed with a lead shield to lower the background radiation level, coupled with a multi-channel analyzer and computer program (MCA) inside the laboratory to display the gamma-ray spectrum of samples. An X-ray spectrometer's energy calibration creates a connection between the MCA channel number and X-ray energy (pulse height), which is necessary for performing X-ray spectrum analysis. Standard sources Cs-137 and Co-60, with gamma lines of 661 KeV and (1332.5 and 1173.2) KeV, respectively, are employed for such calibration. To get energy for each channel from each source, the gamma-ray spectrum was gathered for 3600 seconds in a Marinelli container. Moreover, the detector was calibrated using the same sources. Figure 2 shows the relationship between (Energy/Channel)(Ramadhan & Abdullah, 2018). The detector's efficiency is determined using the same standard sources of gamma rays used for energy calibration. Once the peak light energies and channel numbers for the standard sources have been established. The effectiveness of the detector was determined for the energy of Cs-137 and Co-60 based on the detector's Equation 1. Figure 3 shows the calibration curve for the efficiency of the detector. Using the appropriate gamma lines. The gamma-ray spectra of Cs-137 and Co-60 during detector energy and efficiency calibration with the gamma line 661 KeV and (1332.5 and 1173.2) KeV, respectively, are displayed in Figure 4. Under secular equilibrium conditions, the activity of U-238 was quantified by measuring specific gamma peaks emitted by Bi-214 (609.31 KeV). Likewise, gamma peaks from Pb-212, Ac-228 (238.63 and 968.97 KeV), respectively, were employed to ascertain Th-232 activity. The activity of K-40 was directly measured at 1460.83 KeV(Gilmore, 2008). Through the same calibration, the concentration of radionuclides in groundwater was calculated by taking 0.5 L of water in a Marinelli container for 3600s to calculate the radioactivity in groundwater.

$$y = 0.3419 + -0.0004512x + 1.725 \times 10^{-7}x^2 \quad R^2 = 1 \qquad \text{(Eq. 1)}$$

2.4. Calculation of Activity Concentration

The radioactive activity in the samples was calculated in units of (Bq/L) using Equation 2 (Alsofy & Al-jomaily, 2022).

$$A = \frac{N-B.G}{\varepsilon \times t \times I_{\gamma} \times V} \qquad \text{(Eq. 2)}$$

Where A= radioactive activity, N=The area under the curve of the element's energy in the presence of the sample, B.G= The area under the energy curve of the element in the absence of the sample, I= Relative intensity, t=The spectrum collection time, V=Sample size is in(L), ε= efficiency.

2.5. Assessment of the Effects of Radiological Hazards

Several risk indicators, including the following, were computed to evaluate the radiation danger in the chosen water samples:

2.5.1. Radium Equivalents (Ra_{eq})

It is identified by the sum of the radioactive concentration ratios of radionuclides Th-232, K-40, and U-238 using Equation 3 (Ononugbo & Tutumeni, 2016).

$$Ra_{eq}\left(\frac{Bq}{L}\right) = A_U + 1.43A_{Th} + 0.077A_K \qquad \text{(Eq. 3)}$$

The maximum value of 370 Bq/L can be attributed to the radium activity concerning the activity levels of U-238, Th-232, and K-40 in Bq/L.

2.5.2. Absorption Rate of Doses in the Air (Dγ)

The term "absorbed gamma dose" describes the amount of energy that radiation imparts to a material or human body. It is impossible to quantify the absorbed gamma dose without understanding the radionuclides' qualitative activity. Therefore, $D_\gamma\left(\frac{nGy}{h}\right)$ can be expressed as(Al-kubaisi & Farhan, 2018) using Equation 4:

$$D_\gamma = 0.462A_U + 0.604A_{Th} + 0.0417A_K \qquad \text{(Eq. 4)}$$

2.5.3. Index for Gamma Ray (I_γ) and Internal and External Risk Indices ($H_{in}$and H_{ex})

A defined radiation factor called a hazard index (H) is employed to assess the risk of both internal and external radiation. Equations such as these are used to determine the exterior hazard index (H_{ex}) and the internal hazard index (H_{in}), using Equation (5,6)(Al-Hayani *et al.*, 2021):

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \leq 1 \qquad \text{(Eq. 5)}$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad \leq 1 \qquad \text{(Eq. 6)}$$

The radiation coefficient, known as the gamma index, provides an assessment of the radiation risk levels associated with naturally occurring radionuclides in the samples. You can use the following to perform the computation: Equation 7 (Alsofy & Al-jomaily, 2022):

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad \leq 1 \qquad \text{(Eq. 7)}$$

2.6. Statistical Analysis

Through the EXCEL program, Anova contrast analysis was performed for the radionuclides U-238, Th-232, and K-40, and the P-value was found to be less than 0.05, indicating that there are significant differences between the three groups, and this is shown by Table 2.

The t-test of the samples was carried out by comparing the normal ratio(1Bq/L) with the values obtained in the samples by Excel program, and through Table 3, it was found that the statistical t value is lower than the critical t for U-238 and Th-232 and indicates that there are no statistical differences between the average values obtained and the normal value of radionuclides in groundwater. This shows that all values are within normal limits and are not dangerous for the general public.

As for K-40, the values were compared with the normal ratio (10Bq/L). The statistical t value was found to be greater than the critical t value, which indicates that there are statistical differences between the average values and the normal ratio. This shows that some values are higher than the global limit allowed in groundwater. This increase may pose a danger to the general public; although the human body needs potassium to regulate body functions, and the reason is that the body cannot produce potassium by itself, and the body needs it to perform its functions properly, such as maintaining the health of the heart and blood vessels, maintaining the water balance and salts in the body, and maintaining kidney and bone health. This is shown in Table 3.

The t-test and variance analysis (ANOVA) are fundamental and important statistical tools in the fields of scientific research and quantitative analysis to test hypotheses, compare averages, and identify relationships and effects between variables.

3. RESULTS AND DISCUSSION:

3.1. Results

Table 4 presents the activity concentrations of Th-232, K-40, and U-238 in water samples collected from different localities within the studied regions. Figure 5 illustrates how the levels of U-238, Th-232, and K-40 vary across all samples.

Table 5 presents an analysis of the radiological hazard indices $Ra_{eq}\left(\frac{Bq}{L}\right)$, $D_{\gamma}\left(\frac{nGy}{h}\right)$, I_{γ}, $H_{in}$and H_{ex}.

3.2. Discussion

The samples' radioactivity was computed, and the results shown in Table 4 indicated the range of U-238 concentrations was between 0.025-1.612 Bq/L at a mean of 0.5537Bq/L and the highest value in the sample (WK011) and the lowest value in the sample (WK03). The concentration of Th-232 ranged between 0.001-1.282 Bq/L at a mean of 0.3514 Bq/L, and the highest concentration was in the sample (WK04). In contrast, a low concentration was found in the sample (WK03), and Every value fell between the allowed ranges (1Bq/L) (United Nations, 2000). While the concentration level of K-40 was between 21.523-39.473 Bq/L at a mean of (12.52276 Bq/L), the highest value was in the sample (WK02) and the lowest value in the sample (WK04). Furthermore, these amounts are safe because potassium is a necessary component of human health and is needed by the body to regulate many bodily functions. Except for the sample (WK02 and WK014), both are appropriate for use in construction and agriculture (Alsofy & Al-jomaily, 2022).

We observe that the levels of radioactivity vary from one value to another according to the geological composition of the Earth. The results obtained are shown to be within the specified activity values with the IAEA and the commission UNSCEAR(2000)(United Nations, 2000) except for the sample (WK02 and WK014).

We note that the depth of the Wells does not have a significant impact on increasing the concentration of activity but depends on the nature of the geological area and other factors, such as the use of fertilizers in the study area, which increase the percentage of potassium in the soil and groundwater.

Figure 6 shows the activity concentration of U-238 within the Square, which is within the general average (1Bq/L), while Figure 7 shows the concentration of Th-232, which also falls within the general average. In the case of K-40, we note Figure 8, and most of the values were within the general average(10Bq/L), except for the two samples (WK02 and WK014).

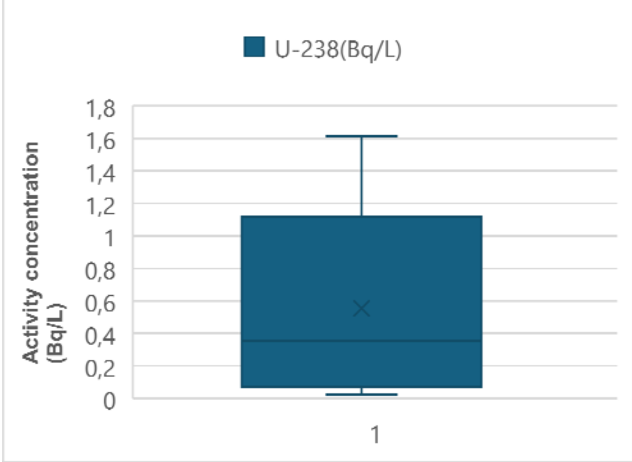

Figure 6. *Box plot of U-238*

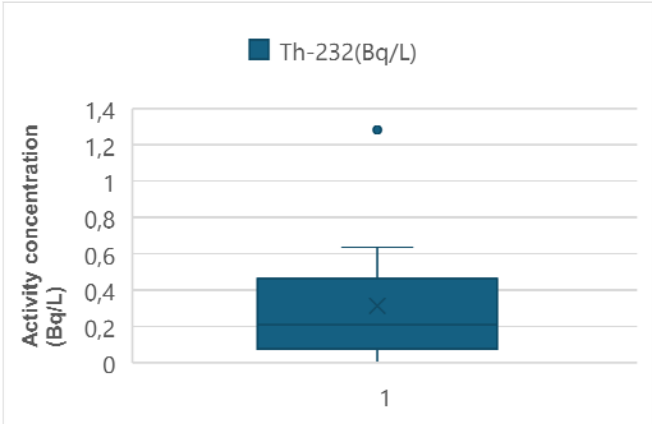

Figure 7. *Box plot of Th-232*

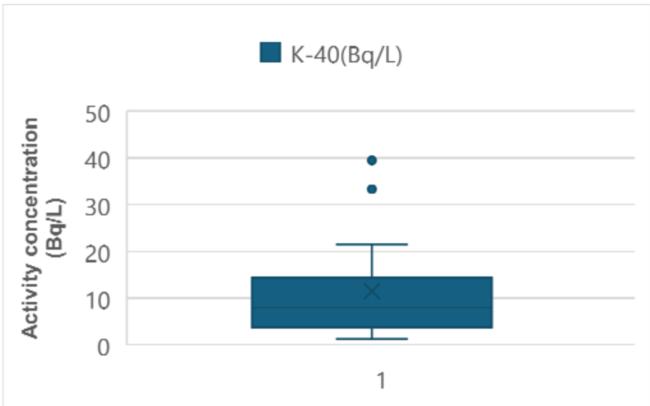

Figure 8. *Box plot of K-40*

Table 6 compares the findings with those of other studies. Th-232, K-40, and U-238 average radiation values were found to be lower than those detected in drinking water samples from Nigeria, Iraq, and Basra. It was discovered that the average K-40 value was higher, and the average U-238 and Th-232 levels were lower than those reported in Iranian groundwater samples. The mean radioactivity values of U-238, Th-232, and K-40 were found to be higher than those detected in the water samples from Basra, Iraq, in the Water from Shutt-Alrab. In contrast to water samples from Indonesia, the U-238 values were found to be lower, whereas the K-40 values were greater. The average values of Th-232 and U-238 were discovered to be lower than those in samples from Karbala, Iraq, and the values of K-40 were higher than them. Th-232 and K-40 concentrations were higher in Namibian groundwater samples, while the average U-238 values were found to be lower than those in the same area.

These differences were caused by several variables, including the samples' geochemistry, components (which might change from one location to another), and the geological characteristics of the area where the samples were gathered. Noteworthy is the possibility that atmospheric radionuclide absorption contributed directly to the radiation-induced pollution.

Radium equivalent (Ra_{eq}) were calculated, and the values ranged between 0.641-3.857Bq/L. In the sample, the highest value was (WK02), and the lowest value was in the sample (WK03) at an average of (1.8961) Bq/L, and all values were less than (370) Bq/L (Ononugbo & Tutumeni, 2016), see Figure 9. The absorbed dose rate ranged ($D_{\gamma} nGY/h$) was between 0.345-2.016 nGy/h, and the highest value was in the sample (WK02) and the lowest value was in the sample (WK03) and at an average of (0.9386) nGy/h, and all the values are within the permissible limits and are less than (55) nGy/h, see Figure 10, as recommended by (WHO)(World Health Organization, 2008). The External Hazard Index (H_{ex}) was calculated, and the values ranged was between 0.00173-0.01041 the highest value was in the sample (WK02), and the lowest value in the sample (WK03) at an average of (0.005116). The internal risk index (H_{in}) was calculated, and the values ranged between 0.00179-0.01211. The sample's highest value (WK02) and the sample's lowest value (WK03) at an average of (0.006457), and all the values were within the permissible limits and did not constitute a danger to the body and did not exceed one [16], See Figure 11. The gamma index ranges (I_{γ}) as between 0.0055-0.03183 and in the sample (WK02), the highest value was found, with the sample (WK03) having the lowest value, at an average of (0.014749), all values are within the permissible limits and less than one according to the Figure 12 (World Health Organization, 2008). All the findings from the computation of the radiation danger indicator values are displayed in Table 3.

Future research should see an increase in the total number of measured sites. From the perspective of this investigation, it was discovered that the majority of the examined samples had low radioactivity concentrations and did not provide a health risk. except for the two samples(WK02 and WK014). The findings offer a foundation for further research, which ought to involve a comprehensive and extensive evaluation of the level of radioactivity in groundwater.

4. CONCLUSIONS:

A study is usually carried out to find out more about the dangerous levels of radioactivity in the samples and the behavior of the naturally existing radionuclides by examining naturally occurring radioactivity in water samples. Groundwater samples' activity concentrations of U-238, Th-232, and K-40 were tested in order to assess the level of health risk associated with drinking water. The data showed that radioactive mean concentration values in water samples have dropped in some of the investigated sites.

The data at hand could be useful in tracking radioactive contamination of environmental water sources. Determining the radiation level in groundwater is essential for consumer safety protection. This study contributes to the quantification of the health impacts of ambient radiation exposure.

The findings indicate that, in comparison to Th-232 and U-238 concentrations, K-40 activity concentrations are higher in all samples. However, the readings fall within the suggested safe ranges. Except for the sample (WK02 and WK014), both are appropriate for use in construction and agriculture. In addition, the analysis shows that the value of equivalents of radium (Ra_{eq}) are less than the allowable thresholds (370) Bq/L. The air-absorbed dosage (D_{γ}) measurements show that they are below the allowable thresholds of (55) nGy/h. The external hazard index (H_{ex}) and the internal hazard index (H_{in}) Calculations found that all values fell between the allowed ranges and did not surpass one. The value of the gamma danger index (I_{γ})is also less than one and does not pose a danger to the body. A comparison with the global average results reported by UNSCEAR revealed that the radionuclide danger indices were lower.

Without a doubt, the study's baseline data will be crucial in determining how much radiation exposure the general public has received. The findings suggest that groundwater in Zubair town does not present a radiological health risk to the general people. All of the acquired data have been determined to be below the international standard limits since they offer valuable information for conducting a dose assessment resulting from the consumption of water samples, except for the sample (WK02 and WK014).

5. DECLARATIONS:

5.1. Study Limitations

In assessing radioactivity in groundwater in (Zubair, Basra, Iraq), the investigation is restricted to a particular region. Radiation is the sole subject of the investigation.

5.2. Funding source

This research was funded by the authors. In accordance with the ethical guidelines of the Periódico Tchê Química, which do not allow donations from authors with manuscripts under evaluation (even when research funds are available), or in cases of authors' financial constraints, publication costs were fully absorbed by the journal under our Platinum Open Access policy, through the support of the Araucária Scientific Association (https://acaria.org/). This policy aims to ensure complete independence between the editorial process and any financial aspects, reinforcing our commitment to scientific integrity and equity in knowledge dissemination.

5.3. Competing Interests

The authors declare no conflict of interest.

5.4. Open Access

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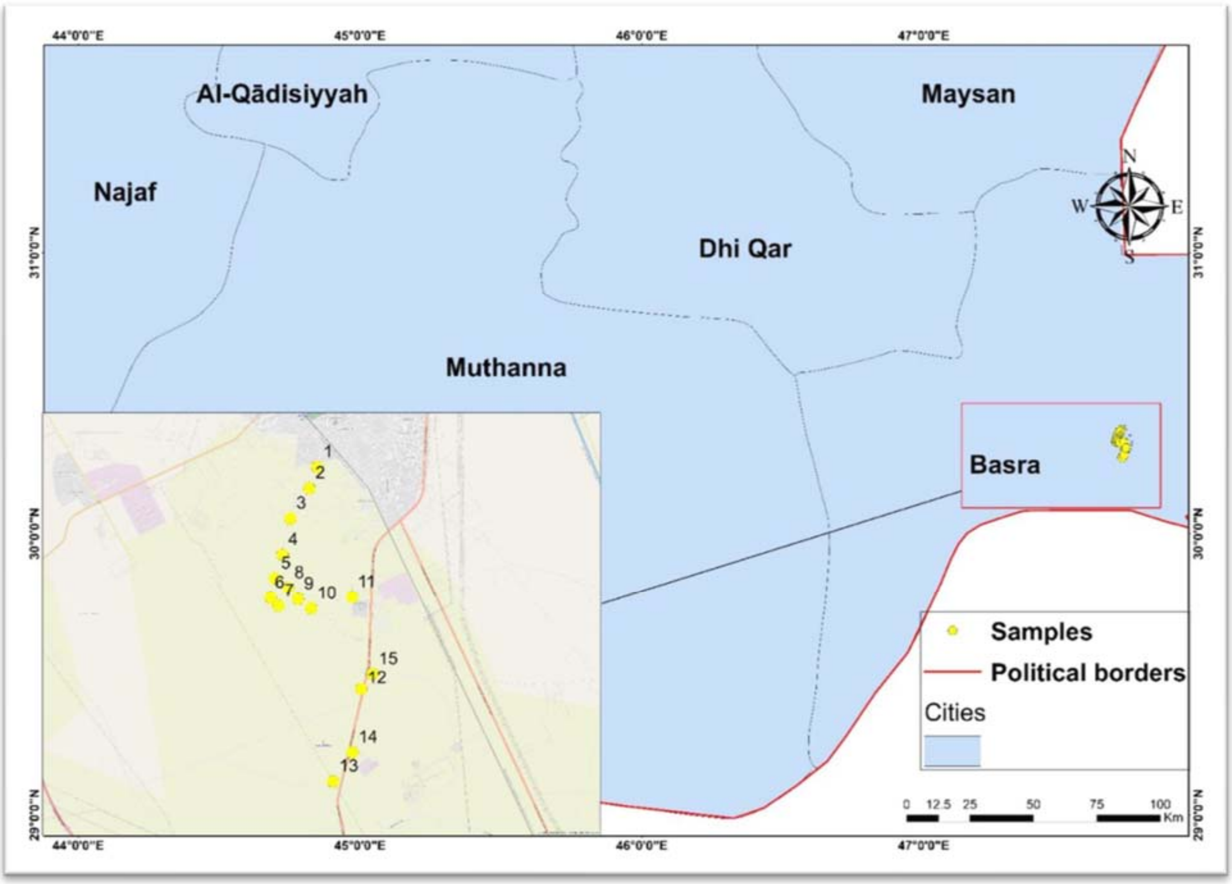

Figure 1. *Study region and sites for sampling*

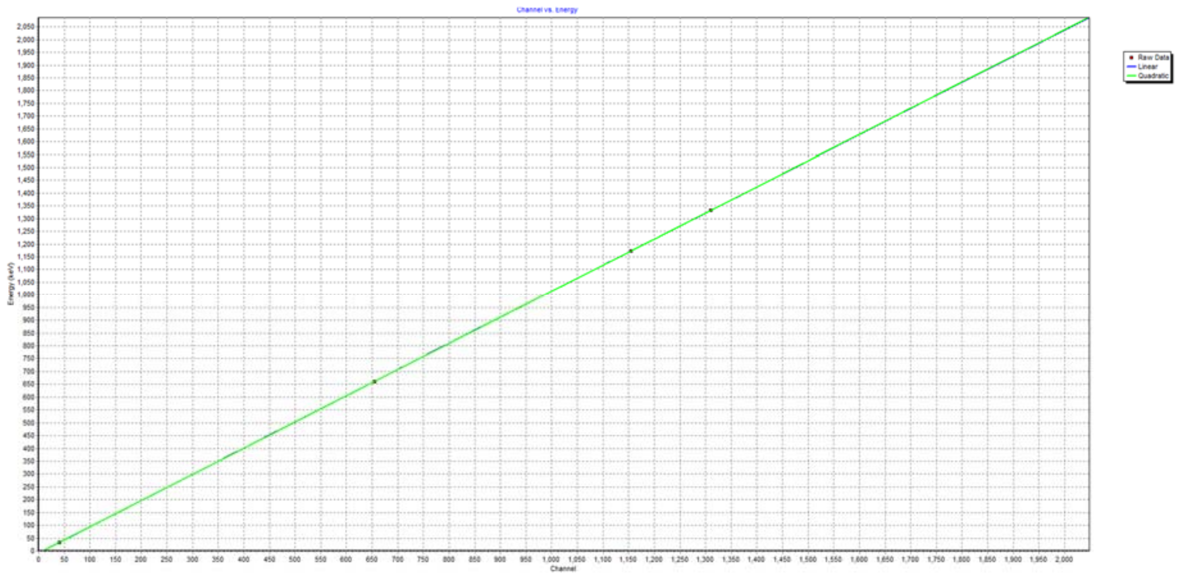

Figure 2. *The relationship between (energy/channel)*

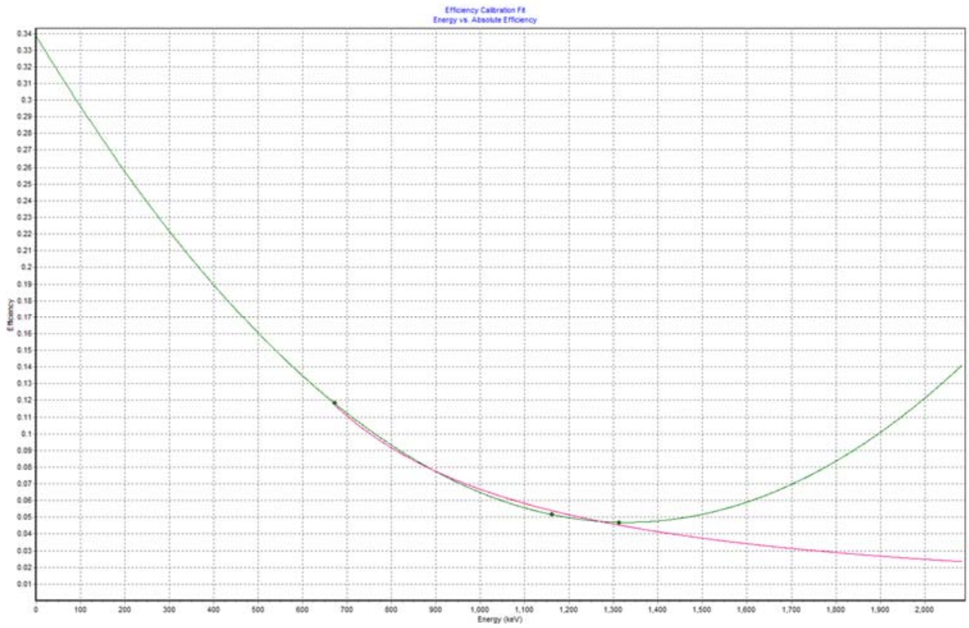

Figure 3. *The efficiency calibration Using standard sources Cs-137, Co-60*

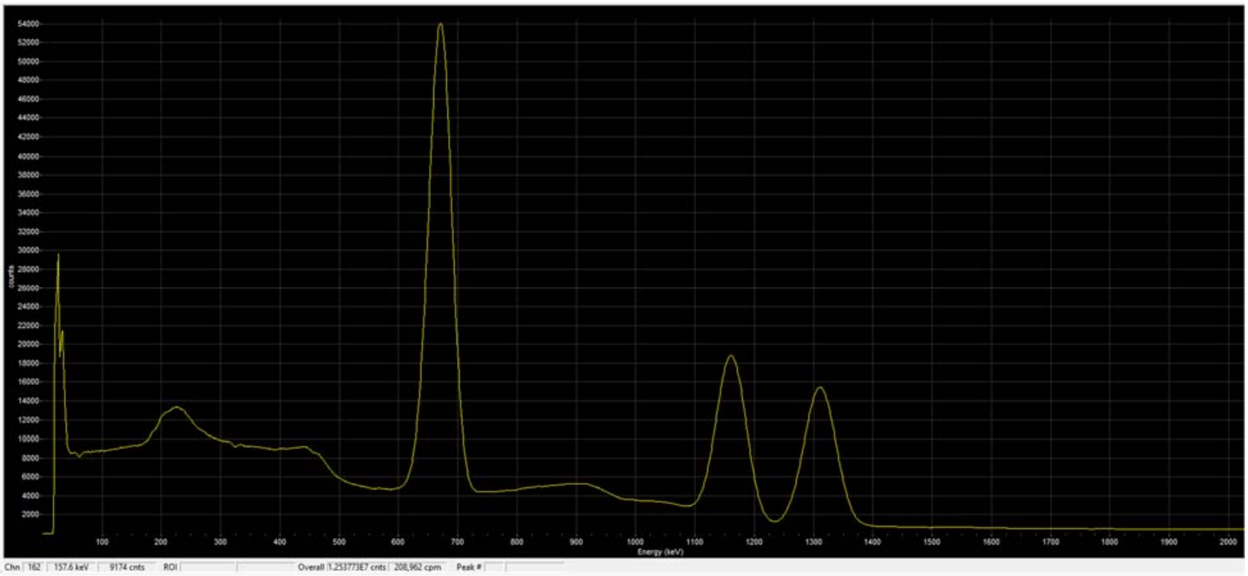

Figure 4. *The gamma-ray spectra of Co-60 and Cs-137*

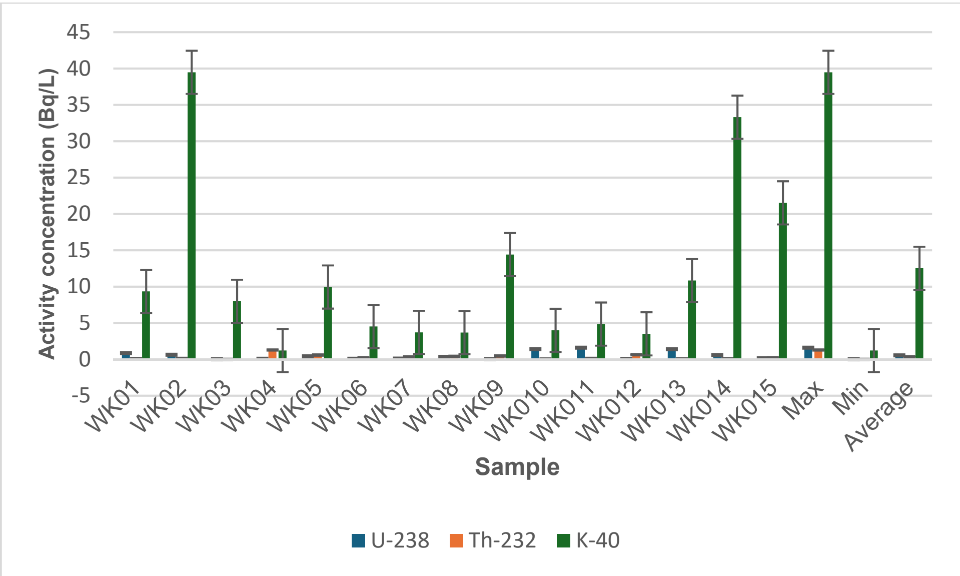

Figure 5. *The radioactivity concentration (Bq/L) for U-238, Th-232, and K-40*

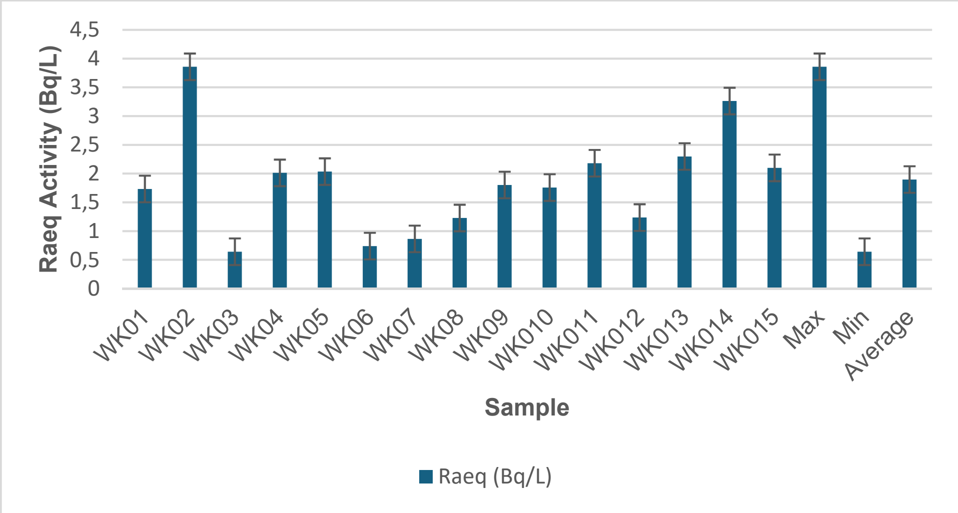

Figure 9. *Radium activity equivalents* ($Ra_{eq}\frac{Bq}{L}$) *at different groundwater levels*

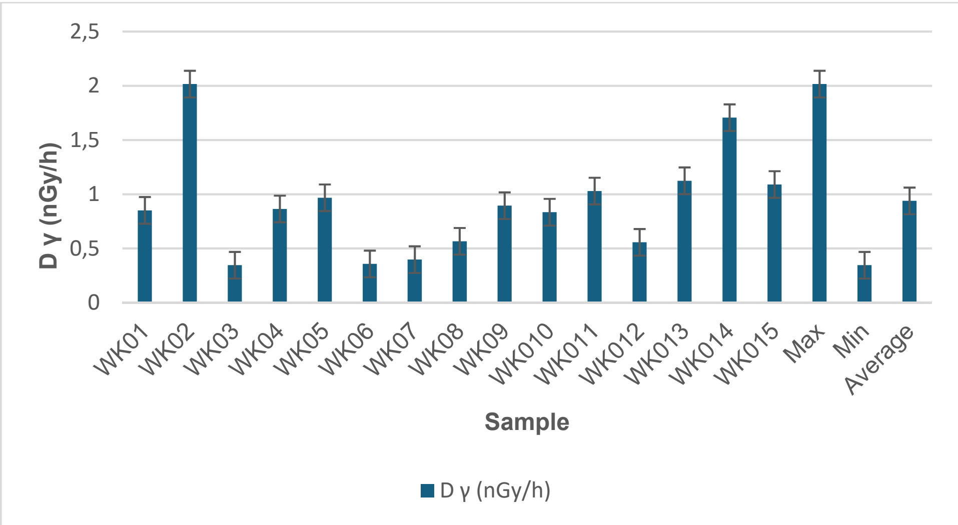

Figure 10. *Absorbed dose levels* ($D_{\gamma} nGy/h$)*of air in groundwater*

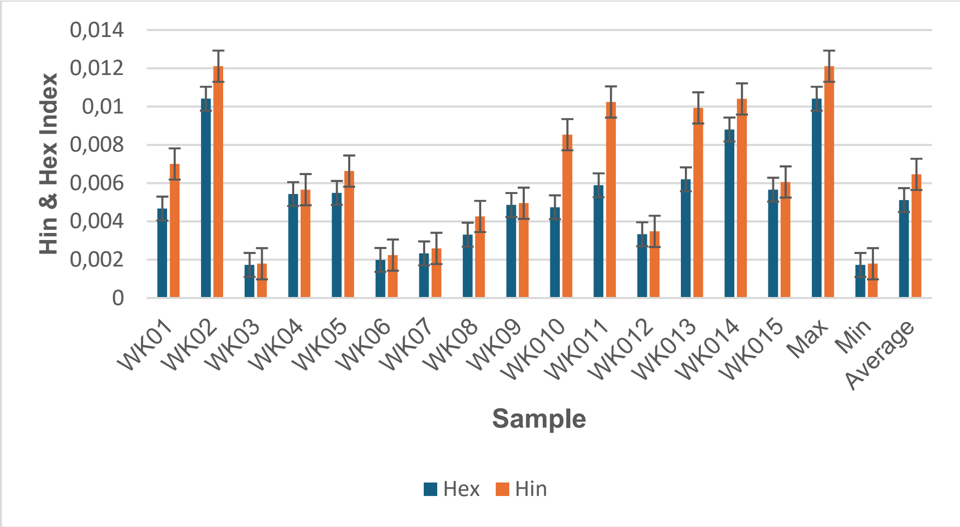

Figure 11. *The values of the internal* (H_{in}) *and external risk* (H_{ex}) *index for groundwater*

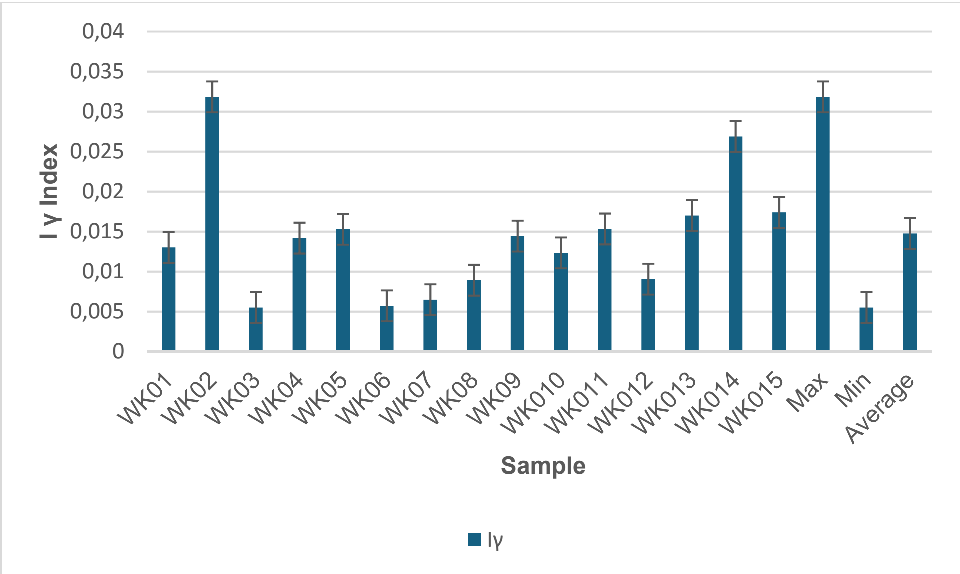

Figure 12. *Levels of the gamma hazard indicator* (I_{γ})*in groundwater*

Table 1. *indicates the locations and code of samples for different areas of Zubair and the depth of each well*

Sample code	Geographical location	Depth
WK01	30.367526, 47.697915	24
WK02	30.361060, 47.695068	20
WK03	30.351799, 47.688336	18
WK04	30.340708, 47.685502	23
WK05	30.333470, 47.682894	20
WK06	30.327511, 47.681322	30
WK07	30.325008, 47.684135	28
WK08	30.330537, 47.687659	26
WK09	30.327114, 47.691053	25
WK010	30.324215, 47.695722	21
WK011	30.327687, 47.710267	24
WK012	30.299492, 47.713460	22
WK013	30.271197, 47.703443	23
WK014	30.280092, 47.710338	27
WK015	30.304065, 47.717490	20

Table 2. *Analysis of Anova contrast for radionuclides U-238, Th-232, and K-40*

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
U-238(Bq/L)	15	7.776	0.5184	0.304381
Th-232(Bq/L)	15	4.691	0.312733	0.112526
K-40(Bq/L)	15	172.206	11.4804	130.5837

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1224.623	2	612.3113	14.02233	2.16E-05	3.219942
Within Groups	1834.008	42	43.66686			
Total	3058.631	44				

Table 3. *T-testing of samples with the normal ratio of radionuclides in water for U-238, Th-232, and K-40*

One-Sample Statistics								
U-238	**N**	**df**	**Mean**	**St. Dev.**	**St. error**	**t statistic**	**p-value**	**t critical**
	15	14	0.5184	0.551707	0.14245012	-3.380832574	#NUM!	-1.761310136
Th-232	**N**	**df**	**Mean**	**St. Dev.**	**St. error**	**t statistic**	**p-value**	**t critical**
	15	14	0.312733	0.335449	0.08661246	-7.934962748	#NUM!	-1.761310136
K-40	**N**	**df**	**Mean**	**St. Dev.**	**St. error**	**t statistic**	**p-value**	**t critical**
	15	14	11.4804	11.42732	2.95052181	0.501741757	0.623647025	-1.761310136

Table 4. *Concentration levels of radioactivity (Bq/L) in groundwater for U-238, Th 232, K-40*

Sample	U-238(Bq/L)	Th-232(Bq/L)	K-40(Bq/L)
WK01	0.859	0.108	9.333
WK02	0.628	0.133	39.473
WK03	0.025	0.001	7.986
WK04	0.086	1.282	1.208
WK05	0.421	0.593	9.942
WK06	0.091	0.211	4.505
WK07	0.097	0.337	3.706
WK08	0.353	0.414	3.669
WK09	0.034	0.461	14.407
WK010	1.401	0.035	3.983
WK011	1.612	0.137	4.843
WK012	0.057	0.635	3.506
WK013	1.378	0.060	10.823
WK014	0.589	0.076	33.299
WK015	0.145	0.208	21.523
Max±sd	1.612±0.607	1.282±0.263	39.473±7.485
Min±sd	0.025±0.160	0.001±0.083	1.208±2.672
Average±sd	0.5537±0.449	0.3514±0.290	12.5227±11.632
WHO	1(Bq/L)	1(Bq/L)	10(Bq/L)

Table 5. *Radiation hazard values indicated*

Sample	$Ra_{eq}(\frac{Bq}{L})$	$D_{\gamma}(\frac{nGy}{h})$	H_{ex}	H_{in}	I_{γ}
WK01	1.732	0.851	0.00467	0.007	0.01302
WK02	3.857	2.016	0.01041	0.01211	0.03183
WK03	0.641	0.345	0.00173	0.00179	0.0055
WK04	2.012	0.864	0.00543	0.00566	0.01419
WK05	2.034	0.967	0.00549	0.00663	0.0153
WK06	0.739	0.357	0.00199	0.00224	0.00572
WK07	0.864	0.397	0.00233	0.00259	0.00648
WK08	1.227	0.566	0.00331	0.00426	0.00893
WK09	1.802	0.894	0.00486	0.00495	0.01444
WK010	1.757	0.834	0.00474	0.00853	0.01234
WK011	2.180	1.029	0.00589	0.01024	0.01533
WK012	1.235	0.556	0.00333	0.00348	0.00906
WK013	2.297	1.124	0.0062	0.00993	0.0170
WK014	3.261	1.706	0.0088	0.0104	0.02688
WK015	2.099	1.090	0.00566	0.00606	0.01739
Max	3.857	2.016	0.01041	0.01211	0.03183
Min	0.641	0.345	0.00173	0.00179	0.0055
Average±sd	1.8961±0.853	0.9386±0.454	0.005116±0.0023	0.006457±0.0028	0.014749±0.00769
WHO	370(Bq/L)	55(nGy/h)	1	1	1

Table 6. *Results comparison with other studies*

Water type	Country	U-238(Bq/L)	Th-232(Bq/L)	K-40(Bq/L)	Reference
groundwater	Nigeria	1.01- 8.21	0.97- 14.81	4.44- 147.33	(Lawal *et al*., 2023)
produced water, in some Iranian oil fields	Iran	7.92- 68.12	8.19- 30.73	27.57- 34.65	(Bashiri *et al*., 2022)
Water	Karbala, Iraq	1.3- 2.4	0.95- 1.80	6.7- 12.4	(AL-Alawy *et al*., 2018)
groundwater	Namibia	1.21 – 2.21	0.054 – 0.039	16.91 – 20.92	(Mathuthu *et al*., 2021)
groundwater	Indonesia	0.103-3.342	---	1.439-5.808	(Purnama & Damayanti, 2020)
Water from Shutt-Alrab	Basra, Iraq	0.001-0.700(pCi/L)	0.000-0.216(pCi/L)	----	(Jebur & Subber, 2015)
drinking water samples	Basra, Iraq	0.029- 3.017	0.025- 2.326	4.706-161.560	(Ramadhan *et al*., 2020)