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Radiological Assessment and Health Risk Analysis of Natural Radionuclides in Surface, Groundwater, and Tap Water of Al-Rifai District, Southern Iraq

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Abstract

This study investigated the levels of natural radionuclides and evaluated the associated radiological health risks in different water resources collected from Al-Rifai District, Dhi Qar Governorate, Southern Iraq. A total of river water, groundwater, and treated tap water samples were analyzed using gamma-ray spectrometry equipped with a NaI (Tl) scintillation detector. The activity concentrations of naturally occurring radionuclides including ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K were determined and compared with internationally recommended limits.The measured activity concentrations ranged from 0.97–2.25 Bq/L for ^{238}U, 0.90–2.25 Bq/L for ^{232}Th, 0.58–1.32 Bq/L for ^{226}Ra, 0.066–1.25 Bq/L for ^{228}Ra, and 11.40–40.30 Bq/L for ^{40}K. Groundwater samples exhibited relatively higher radionuclide concentrations compared with river and tap water samples, reflecting the influence of geological formations and water-rock interactions. Several radiological hazard parameters were calculated, which is significantly lower than the globally accepted limit recommended by international radiological protection agencies. The obtained results demonstrate that all investigated water sources are radiologically safe for human consumption and do not pose significant environmental or long-term health hazards to the local population.

Keywords: Natural radioactivity; Water quality; Gamma spectrometry; Radiological hazard indices; NaI (Tl) detector; Iraq.

التقييم الإشعاعي وتحليل المخاطر الصحية للنويدات المشعة الطبيعية في المياه السطحية، والجوفية، ومياه الحنفية في قضاء الرفاعي، جنوب العراق

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الخلاصة

هدفت هذه الدراسة إلى تقييم مستويات النويدات المشعة الطبيعية وتحليل المخاطر الإشعاعية الصحية المرتبطة بمصادر المياه المختلفة في قضاء الرفاعي، محافظة ذي قار، جنوب العراق. شملت الدراسة تحليل عينات من مياه الأنهار والمياه الجوفية ومياه الإسالة باستخدام تقنية مطيافية أشعة غاما المعتمدة على كاشف الوميض من نوع NaI (Tl) scintillation detector. وتم تحديد تراكيز النشاط الإشعاعي للنويدات الطبيعية المتمثلة بـ ^{238}U و^{232}Th و^{228}Ra و^{226}Ra و^{40}K، ومقارنتها بالحدود العالمية الموصى بها. أظهرت النتائج أن تراكيز النشاط الإشعاعي تراوحت بين 0.97–2.25 بيكريل/لتر لليورانيوم-238، و0.90–2.25 بيكريل/لتر للثوريوم-232، و0.58–1.32 بيكريل/لتر للراديوم-226، و0.066–1.25 بيكريل/لتر للراديوم-228، و11.40–40.30 بيكريل/لتر للبوتاسيوم-40. كما بيّنت الدراسة أن عينات المياه الجوفية سجلت تراكيز أعلى نسبيًا مقارنة بمياه الأنهار ومياه الإسالة، نتيجةً لتأثير التكوينات الجيولوجية وتفاعلات الماء والصخور. ولغرض التقييم الإشعاعي الشامل، تم حساب عدد من مؤشرات الخطورة الإشعاعية، وهي أقل بكثير من الحد العالمي الموصى به من قبل الهيئات الدولية للحماية الإشعاعية. كذلك أظهرت جميع قيم معاملي الخطورة الداخلي والخارجي مستويات أقل من الحد المسموح به. تشير النتائج النهائية إلى أن جميع مصادر المياه المدروسة تقع ضمن الحدود الإشعاعية الآمنة للاستهلاك البشري، ولا تمثل أي مخاطر صحية أو بيئية طويلة الأمد على السكان المحليين.

1. Introduction

Since the beginning of time, ionizing radiation from both natural and artificial radioactive nuclides has been a constant hazard to human health [1].Naturally occurring radionuclides may be found in every human environment[2]. including food, water, air, soil, and even our own bodies (NORM). It was set aside for any radioactive elements found in nature[3]. Radionuclides are often found in relatively small concentrations in the environment [4].Both man-made and natural sources contribute to these radionuclides [5].The natural radioactive background is caused by the ^{238}U and ^{232}Th series, ^{40}K, and the interaction of cosmic radiation with matter; man-made sources include the many applications of radionuclides in consumer products, industry, and medicine [6]. ^{40}K is necessary for living cells, ^{238}U may dissolve and seep into groundwater, ^{232}Th is less soluble but plentiful in some minerals (like monazite), and ^{226}Ra tends to accumulate in bones due to its chemical resemblance to calcium [7].

Water is essential for human life, but its quality has been affected by a number of geological and environmental factors, such as the presence of naturally occurring radionuclides, which dissolve in water and vary in solubility from one nuclide to another[8, 9]. An increased risk of cancer, kidney disease, has been linked to exposure to and the continued use of water contaminated with radioactive isotopes[10, 11]. Igneous, metamorphic, and sedimentary rocks with uranium and thorium deposits are the source of radionuclides found in groundwater. Vengosh et al[12]. ^{232}Th concentrations in groundwater varied according to mineralogical composition, with greater levels in regions with phosphate-rich rocks, according to Akortia et al. [13].Studies conducted in coastal areas have also revealed fluctuations in radioactive concentrations as a result of saltwater intrusion and sediment deposition. Salama et al.'s study [26]. in Egypt discovered that groundwater close to coastal areas had higher. While Othman & Asaad [14] discovered that radon levels in certain water sources in Sudan surpassed WHO safety guidelines, Kilavi et al [15].recorded ^{238}U values ranging from 0.2 to 16.7 Bq/L in Kenya. The quantities of 238U and 224Ra in drinking water ranged from 5.41 ± 1.37 Bq/l to 1.36 ± 0.51 Bq/l and 5.75 ± 1.30 Bq/l to 1.95 ± 0.58 Bq/l, respectively, according to a research conducted in Nigeria by Godwin et al. [16]. Comparatively few studies have been carried out in Somalia; importance of understanding the distribution of radionuclides in Somalia's water sources [17].

This article presents a comprehensive study on NORMs in the environment, specifically focusing on the radionuclides belonging to the radioactive decay series of ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra, and ^{40}K within Al-Rifai District, Dhi Qar Governorate, Iraq. By comparing the measured radioactivity levels with international standards, related radiological hazard indices for the studied area, such as absorbed dose rate (D), radium equivalent activity (Ra_{eq}) external hazard index (H_{in}) internal hazard index (H_{ex}), and excess lifetime cancer risk (ELCR), were successfully computed to evaluate the radioprotection status. An excess of adioactive materials can degrade it. [17]. Radioactive sources' total and individual radiation doses must be calculated to assess their health effects. These dosage calculations use water and soil radioactivity [13]. Radionuclide concentrationsvary by region on Earth, with natural elements exposing only ten percent of the communalyearly dosage to the hominoid physique.

Radioactivity is present in all Earth materials, andexposure can cause cancer in humans andanimals [18]. The obtained results demonstrate that all investigated water sources are radiologically safe for human consumption and do not pose significant environmental or long-term health hazards to the local population. This study provides important baseline radiological data for water quality monitoring and environmental protection in Southern Iraq.

2. Materials and Methods

2.1 Sampling Area

The study area is located in the northern part of Dhi Qar Governorate, within latitude (13.34-31.55) North and longitude (45.45-46.27) East. It consists of Al-Rifai District, bordered by Qalat Sukkar District to the north, Maysan Governorate to the east, Al-Qadisiyyah and Al-Muthanna Governorates to the west, and Al-Nasr and Al-Dawaya Districts to the south (see map 1). The district's area is 1404.55 km², which is equivalent to 10.89% of Dhi Qar Governorate's area of 12,900 km², out of the total area of Iraq (435,053 km²). Geographical location is a factor of dual importance and influence on any region. It is The soils in the study area are relatively recent deposits dating back to the Quarter, during which significant and influential environmental changes occurred Alluvial plain deposits, intrusion delta deposits, shallow swamp deposits, sand dune deposits, and anthropogenic deposits, represents the sections of the geological structure in Al-Rifai District [18, 19].

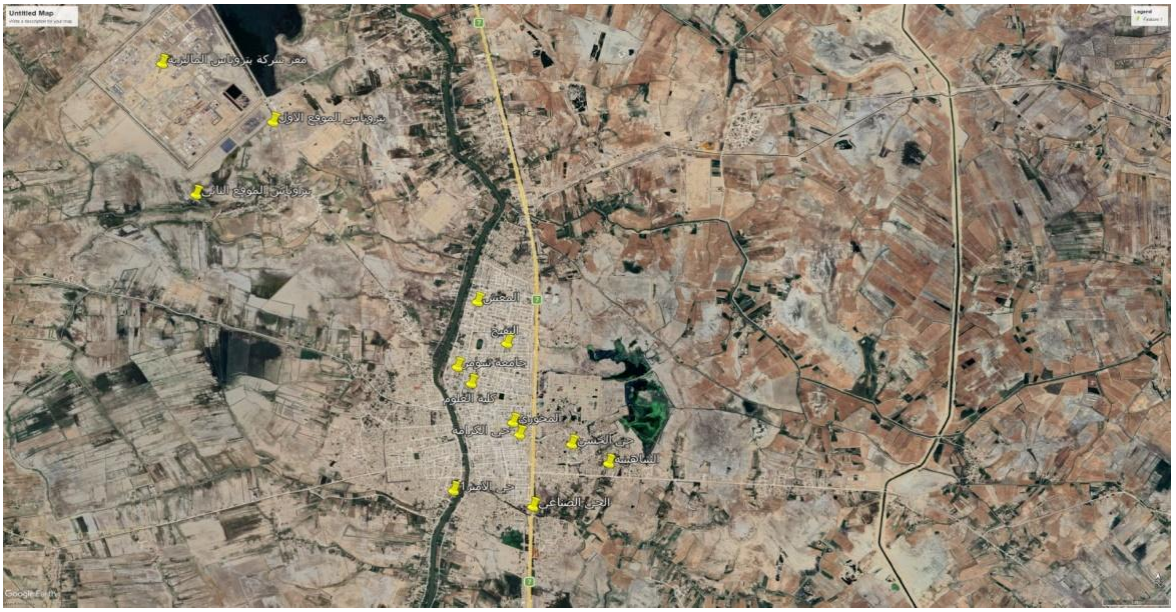

Figure -1 Map of the study Area, Rifai District

2.2 Sampling procedure

collecting water samples from different areas within Al-Rifai, covering most parts of the city. The collected samples included water from the Al-Gharraf River, well water, and tap water (domestic supply water). The samples were collected in clean 1-liter polyethylene containers and organized appropriately. Each sample was coded and labeled with the

sampling location and collection date. Afterward, the samples were transported to the laboratory to carry out the required measurements and analyses.

Figure- 2 Collected Water sample prepared for laboratory Measurement

2.3 Measurement system

The gamma spectrometry system, featuring a NaI (Tl) detector (Model D-1212, Teledyne Isotope), was calibrated for energy and efficiency. Standard radioactive point sources, including ^{133}Ba, ^{137}Cs, and ^{60}Co, were utilized to perform the calibration process as detailed in Table (1). This procedure ensured precise energy peak identification and accurate calculation of the specific activity for the studied samplesThe counting time for each collected sample, as well as the background radiation, was set to 10 hours (36,000 s) to ensure optimum [20].

Table 1- The standard radioactive source used in calibration of detection system

Standard Source	Energy (keV)	Relative Intensity (%)	Half-life (Days)	Activity (Bq/L)	Present Activity (Bq/L)	Product Date
^{133}Ba	276.4	7.1	3847.91	37	21.83	Dec.2009
	356.0	62.2				
	383.8	8.9				
^{137}Cs	661.66	85.21	11004.98	185	150.47	Dec.2008
^{60}Co	1173.23	99.9	1925.31	37	13.0	Dec.2009
	1332.51					
^{22}Na	511	99.64	950.5	-----	-----	Dec. 2009
	1274					

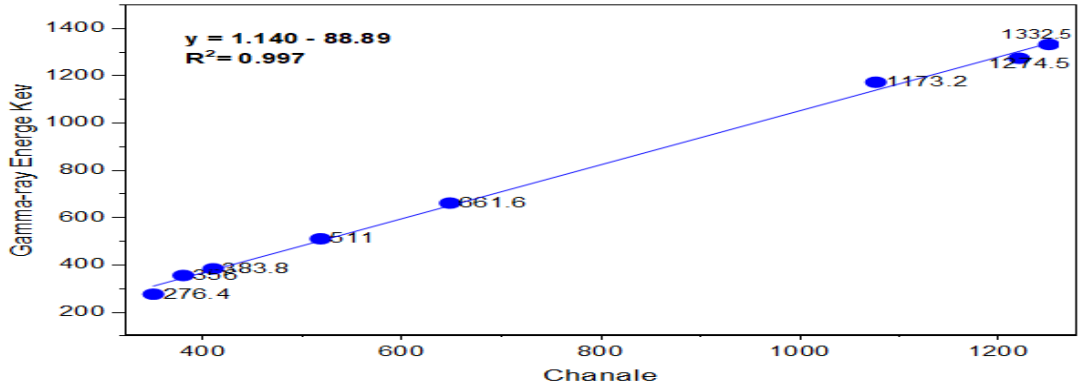

Figure -3 Calibration of detection system using standard point radioactive sources

3.Radiological Dose Calculation

Specific activity

This is the radioactivity per unit mass or volume of radioactive material, measured in Bq/kg or Bq/L.Specific activity is calculated using the following E(1) [17].

$$A = \frac{N}{\varepsilon\gamma.I\gamma.t.m} \quad (1)$$

1.Radium equivalent activity (Ra-eq)

This parameter was utilized to evaluate the radiological risks related to the state of the irradiated environment. This general index compares the particular activity of materials that include ^{40}K, ^{232}Th, and ^{226}Ra while accounting for the radiation risks connected to each of these elements E(2) [21].

$$Ra_eq = c_{Ra} + 1 \cdot 43C_{Th} + 0.077C_k \quad (2)$$

provides a mathematical definition of Raeq activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K [22].

2.Absorbed Dose Rate

It is the amount of radiant energy absorbed in the air at a height of 1 meter from the Earth's surface and is measured in nGy/h and calculated using the following Eq (3) [23, 24].

$$DR = 0 \cdot 461C_{Ra} + 0.623C_{Th} + 0.041C_k \quad (3)$$

3.The Annual Effective Dose

The evaluation is a parameter used to quantify the extent of health effects resulting from absorbed dose and is measured [25] .The annual effective dose is estimated in $mSv \cdot y^{-1}$ (0.7 $Sv \cdot Gy^{-1}$)) which is 0.7 $Sv \cdot Gy^{-1}$ using a conversion factor converts the absorbed dose in sieverts to effective dose (0.8)as well as using the indoor occupancy factor and the occupancy factor and 0.2 is the ratio of time spent abroad Eq (4,5) [26].

$$AEDE(outdoor)\ (msv/y) = D \times 10^{-6} - \times 8760 \times 0.7 \times 0.2 \quad (4)$$

$$AEDE(indoor)\ (msv/y) D \times 10^{-6} \times 8760 \times 0.7 \times 0.8 \quad (5)$$

4. Internal Hazard Index

The following formula is used to determine the external guide's hazard assessment of the danger of natural gamma radiation Eq (6)

$$H_{ex} = \frac{c_{Ra}}{370} + \frac{c_{Th}}{259} + \frac{c_k}{4810} \quad (6)$$

This factor must be less than one; if it is equal to or more than one, radiation danger is present [27, 28].

5. Internal Hazard Index

The internal hazard index, which is determined by the Eq (7) that follows.

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad (7)$$

Can be used to indicate the internal exposure, which is brought on by the inhalation of radon gas and daughters Additionally this factor needs to be lower than the one that falls inside the permitted universal boundary [25].

6.Excess lifetime cancer risk (ELCR)

This indicates the lifetime risk of developing cancer at a specific exposure level. Eq(8) was used to compute the Excess Lifetime Cancer Risk (ELCR) is given by[29].

$$ElCR = \text{AEDR} \times \text{DL} \times \text{RF} \quad (8)$$

AEDE stands for annual effective dose equivalent, DL for average life expectancy (70 years), and RF for risk factor (Sv-1) for fatal cancer risk per Sievert. ICRP 60 for stochastic effects with RF=0.05 for the general public[30].

4. Result and Discussion

4.1 Activity Concentration of Radionuclides

In this section, we present the results of the activity concentrations for several key natural radionuclides identified in the collected Water samples. Specifically, the analysis focuses on the distribution of ^{232}Th, ^{238}U,^{40}K, ^{226}Ra, and ^{228}Ra. These measurements, calculated in Becquerel per kilogram (Bq/kg), are essential for establishing the radiological profile of the study area. The detailed data for each sampling site are organized and summarized in Table 2 as follows

Table 2- The Averg activity concentrations of natural radionuclides ^{238}U, ^{232}Th, ^{226}Ra, ^{228}Ra and ^{40}k in water

	Activity Concentration (Bq/L)					
Sample ID	**^{238}U**	**^{232}Th**	**^{226}Ra**	**^{228}Ra**	**^{40}K**	**Type of water**
GRW-L1	1.65	1.62	1.63	0.070	26.00	AL-Gharraf River water
GRW-L 2	1.75	0.98	0.95	0.078	26.92	
GRW-L3	1.85	0.94	0.90	0.086	27.84	
G_{av}	1.75	1.2	1.16	0.078	26.92	
BRW-L1	1.35	1.10	1.51	0.80	29.50	Baeer River water
BRW-L2	1.42	1.20	0. 95	0.82	30.16	
BRW-L3	1.49	1.00	0.90	0.84	29.50	
B_{Av}	1.42	1.1	1.12	0.82	30.16	
SRW-L1	1.25	0.90	2.33	0.075	28.00	Sablh River water
SRW-L2	1.32	0.96	0.80	0.081	28.98	
SRW-L3	1.39	1.02	0.50	0.087	29.96	
S_{av}	1.32	0.96	1.21	0.081	28.98	
CTW-L1	0.90	0.97	0.98	0.062	15.50	Tap Water (College of scinence)
CTW-L2	0.97	0.98	0.70	0.066	17.10	
CTW-L3	1.04	0.99	0.06	0.070	19.30	
C_{av}	0.97	0.98	0.58	0.066	17.30	

KTW-L1	1.20	2.00	0.80	0.650	20.00	Tap Water (AL-Karama)
KTW-L2	1.27	0.70	0.87	0.669	20.77	
KTW-L3	1.34	0.60	0.94	0.688	21.54	
K_{av}	1.27	1.13	0.087	0.669	20.77	
ATW-L1	2.55	1.00	1.04	0.060	10.20	Tap Water (AL-Amin)
ATW-L2	0.99	0.84	0.82	0.065	11.50	
ATW-L3	0.99	0.86	0.78	0.073	12.50	
A_{av}	1.51	0.09	0.88	0.006	11.40	
AWW-L1	1.76	0.90	1.79	0.05	28.4	Well, water (AL-Amin)
AWW-L2	1.83	0.97	0.98	0.07	30.5	
AWW-L3	1.90	1.04	0.98	0.09	32.9	
A_{av}	1.83	0.97	1.25	0.07	30.6	
P1WW-L1	2.02	1.90	0.95	0.065	38.5	Petronas Well water1
P1WW-L2	2.10	0.99	0.99	0.070	40.1	
P1WW-L3	2.22	0.95	2.02	0.081	42.3	
P_{Av1}	2.11	1.28	1.32	0.072	40.3	
P2WW-L1	2.16	2.17	2.33	0.95	34.2	Petronas Well water2
P2WW-L2	2.34	2.23	0.71	1.30	36.8	
P2WW-L3	2.24	2.35	0.59	1.50	39.1	
P_{Av2}	2.25	2.25	1.21	1.25	36.7	
WHO [31] guideline	10	1	1	1	Not limited	

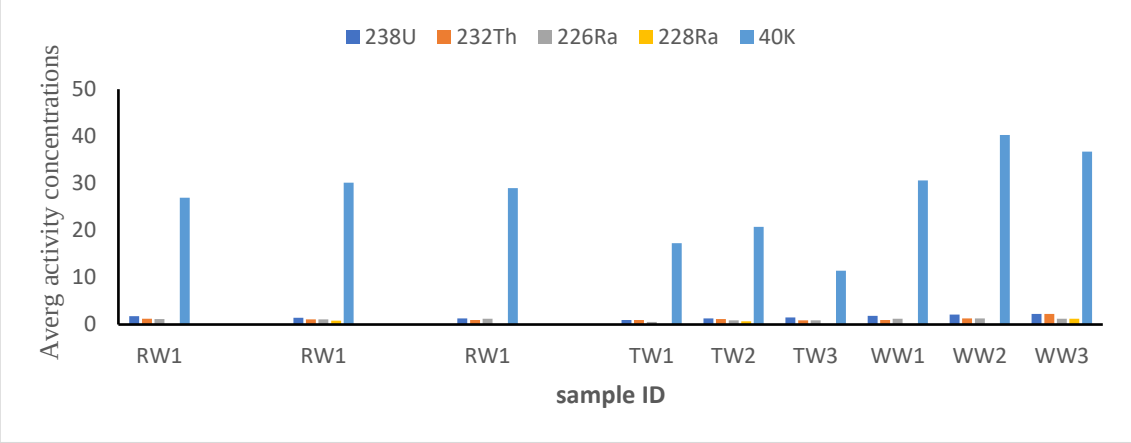

Figure - 4 Averg activity concentrations in the studied samples

Figure (4) Show There is a significant variation in the radioactivity concentrations of the isotopes studied, as evidenced by a relative increase in the concentrations of both ^{232}Th and ^{226}Ra in some samples, which are shown in red; in some samples, there was a common increase in both isotopes (RW1, RW2, WW2, WW3). This indicates the influence of distinct geological formations rich in radioactive isotopes and their increased solubility, as the solubility of each isotope differs from the others.

In contrast, ^{238}U concentrations were moderate and safe in all samples and did not exceed the internationally accepted limit of 10 Bq/L, as set by the World Health Organization. This indicates limited ^{238}U release as well as the absence of radioactive contamination from this

isotope. Meanwhile, the decrease in radium recorded in most samples indicates a low concentration of this isotope in the aquatic environment studied in the region. Meanwhile, the clear increase in ^{40}K activity compared to the other four isotopes is quite natural, given its high natural abundance in environmental resources, its ease of transport within ecological systems, and the fact that rocks contain very high levels of potassium, with the highest concentration recorded in sample (WW2). These differences in isotope concentrations depend on the type of water source (surface water, groundwater, tap water), as the source plays a fundamental role in the variation and distribution of these concentrations. The highest concentrations were observed in well water (groundwater), as groundwater is more significantly influenced by geological composition and storage compared to other sources that are constantly subject to renewal.

4.2 Radiological Hazard Indices

To further evaluate the potential radiological hazards associated with the studied water samples, several radiation risk indices were calculated. These parameters include the Radium Equivalent Activity (Ra_{eq}), absorbed gamma dose rate (D_γ), annual effective dose equivalent (AED), and the excess lifetime The calculated values for these radiological hazards are summarized and compared in Table 3 below.

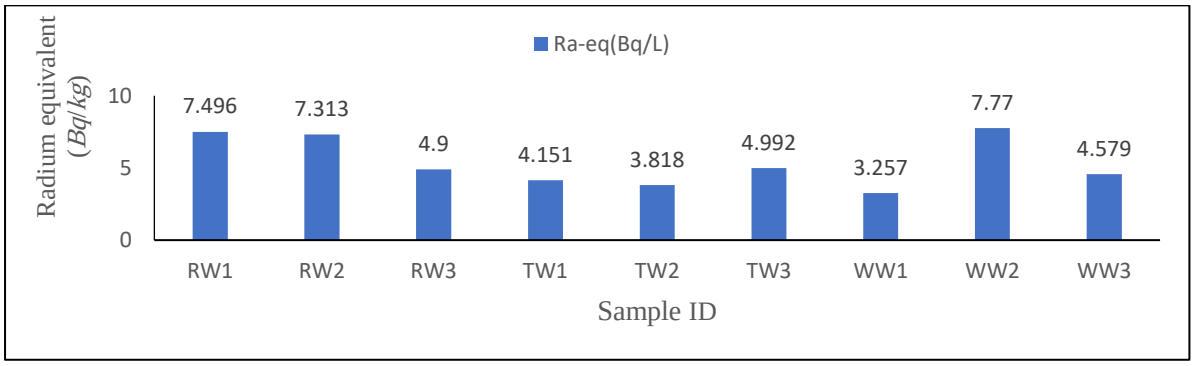

Figure- 5 Radium equivalent (*Bq/kg*) in the studied samples

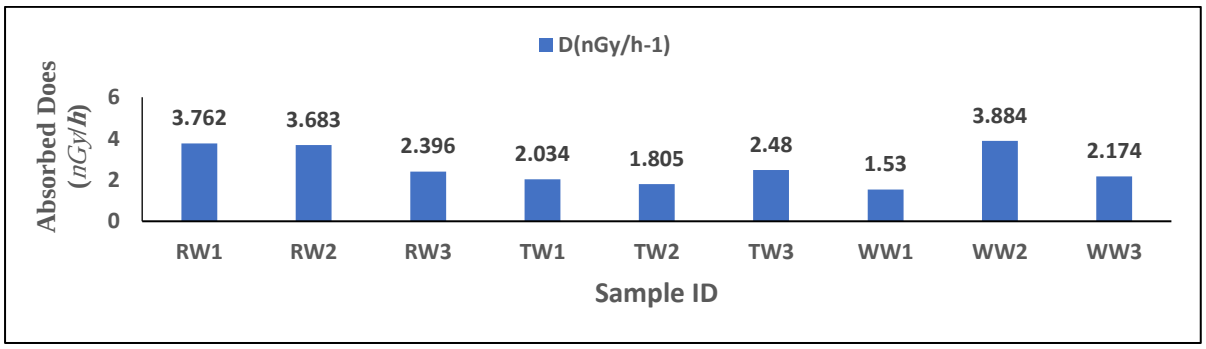

Figure - 6 Absorbed dose(*nGy/h*) for the studied water samples

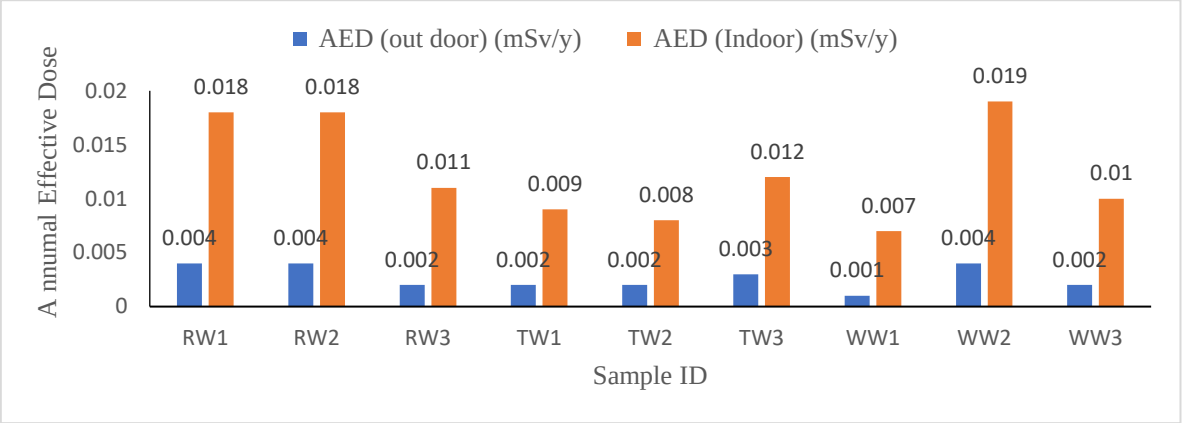

Figure- 7 Annual Effective dose (out door and in door) in (*mSv/y*) for the studied water samples

Studying natural radioactivity in water sources is an essential step in assessing environmental and health risks to humans. Analysis of the data collected in this study shows that the radium equivalence (Ra_{eq}) values for all water samples ranged from a min of 3.257 Bq/kL in the water sample from (WW1) and a max of 7.770 Bq/kL in the Petronas 1 well water sample (WW2), with an overall average of 5.309 Bq/L. When comparing these results to the globally accepted limit recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which is 370 Bq/kL, it is clear that all sample values fall well below this global limit by a factor of several times, confirming the low concentrations of naturally occurring radioactive isotopes (such as the ^{238}U series, ^{232}Th and ^{40}K in this water.

In a related context, this decrease in radioactivity levels had a positive impact on the values of the air dose rate (D_γ), with the lowest value recorded at 1.530 nGy/h and the highest value at 3.884 nGy/h, with an overall average of 2.624 nGy/h. These values are very low and pose no environmental risk when compared to the global average of 59 nGy/h. As for the assessment of health risks to consumers using the Annual Effective Dose (AED) index, both external and internal, the results showed that the highest recorded internal dose was 0.019 mSv/y (in sample WW2), a value that is negligible when compared to the internationally accepted critical limit for humans of 1 mSv/y. The relative higher values of indoor effective doses compared to outdoor doses are attributed to mathematical modeling factors and the nature of confinement and exposure to

Evaluating the radiological quality of various water sources is essential to ensure environmental safety and public health Table (4) presents the calculated radiological hazard indices for different water samples collected from diverse sources, including surface water, tap/treated water, and groundwater. The table details the Excess Lifetime Cancer Risk (ELCR x 10^{-4}), as well as the internal (H_{in}) and external (H_{ex}) hazard indices, comparing them against the globally accepted permissible limits to evaluate the safety of these water sources for human use.

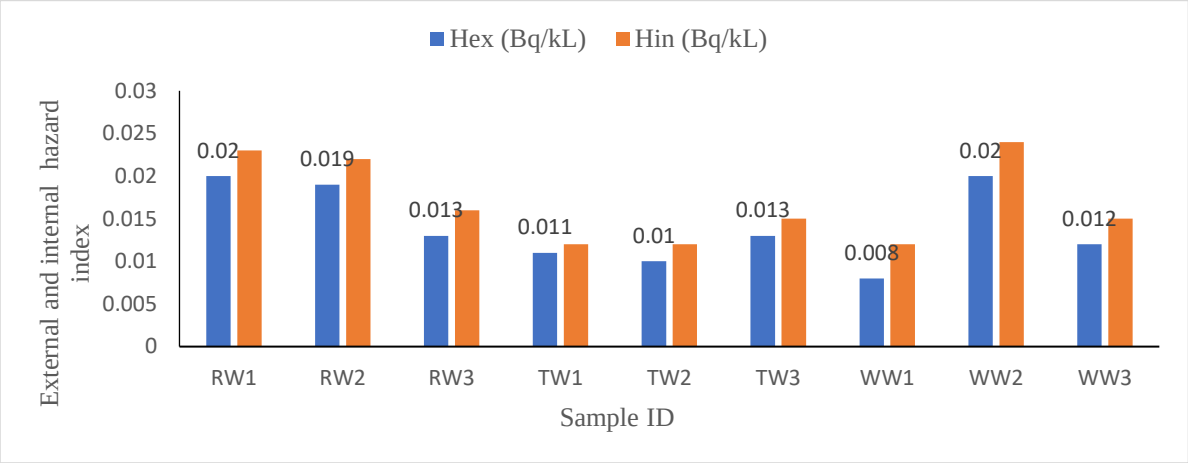

Figure – 8 External and internal hazard index(H_{ex} andH_{in}) in studiy area samples

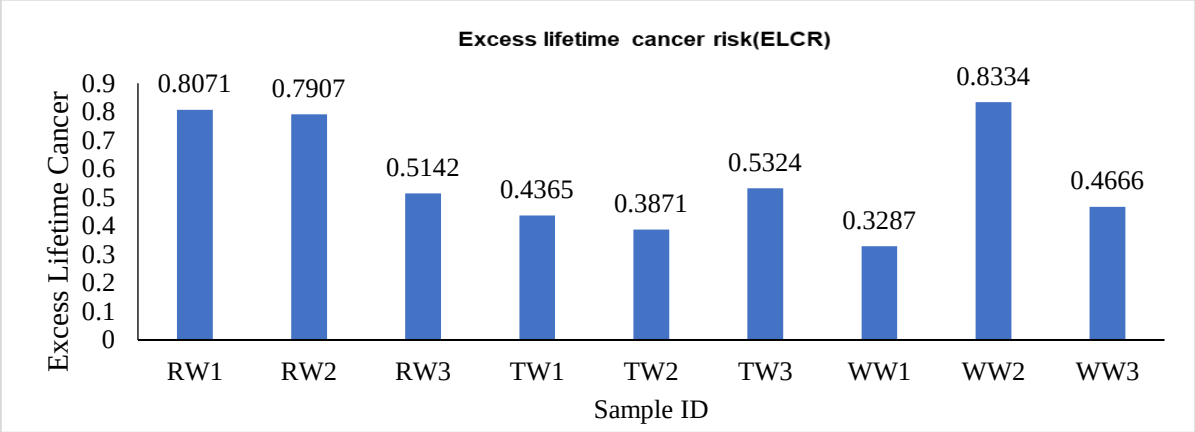

Figure -9 Excess lifetime cancer risk(ELCR) Values and in the study area samples

Table 3 encapsulates the advanced radiological risk parameters calculated for the surveyed water samples, specifically highlighting the Excess Lifetime Cancer Risk (ELCR), alongside the internal (H_{in}) and external (H_{ex}) hazard indices, to determine their radiological safety and suitability for human consumption.The computational analysis reveals that the Excess Lifetime Cancer Risk (ELCR 10^{-4} values fluctuated between a minimum of 0.3287 10^{-4} in well water (WW1) and a maximum of 0.8334 x 10^{-4} in Petronas well water 1 (WW2), yielding a mean value of 0.5986 10^{-4} Since all the obtained values are prominently lower than the worldwide acceptable average limit of 2.9 10^{-4}, it can be confidently argued that the probability of developing carcinogenic health issues from long-term exposure or utilization of these water resources is negligible.

In a corresponding trend, both external and internal hazard indices demonstrated remarkably low levels, hovering close to zero. The external hazard index (H_{in})ranged from 0.008 to 0.020 with an overall average of 0.0140, while the internal hazard index (H_{in}) varied between 0.012 and 0.024, producing a calculated mean of 0.0164.

From a radiation protection standpoint, international guidelines dictate that both H_{in} and H_{ex} must remain strictly below unity (≤ 1) to ensure the medium is radiologically safe for the public. Given that all the calculated indices in this study are vastly below this threshold, it is concluded that the assessed water sourcesencompassing surface, ground, and filtered tap water exhibit typical, safe background radiation levels and pose no significant environmental health hazards to the local population

Table 3- Comparison of activity concentrations (Bq/L) of various radionuclides in water samples from the present study with other global and regional studies.

Country	^{238}U(Bq/L)	^{232}Th (Bq/L)	^{226}Ra (Bq/L)	^{228}Ra (Bq/L)	^{40}K(Bq/L)	References
Karbala-Iraq	1.9	1.23	---	-----	10.08	[34]
Oman	-----	1.43-0,05	1.71-0.09	-----	14.16-0.45	[35]
Uganda	6.23	1.25	1.45	-----	15.28	[11]
Saudi Arabia	0.12-0.04	-----	0.33-0.04	0.14-0.03	------	[36]
Jordan	-------	1.42-2.37	3.8-6.8	------	------	[37]
Egypt	------	0.08	0.04	-----	-----	[38]
AL-Rifai,Iraq	1.60	1.18	0.99	0.35	27.05	Present study

Table 3 compares the radionuclide activity concentrations (Bq/L) of the present study (Al-Rifai, Iraq) with other regional and global data. The mean ^{238}U concentration (1.60 Bq/L) and ^{232}Th concentration (1.18 Bq/L) in Al-Rifai are highly comparable to Karbala-Iraq (1.9 and 1.23 Bq/L), respectively), remaining well below the elevated levels reported in Uganda and Jordan. Similarly, the mean concentrations of ^{226}Ra (0.99 Bq/L) and ^{228}Ra (0.35 Bq/L) are within safe regional ranges. However, ^{40}K exhibited the highest mean concentration (27.05 Bq/L) among the compared regions, likely due to agricultural fertilizers and clay mineral dissolution in the Al-Rifai area. In conclusion, the overall radioactivity levels in Al-Rifai water samples fall within safe thresholds and pose no significant radiological risks to human health.

5. Conclusion

The radiological assessment reveals that all water sources in Al-Rifai District exhibit safe, natural background radiation levels, with ^{238}U and Ra_{eq} values falling well below WHO and UNSCEAR global limits. Despite minor geological variations in groundwater ^{232}Th and ^{226}Ra, the recorded AED, health hazard indices $H_{ex,}$ Hin ≤1), and excess lifetime cancer risks (ELCR) are remarkably negligible. Consequently, these water resources are radiologically safe for public consumption and pose no significant environmental or health hazards to the local population.

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