RPE | Radiation Physics & Engineering
A Peer-Reviewed Journal
Published by K.N. Toosi University of Technology
http://rpe.kntu.ac.ir
Research Article

Radiation Physics and Engineering 2027; ?(?):?–?

Determination of radiation hazard indicators in naturally occurring radionuclides in sediments of the Al-Adhaim river tributary

Hayder Hameed Saeed[a,*], Mustafa Mohammed Jabbar[b], Zainab F. Abd-Sada[a]

[a] *Department of Laser Physics, College of Science for Girls, University of Babylon, Babylon, Iraq*
[b] *Ministry of Education, Al-Qadisiyah Directorate of Education, Al-Diwaniyah, Iraq*

Rejected

HIGHLIGHTS

- Natural radionuclides were quantified in Al-Adhaim River sediments.
- Mean U-238, Th-232 and K-40 activities were 13.116, 11.863 and 361.29 Bq.kg^{-1}.
- Cs-137 showed a mean activity of 3.897 Bq.kg^{-1} in the studied sediments.
- Radionuclide distributions varied spatially across the sampling sites.
- Radiological hazard indices indicated low radiological risk.

ABSTRACT

This study was conducted to establish a radiological baseline for the investigated area and determine the concentrations. concentrations of naturally occurring radionuclides, together with their associated gamma-radiation hazard indices in sediment samples collected from a tributary of the Al-Adhaim River. Twenty sediment samples were obtained from different locations along the river course. A systematic random sampling approach to ensure adequate representation of the sediment characteristics across the investigated sections. Gamma-ray measurements were performed using a NaI(Tl) detector connected to a multichannel analyzer (MCA), with the Genie 2000 software used for spectral analysis. The measured activity concentrations showed considerable variation between the sampling locations. The mean activity concentrations of the investigated radionuclides were from $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), $^{40}_{19}$K, and $^{137}_{55}$Cs in (Bq.kg^{-1}) samples sediment 26.23, 18.25, 361.29, and 5.99 Bq.kg^{-1}, respectively. All measured mean concentrations were below the corresponding world average values reported by UNSCEAR. In addition, the calculated radiological hazard parameters were within the internationally recommended limits, indicating that the investigated sediments do not represent a significant radiological hazard under the conditions of the present study.

KEYWORDS

Hazard indices
Natural radioactivity
River sediment
NaI(Tl) detector

HISTORY

Received:
Revised:
Accepted:
Published:

1 Introduction

Natural radioactivity is a normal part of the Earth's environment and is mainly associated with primordial radionuclides, particularly those in the natural decay series, together with naturally occurring potassium. These radionuclides are present in a wide range of geological materials, including rocks, soils, sediments, and aquatic environments. Consequently, they are an important source of terrestrial gamma radiation and contribute substantially to the effective radiation dose received by the population through external exposure (Saeed and Battawy, 2019).

Exposure to ionizing radiation remains an important scientific and environmental concern because of its potential implications for human health. Geological deposits can play an important role in the accumulation, redistribution, and transport of contaminants within a given geographical area (Ramasamy et al., 2014). Prolonged exposure to radioactive materials, particularly through the inhalation of radioactive isotopes, may result in serious health consequences, including chronic lung cancer and leukemia (Qureshi et al., 2014).

Natural sources of radioactivity account for a substantial proportion of the radiation dose received by the general population, estimated at approximately 50% of the total exposure. This contribution is comparable in mag-

*Corresponding author: sci899.hayder.hameed@uobabylon.edu.iq

https://doi.org/

nitude to that associated with artificial sources, including medical diagnostic and therapeutic applications (Alrefae et al., 2018).

Radioactivity occurring naturally in sediments is closely related to the rocks and soils forming the Earth's crust and may therefore vary considerably from one location to another. The concentration of naturally occurring radionuclides in sediment is influenced largely by the nature and composition of the parent soil and rock materials. Weathering of rocks generates sedimentary materials that retain characteristics of their parent rocks and consequently provide an indication of the geological processes associated with weathering, erosion, and subsequent transportation (Obayes, 2024). River sediments constitute an important pathway for the movement and accumulation of radionuclides within aquatic environments. They may also contribute to radiation exposure among aquatic organisms and provide a medium through which radioactive materials can be transported and deposited. Riverbed sediments commonly contain mixtures of sand and gravel with different grain sizes, materials that are also widely used in construction applications (Isinkaye and Emelue, 2015).

Naturally occurring radioactive nuclides in aquatic sediments can gradually be released and transported within the surrounding environment. They may subsequently enter food chains and become available to aquatic organisms and, ultimately, humans. Therefore, determining the concentration and spatial distribution of these radionuclides is important for evaluating possible radiation exposure to the population.

Information on the concentrations and distributions of radionuclides in river sediments is important for environmental radioactivity monitoring. The activity concentrations of radionuclides in sediments can provide useful information for investigating their possible sources, transport mechanisms, and environmental fate. Such information is valuable for long-term environmental radiation monitoring and assessment. In addition, determining the activity concentrations of natural radionuclides is vital for evaluating radiological hazard indices and estimating potential radiation exposure under specified conditions. Therefore, assessing radioactivity in river sediments is an essential step toward establishing baseline data on environmental radioactivity and evaluating the potential radiological significance of the investigated area.

Natural radionuclides commonly detected in river sediments include those associated with the uranium and thorium decay series, as well as potassium. Previous studies in Iraq have investigated natural radioactivity in sediments of major rivers, including the Tigris and Euphrates. However, no previous study specifically addressing radionuclide activity concentrations and associated radiological hazard indices in sediments of the Al-Adhaim River tributary was identified in the literature reviewed for this study. This gap highlights the need for a site-specific investigation of the tributary.

The present study determines the activity concentrations of the investigated radionuclides in sediment samples collected from the Al-Adhaim River tributary using gamma-ray spectrometry, evaluates the associated radiological hazard indices, and examines the spatial variability of the measured values among the sampling sites. The findings provide site-specific baseline data that extend the available information on natural radioactivity in river sediments in Iraq.

2 Materials and Methods

2.1 Study area description

The investigated area extends longitudes $44°10' - 44°40'$ E and latitudes $34°00' - 34°30'$ N. It is located in Salah Al-Din Governorate, Iraq, and is bounded to the east by Diyala Governorate. The Al-Adhaim River originates on the southern slopes of the Qaradagh and Shawan Heights in northeastern Iraq. It represents one of the principal tributaries of the Tigris River and extends for approximately 230 km from its source to its confluence with the Tigris south of Balad. The section between the Al-Adhaim Dam and the river mouth extends for approximately 90 km. The study region exhibits a range of geomorphological features, including river meanders, both old and recent fluvial islands, the active river channel, and the surrounding floodplain. The geological setting is mainly represented by the Injana and Mukdadiya Formations, accompanied by widespread Quaternary alluvial deposits. The Injana Formation is composed predominantly of alternating sandstone, siltstone, and claystone layers, while the Mukdadiya Formation mainly comprises sandstone, siltstone, and claystone. Ongoing weathering and fluvial erosion of these geological formations have resulted in the formation and redistribution of alluvial materials consisting mainly of gravel, sand, silt, and clay. Accordingly, the mineralogical and geochemical characteristics of the river sediments are closely related to the lithology of the surrounding formations, which may affect the occurrence and spatial distribution of naturally occurring radionuclides within the deposited sediments (Jassim and Goff, 2006; Sissakian and Jabbar, 2013). The study area and the sediment sampling locations in Fig. 1.

2.2 Sediment sample collection and preparation

Twenty sediment samples were collected from the Al-Adhaim River tributary in Al-Duluiya city for the assessment of radiological hazards, The sediment samples were withdrawn from a depth of 15 cm, where uniform quantity of sediment was collected from all the sampling stations spaced at average intervals of 3km along the tributary, for the assessment of radiological hazards, with each sample weighing approximately 1.3 kg. Following collection, the samples were placed in appropriately labeled polyethylene bags and exposed to sunlight for 20 days to remove the contained moisture. The dried samples were then mechanically crushed using a mortar and pestle until a fine and relatively homogeneous material was obtained. The resulting material was passed through a 75 μm sieve. From each prepared sample, 1 kg was transferred into a Marinelli beaker and hermetically sealed for one month to allow secular equilibrium to develop between the parent radionuclides and their respective decay products.

Uncorrected Proof

Table 1: Sample code and Sampling locations.

Sample Code	Location
Al1	Al-Dhuluiya - Beshkan Village - Central Al-Adhaim Island
Al 2	Al-Dhuluiya - Beshkan Village - Isolated Area
Al 3	Al-Dhuluiya - End of Al-Adhaim (Beshkan Side)
Al 4	Al-Dhuluiya - Beshkan Village - Al-Darawish Area
Al 5	Al-Dhuluiya - Beshkan Village - Al-Huwaija 1
Al 6	Al-Dhuluiya - Beshkan Village 1
Al 7	Al-Dhuluiya - Beshkan Village 2
Al 8	Al-Dhuluiya - Beshkan Village - Main Ferry Crossing
Al 9	Al-Dhuluiya - Beshkan Village 3
Al 10	Al-Dhuluiya - Beshkan Village - Al-Huwaija 2
Al 11	Al-Dhuluiya - Beshkan Village - Al-Tanira
Al 12	Al-Dhuluiya - Beshkan Village - Second Ferry Crossing
Al 13	Al-Dhuluiya - Beshkan Village - Al-Arifiyah
Al 14	Al-Dhuluiya - Beshkan Village - Al-Arifiyah 2
Al 15	Al-Dhuluiya - Beshkan Village - Al-Latwa
Al 16	Al-Dhuluiya - Beshkan Village - Al-Latwa 2
Al 17	Al-Dhuluiya - Beshkan Village - Diyala Side 2
Al 18	Al-Dhuluiya - Beshkan Village - Diyala Side 3
Al 19	Al-Dhuluiya - Beshkan Village - Isolated Area (Diyala Side)
Al 20	Al-Dhuluiya - Beshkan Village - End of Al-Adhaim (Diyala Side

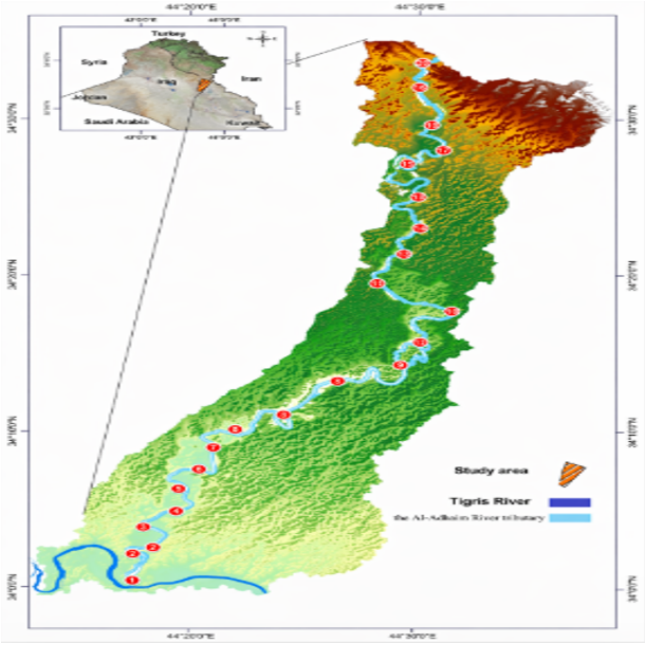


Figure 1: Location map of the study area and sediment sampling sites along the Al-Adhaim River tributary.

2.3 Gamma spectrometric analysis

Gamma-ray spectrometric measurements were performed on all prepared samples using a $3'' \times 3''$ NaI(Tl) detector with a counting period of 7200 s. The detector system was used to measure the gamma emissions associated with the radionuclides present in the Al-Adhaim River sediment samples. A lead shield surrounded the detector crystal in order to reduce the background radiation by approximately 95%. The activity concentrations of the radionuclides were determined in $\mathrm{Bq.kg^{-1}}$ from the recorded gamma-ray spectra using the Genie 2000 analytical software. All measurements were conducted in the Department of Physics, College of Science, Al-Nahrain University.

Energy calibration of the detector was established by relating the energy of the incident photons to the corresponding positions of the detected peaks. Standard radioactive sources with known gamma-ray energies were therefore employed for calibration, including sources with energies of 59.5 keV, 661 keV, and 1173 and 1332 keV, as shown Fig. 2. The background radiation was measured by placing an empty Marinelli beaker in the setup for 7200 seconds. The background counts at the relevant gamma-ray energies were determined and subtracted from the corresponding counts measured for the sediment samples to obtain the net peak counts used to calculate radionuclide activity concentrations.

The minimum detection activity (MDA) is defined as the lowest level of radioactivity of radionuclides that can be accurately detected. A detector connected to a personal computer equipped with a 4096-channel multichannel analyzer (PC-MCA) system (manufactured by Canberra, USA) was used. Spectral data from the detector were analyzed using the Genie 2000 software, with the measurement duration for the samples being the same (Darko et al., 2005).

$$MDA = \frac{LD}{T \times Eff(E) \times P(E) \times M} \tag{1}$$

where T is the counting time (s), $Eff(E)$ the photopeak efficiency, $P(E)$ is the gamma emission probability, M (kg) is the mass of the sample, LD is the detection of limit calculated from Eq. (2) (UNSCEAR, 2000):

$$LD = LC + K\sigma D \tag{2}$$

where LC is the critical level below which no signal can be detected, σD is the standard deviation, and K is the error probability. The MDA values were obtained from the Genie 2000 software output. For radionuclides where no activity concentration was detected, the corresponding MDA

Corrected Proof

value was recorded as an indication of the detection limit and was not treated as a measured activity concentration. When calculating the mean activity concentrations, only detected values were included, while non-detected results were excluded. For calculating the radiological hazard indices, the contributions of non-detected radionuclides were assumed to be zero.

2.4 Activity concentration of sediment Samples

The activity concentration was estimated through the equation.

$$A = \frac{N}{p(E_\gamma) \times Eff \times T_c \times M} \tag{3}$$

where A is the activity concentration in (Bq.kg^{-1}), N is net area under the peak, $p(E_\gamma)$ is the abundance at energy E_γ, Eff is the efficiency of the detectors at energy E_γ, M is mass of the sediment sample (kg), and T_c is the time of measurement which was equal to 7200 s.

2.4.1 Radium Equivalent Activity (Ra_{eq})

Equation (4) was applied to determine the radium equivalent activity (Ra_{eq}), which provides an estimate of the combined radiological contribution of uranium, thorium, and potassium expressed in Bq.kg^{-1} (Akpanowo et al., 2020).

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_k \tag{4}$$

where A_U, A_{Th}, and A_K are the activity concentrations of $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), and $^{40}_{19}$K, respectively.

2.4.2 Gamma index

The gamma index was calculated using Eq. (5). This index provides a radiation-related parameter for estimating the potential gamma-radiation risk associated with the naturally occurring radionuclides present in the investigated sediment samples (Kolo et al., 2016).

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \tag{5}$$

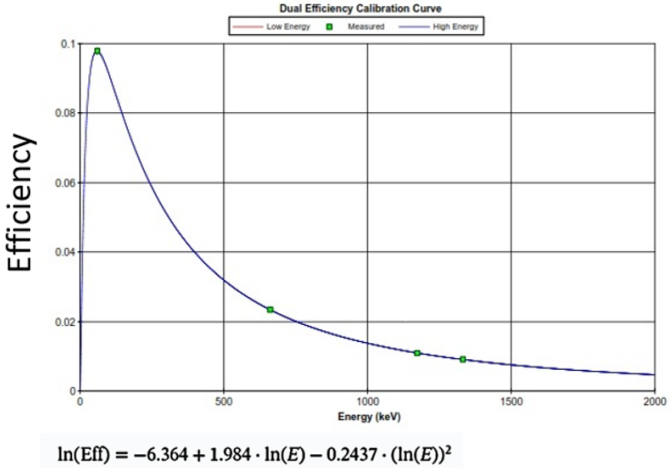


Figure 2: Efficiency calibration curve of the $3'' \times 3''$ NaI(Tl) detector.

2.4.3 Internal and external hazard indices

Equations (6) and (7) were used to calculate the internal and external hazard indices. These indices are employed as radiation-related measures for evaluating the potential risks associated with internal and external exposure to natural radioactivity (Asaduzzaman et al., 2015).

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{6}$$

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{7}$$

where A_U, A_{Th}, and A_K are the activity concentrations of $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), and $^{40}_{19}$K, respectively.

2.4.4 Absorbed Dose Rate in Air and Annual Effective Dose Equivalent

Equations (8) to (10) were used to determine the absorbed dose rate in air and the annual effective dose equivalent (AEDE) was calculated using a dose conversion coefficient of 0.7 Sv.Gy^{-1} to convert the absorbed dose rate in air into effective dose. Indoor and outdoor occupancy factors of 0.8 and 0.2, respectively, were assumed to represent the fractions of time an adult spends indoors and outdoors. An annual exposure duration of 8760 h was used in the calculations (Tawfiq et al., 2015).

$$D_\gamma = 0.462A_U + 0.621A_{Th} + 0.0417A_k \tag{8}$$

$$AEDE_{in}\ (\text{mSv.y}^{-1}) = D_\gamma\ (\text{nGy.h}^{-1}) \times 8760\ (\text{h.y}^{-1}) \times 0.80 \times 0.7\ (\text{Sv.Gy}^{-1}) \tag{9}$$

$$AEDE_{out}\ (\text{mSv.y}^{-1}) = D_\gamma\ (\text{nGy.h}^{-1}) \times 8760\ (\text{h.y}^{-1}) \times 0.20 \times 0.7\ (\text{Sv.Gy}^{-1}) \tag{10}$$

In these calculations, D_γ represents the absorbed dose rate in air, expressed in nGy.h^{-1}, whereas AEDE denotes the annual effective dose equivalent expressed in mSv.y^{-1}.

3 Results and discussion

3.1 Activity concentrations of $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), $^{137}_{55}$Cs, and $^{40}_{19}$K in the sediments

The activity concentration of the investigated radionuclides in the sediment samples were determined and are presented in Table 2. The measured values showed clear spatial differences among the sampling sites, demonstrating that the radionuclides were not uniformly distributed throughout the study area. Such differences may be related to variations in mineralogical composition, weathering conditions, sediment transport, and depositional processes occurring within the drainage basin. The calculated mean activity concentrations for each $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), $^{40}_{19}$K, and $^{137}_{55}$Cs were 26.23, 18.25, 361.29, and 5.99 Bq.kg^{-1}, respectively.

The highest activity concentration of $^{238}_{92}$U($^{226}_{88}$Ra) was recorded at site A_{12} (50.02) Bq.kg^{-1}, whereas the highest, $^{232}_{90}$Th($^{228}_{89}$Ac) concentration was observed at A_{18} (48.36)

Uncorrected Proof

Table 2: Activity concentrations of $^{238}_{92}$U($^{226}_{88}$Ra), $^{232}_{90}$Th($^{228}_{89}$Ac), $^{137}_{55}$Cs, and $^{40}_{19}$K radionuclides in sediments samples of the Al-Adhaim River tributary

Samples Code	$^{238}_{92}$U($^{226}_{88}$Ra) (Bq.kg^{-1})	$^{232}_{90}$Th($^{228}_{89}$Ac) (Bq.kg^{-1})	$^{40}_{19}$K (Bq.kg^{-1})	$^{137}_{55}$Cs (Bq.kg^{-1})
Al_1	3.65±0.514	3.21±0.218	735.98±34.411	2.14±0.285
Al_2	MDA	MDA	453.22±22.152	2.84±0.310
Al_3	MDA	24.67±2.499	279.11±17.074	MDA
Al_4	MDA	6.30±0.461	573.21±26.911	11.48±0.917
Al_5	14.36±0.895	26.73±2.564	309.84±17.118	MDA
Al_6	31.70±3.601	MDA	138.99±12.088	MDA
Al_7	MDA	2.59±0.287	403.38±20.193	1.15±0.240
Al_8	23.54±2.489	MDA	342.95±18.913	MDA
Al_9	7.26±0.690	MDA	305.05±17.012	10.08±0.812
Al_{10}	17.37±2.351	35.36±2.921	504.78±24.980	6.93±0.717
Al_{11}	MDA	29.49±2.697	269.18±16.811	2.84±0.311
Al_{12}	50.02±5.659	MDA	604.76±28.983	MDA
Al_{13}	MDA	29.93±2.589	258.20±16.236	8.75±0.809
Al_{14}	MDA	6.83±0.766	252.94±15.611	7.30±0.806
Al_{15}	41.84±5.458	MDA	418.33±21.059	MDA
Al_{16}	MDA	7.80±0.807	219.39±14.033	2.50±0.301
Al_{17}	47.77±5.545	MDA	221.67±14.143	11.21±0.911
Al_{18}	MDA	48.36±3.521	299.71±16.341	5.64±0.757
Al_{19}	MDA	10.86±0.906	398.36±21.126	MDA
Al_{20}	24.81±3.110	5.13±0.623	236.85±14.152	5.07±0.590
Max	50.02±5.659	48.36±3.521	735.98±34.411	11.48±0.917
Min	MDA	MDA	138.99±12.088	MDA
Average	26.23±1.05	18.25±0.44	361.29±4.79	5.994±0.17
Worldwide	35	30	400	14.8

Bq.kg^{-1}. In contrast, the highest $^{40}_{19}$K concentration occurred at A_1 (735.98) Bq.kg^{-1}, while the highest $^{137}_{55}$Cs concentration was recorded at A_4 (11.48) Bq.kg^{-1} , These differences indicate that the radionuclides exhibited distinct spatial distributions across the investigated sites.

Regarding detectability, $^{238}_{92}$U($^{226}_{88}$Ra) activity concentrations were below the minimum detectable activity (MDA) in 10 of the 20 samples (50%), while $^{232}_{90}$Th($^{228}_{89}$Ac) and $^{137}_{55}$Cs were below the MDA in 7 samples each (35%). These findings indicate that the detection of these radionuclides varied among the sampling sites. However, results below the MDA should not be interpreted as evidence of complete absence, nor do they alone establish the geological cause of the observed distribution. The activity concentrations observed in the samples generally followed the order $^{40}_{19}$K >$^{238}_{92}$U >$^{232}_{90}$Th.

The relatively higher concentration of potassium can be associated with the presence of potassium-bearing minerals, particularly feldspars, micas, and clay minerals, which commonly occur within the sandstone, siltstone, and claystone units of the Injana and Mukdadiya Formations. Weathering and continuous fluvial erosion of these formations can facilitate the breakdown, transport, and redistribution of potassium-bearing minerals within the river sediments. These processes may consequently explain the relatively elevated K activity concentrations measured in several locations, as shown in Fig. 3.

The activity concentrations obtained in this investigation were also compared with values reported in previous studies conducted in different regions of Iraq and in other countries. The mean concentrations of the investigated radionuclides were generally lower than the corresponding worldwide average values reported by UNSCEAR, as shown in Table 4 and Fig. 4.

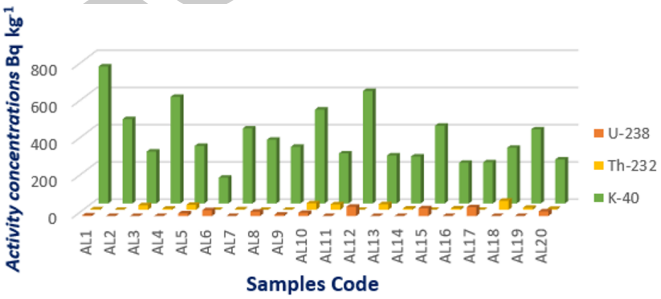


Figure 3: Activity of $^{238}_{92}$U, $^{232}_{90}$Th and $^{40}_{19}$K in sediment samples.

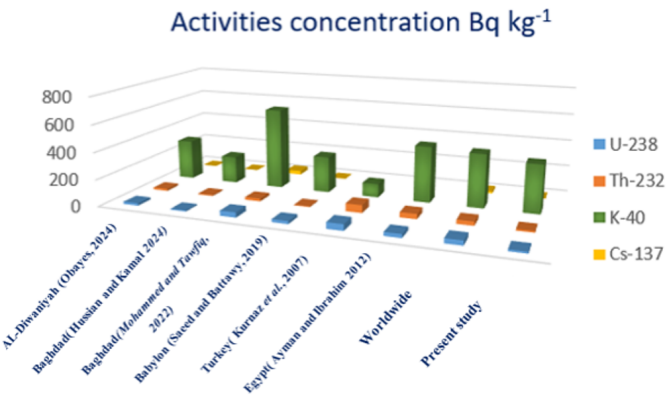


Figure 4: Comparison of the activity concentrations in sediment samples from the present study with those reported in other studies around the world.

Uncorrected Proof

Table 3: The radiation hazard indicators represented by Ra_{eq}, D_γ, I_γ, hazard indices (H_{ex}, H_{in}), and $AEDE$ (Indoor, outdoor) in the studied samples.

Samples Code	Ra_{eq} (Bq.kg^{-1})	D_γ (nGy.h^{-1})	H_{in}	H_{ex}	$AEDE_{indoor}$ (mSv.y^{-1})	$AEDE_{outdoor}$ (mSv.y^{-1})	I_γ
Al_1	64.91	34.37	0.185	0.175	0.168	0.042	0.547
Al_2	34.90	18.90	0.094	0.094	0.092	0.023	0.302
Al_3	56.77	26.96	0.153	0.153	0.132	0.033	0.432
Al_4	53.15	27.82	0.143	0.143	0.136	0.034	0.445
Al_5	76.44	36.15	0.245	0.206	0.177	0.044	0.569
Al_6	42.40	20.44	0.200	0.114	0.100	0.025	0.304
Al_7	34.76	18.43	0.093	0.093	0.090	0.022	0.294
Al_8	49.95	25.18	0.198	0.134	0.123	0.030	0.385
Al_9	30.75	16.07	0.102	0.083	0.078	0.019	0.251
Al_{10}	106.80	51.03	0.335	0.288	0.250	0.062	0.805
Al_{11}	62.90	29.54	0.169	0.169	0.144	0.036	0.474
Al_{12}	96.59	48.33	0.396	0.260	0.237	0.059	0.736
Al_{13}	62.68	29.35	0.169	0.169	0.144	0.036	0.471
Al_{14}	29.24	14.79	0.079	0.079	0.072	0.018	0.236
Al_{15}	74.05	36.77	0.313	0.200	0.180	0.045	0.557
Al_{16}	28.05	13.99	0.075	0.075	0.068	0.017	0.224
Al_{17}	64.84	31.31	0.304	0.175	0.153	0.038	0.466
Al_{18}	92.23	42.53	0.249	0.249	0.208	0.052	0.683
Al_{19}	46.20	23.36	0.124	0.124	0.114	0.028	0.374
Al_{20}	50.38	24.52	0.203	0.136	0.120	0.030	0.375
Max	106.80	51.03	0.396	0.288	0.250	0.062	0.805
Min	28.05	13.99	0.076	0.076	0.068	0.017	0.224
Average	57.90	28.49	0.192	0.156	0.139	0.034	0.446
Worldwide	370	84	≤ 1	≤ 1	1	1	1

Such differences may reflect variations in the source materials contributing to the sediments, sediment transport and deposition conditions and the distribution of potassium -and thorium bearing mineral phases. Differences in sampling procedures and measurement conditions may also contribute to the variability reported among studies. Since grain size and mineralogical analyses were not performed in the present work, the proposed relationships between radionuclide concentrations and sediment characteristics should be considered interpretive rather than conclusive. Nevertheless, comparison of mean activity concentrations alone is insufficient to provide a complete evaluation of the possible radiological implications of the investigated sediments. For this reason, several radiological hazard indices were calculated to assess potential exposure pathways and determine whether the measured natural radioactivity levels could represent a significant radiological health concern.

3.2 Evaluation of Radiological Hazard Indices for sediment samples

The radiological characteristics of the investigated sediments were evaluated using seven indicators, namely Ra_{eq}, D_γ, I_γ, the internal and external hazard indices (H_{in} and H_{ex}), and the indoor and outdoor annual effective dose equivalents (AEDE). These parameters were calculated from the measured activity concentrations of the relevant natural radionuclides in surface sediment samples collected from the Al-Adhaim River tributary. The resulting values are presented in Table 3. The radium equivalent activity (Ra_{eq}) ranged from 28.05 to 106.80 Bq.kg^{-1}, with a mean value of 57.90 Bq.kg^{-1}. This average is substantially lower than the recommended reference criterion of 370 Bq.kg^{-1} (UNSCEAR, 2000; Al-Ubaidi, 2014). The absorbed dose rate in air ranged between 13.99 and 51.03 nGy.h^{-1}, with an average value of 28.49 nGy.h^{-1}. This value is considerably lower than the worldwide average of 84 nGy.h^{-1} (UNSCEAR, 2000; Al-Ubaidi, 2014). The absorbed dose rate is an important indicator for estimating external exposure to ionizing radiation and for assessing the potential radiation risk to populations residing in or near the investigated environment. The gamma risk index (I_γ) ranged from 0.224 to 0.805, with a mean value of 0.446. The mean value remained below the reference value of 1 (UNSCEAR, 2000; Al-Ubaidi, 2014). indicating that the gamma-radiation contribution associated with the investigated sediments is within the recommended level. Potential internal exposure associated with Rn and its progeny was assessed using the internal hazard index (H_{in}), together with the external hazard index (H_{ex}). The calculated mean values were 0.192 for H_{in} and 0.156 for H_{ex}). Both values were below the recommended reference level of 1 (UNSCEAR, 2000; Al-Ubaidi, 2014), indicating a low potential for radiological hazards arising from the measured natural radionuclide concentrations. The calculated indoor and outdoor annual effective dose rates ranged from 0.068 to 0.250 mSv.y^{-1} and from 0.017 to 0.062 mSv.y^{-1} respectively. Their corresponding mean values were 0.139 and 0.034 mSv.y^{-1} respectively, which are below the recommended reference level of 1 mSv.y^{-1} (UNSCEAR, 2000; Al-Ubaidi, 2014). Although the calculated radiological parameters were within the relevant international reference values, the possible long-term accumulation of naturally occurring radionuclides in environmental sediments should not be disregarded, particu-

Uncorrected Proof

Table 4: Comparison of the activity concentration in the present study with those reported in other studies.

Location	$^{238}_{92}$U	$^{232}_{90}$Th	$^{40}_{19}$K	$^{137}_{55}$Cs	Reference
AL-Diwaniyah	17.3	15.5	302.3	-	(Obayes, 2024)
Baghdad	8.2	7.5	205.2	-	(Hussian and Ali, 2024)
Baghdad	38.42	21.08	606.97	28.92	(Mohammed and Tawfiq, 2022)
Babylon	21.851	5.326	273.37	0.879	(Saeed and Battawy, 2019)
Turkey	47.48	57.87	102.4	-	(Kurnaz et al., 2007)
Egypt	27.38	38.45	419.4	-	(El-Gamal and Saleh, 2012)
Worldwide	35	30	400	14.8	(UNSCEAR, 2000; Al-Ubaidi, 2014)
Present study	26.23	18.25	361.29	5.99	-

larly where environmental conditions may promote their redistribution or accumulation. Continued monitoring can therefore provide useful information on any future changes in the radiological characteristics of the area.

4 Conclusions

Gamma-ray spectrometric measurements using a NaI(Tl) detector were used to investigate the concentrations of naturally occurring radionuclides in sediment samples collected from the Al-Adhaim River. In addition to determining radionuclide activity concentrations, the study evaluated the associated radiological hazard parameters, including Ra_{eq}, D_{γ}, H_{ex}, H_{in}, $AEDE$, and I_{γ}. The results showed that the mean activity concentrations measured in the sediment samples, as well as the calculated gamma-radiation hazard indices, were generally below internationally recommended reference values. The observed activity concentrations may primarily reflect variations in the geological composition and natural mineralogical characteristics of the investigated region.

Although the mean activity concentrations remained within the recommended limits, relatively elevated $^{40}_{19}$K activity concentrations observed in some sediment samples may be associated with differences in the natural mineralogical composition, including the presence of potassium-bearing minerals such as feldspars and clay minerals. Although agricultural activities and fertilizer application may also influence the potassium content of sediments, their contribution cannot be established from the present data because no geochemical or mineralogical analyses were performed. Therefore, agricultural inputs are considered a possible explanation rather than a confirmed source of the observed $^{40}_{19}$K activity.

The detection of $^{137}_{55}$Cs in most samples at levels below the worldwide average indicates some artificial contribution (possibly global fallout) although its source was not determined in this study. Despite these localized variations, all calculated radiological hazard indices remained below the relevant internationally recommended reference values established by relevant international organizations, including WHO and UNSCEAR. On the basis of the measured values, the investigated sampling locations do not currently indicate a significant radiological risk to the local population. However, continued environmental accumulation or redistribution of radionuclides may alter exposure conditions over longer periods. Periodic radiological monitoring of the area is therefore recommended to identify any future changes in environmental radioactivity and to support the continued assessment of environmental and public health conditions in the governorate.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

Funding

The authors declare that no funds, grants, or other financial support were received during the preparation of this manuscript.

References

Akpanowo, M., Umaru, I., Iyakwari, S., et al. (2020). Determination of natural radioactivity levels and radiological hazards in environmental samples from artisanal mining sites of Anka, North-West Nigeria. *Scientific African*, 10:e00561.

Al-Ubaidi, A. M. (2014). *Environmental Radioactivity of Al-Rashidiyah Site Baghdad*. Ph.D. thesis, University of Baghdad, College of Science for Women.

Alrefae, T., Nageswaran, T. N., Alshemaly, T., et al. (2018). Radiological assessment of flour consumed in Kuwait. *Kuwait Journal of Science*, 45(2).

Asaduzzaman, K., Mannan, F., Khandaker, M. U., et al. (2015). Assessment of natural radioactivity levels and potential radiological risks of common building materials used in Bangladeshi dwellings. *PLoS One*, 10(10):e0140667.

Darko, E. O., Tetteh, G. K., and Akaho, E. H. K. (2005). Occupational radiation exposure to norms in a gold mine. *Radiation Protection Dosimetry*, 114(4):538–545.

El-Gamal, A. A. and Saleh, I. H. (2012). Radiological and mineralogical investigation of accretion and erosion coastal sediments in Nile Delta region, Egypt. *Journal of Oceanography and Marine Science*, 3(3):41–55.

Hussian, H. A. and Ali, K. K. (2024). The natural radioactivity and accompanying radiation hazard in the Tigris River sediments in Baghdad, Iraq. *Iraqi Journal of Science*, pages 6544–6556.

Uncorrected Proof

Isinkaye, M. O. and Emelue, H. U. (2015). Natural radioactivity measurements and evaluation of radiological hazards in sediment of Oguta Lake, South East Nigeria. *Journal of Radiation Research and Applied Sciences*, 8(3):459–469.

Jassim, S. Z. and Goff, J. C., editors (2006). *Geology of Iraq*. DOLIN, sro, distributed by Geological Society of London.

Kolo, M. T., Khandaker, M. U., Amin, Y. M., et al. (2016). Quantification and radiological risk estimation due to the presence of natural radionuclides in Maiganga coal, Nigeria. *PLoS One*, 11(6):e0158100.

Kurnaz, A., Kkmerolu, B., Keser, R., et al. (2007). Determination of radioactivity levels and hazards of soil and sediment samples in Frtna Valley (Rize, Turkey). *Applied Radiation and Isotopes*, 65(11):1281–1289.

Mohammed, A. A. and Tawfiq, N. F. (2022). Radioactivity levels in Sediment Specimens of Tigris Stream in Baghdad governorate, Iraq. In *International Congress on Human-Computer Interaction, Optimization and Robotic Applications (HORA)*, pages 1–5, Ankara, Turkey.

Obayes, K. H. (2024). Evaluation of radioactivity levels and cancer risk of sediment samples from the Euphrates River (Al-Diwaniyah Province, Iraq). *International Journal of Environmental Science and Development*, 15(6).

Qureshi, A. A., Tariq, S., Din, K. U., et al. (2014). Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan. *Journal of Radiation Research and Applied Sciences*, 7(4):438–447.

Ramasamy, V., Paramasivam, K., Suresh, G., et al. (2014). Role of sediment characteristics on natural radiation level of the Vaigai river sediment, Tamilnadu, India. *Journal of Environmental Radioactivity*, 127:64–74.

Saeed, H. H. and Battawy, A. A. (2019). Determination of Radioactivity Concentrations on Sediment the Euphrates River on Babylon Governorate. *Journal of University of Babylon for Pure and Applied Sciences*, 27(4):30–35.

Sissakian, V. K. and Jabbar, F. A. (2013). Geomorphology and morphometry of the three tributaries of Adhaim river, central part of Iraq. *Journal of Environmental Sciences*, 2-3:2–3.

Tawfiq, N. F., Mansour, H. L., and Karim, M. S. (2015). Natural radioactivity in soil samples for selected regions in Baghdad governorate. *International Journal of Recent Research and Review*, 8(1):1–7.

UNSCEAR (2000). Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation. Technical report, United Nations, New York.

©2027 by the journal.

RPE is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0).

OPEN ACCESS

To cite this article:

H. Hameed Saeed, M. Mohammed Jabbar, Z. F. Abd-Sada. Determination of radiation hazard indicators in naturally occurring radionuclides in sediments of the Al-Adhaim river tributary. *Radiation Physics and Engineering*, In Press.

DOI:

To link to this article: