Measuring the radioactivity of sediment samples from the Shatt Al-Arab river in basra and comparing it statistically

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Given the economic and tourism importance of the Shatt al-Arab River in Basra Governorate, this study aimed to evaluate the radiation levels in 20 sediment samples from different areas of the river. A gamma-ray spectrometer system coupled with a NaI(Tl) detector was used to determine the specific activities of the radioactive isotopes ^{226}Ra, ^{232}Th and ^{40}K in the sediments. Specific activity values ranged from 0 to 16.80 Bq/kg (mean = 3.29 Bq/kg) for ^{226}Ra; 0 to 4.31 Bq/kg (mean = 1.08 Bq/kg) for ^{232}Th; and 17.58 to 464.25 Bq/kg (mean = 213.02 Bq/kg) for ^{40}K. The internal and external doses, absorbed doses, and equivalent radioactivity (Ra_{eq}) were also calculated. The results showed that all radiological indicators and calculated doses were within the internationally permissible limits. The annual gonadal equivalent dose (AGED) calculated was less than the international limit (300 μSv·y^{-1}), and the excess lifetime cancer risk (ELCR) was lower than the internationally permissible value (2.9×10^{-3}) according to the UNSCEAR 2000 report. The data were also statistically analyzed to compare sediments between four different areas of the Shatt al-Arab, and the results showed no statistically significant differences, with the highest radioactivity recorded in the riverbank sediments compared to the areas closer to the riverbed. This study represents an important first step towards developing an integrated radiological map of the Shatt al-Arab.

Keywords: Basra; gamma spectroscopy; NORMs; sediments; Shatt al-Arab.

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1. Introduction

Three naturally occurring radionuclides with long half-lives are found in the earth's crust: ^{40}K, ^{232}Th, and ^{238}U. Natural sources (mostly from the ^{232}Th and ^{238}U family) and man-made sources (^{137}Cs) are the two main sources of environmental radionuclides. Human activity has the potential to release these radionuclides back into the environment. Human activities include military nuclear weapons testing, energy production, or nuclear accidents (like the 2011 Fukushima earthquake and the 1986 Chernobyl disaster) [1].

Studying radionuclide distribution, characteristics, and environmental effects is crucial. Radionuclides like the decay product of thorium and uranium can become a threat to human health because they emit ionizing radiation. Measuring the natural radioactivity in rocks and sediments is crucial for controlling the fluctuating nature of the background activity and safeguarding the environment [2]. Because of differences in the quantity of radionuclides in the crust of the earth, the radiation level fluctuates around the world. The sediments' natural levels of radionuclides are naturally correlated with the substratum's radionuclide content [3].

The levels of natural background in the agro-ecosystem may increase when fertilizers with phosphorus are used. Naturally occurring radioactive materials (NORMs) can be present in phosphorus fertilizers in amounts that are either 10 times higher or similar to the normal concentrations in sediments [4]. Thorium isotopes, terrestrial potassium and uranium are incorporated in the human body through the food chain, mainly by ingestion [5]. Through their roots, plants take up these radionuclides, which then build up in the plant sections that are consumed. The radioactive elements in these plants build up and cause internal radiation exposure in humans when they are processed and eaten [6]. There are many scientific studies on cancer incidence rates indicating a significant increase in diseases such as colon cancer [7]. There have been many studies on the radiation ratios of radionuclides in various types of water and their relationship to the soil and their effect on plants and human beings. There was also a study on the concentrations of radon that are emitted from radioactive chains in water [8]. The spread and increasing number of patients with leukemia, thalassemia, and blood diseases, and their relationship to toxic elements in the body, may be linked to water, because it is the basis of life [9, 10]. Also, the relationship between radiation and lung cancer has been studied extensively in this field [11] and the soil [12–14]. The association between cancer incidence and water of the river as also internal risk factors like high water usage have been investigated [15]. This study is consistent with our previous work, which focused on measuring the concentrations of naturally occurring radionuclides such as potassium-40, uranium-238, and thorium-232 in various samples, as well as assessing the levels of radioactivity in nutrients and food products. The presence of these radionuclides in biological and food systems can lead to chronic, low-intensity radiation exposure, which can, in turn, affect the physical and chemical properties of materials, including the corrosion behavior and resistance of metal alloys used in medical applications, as demonstrated in this study [16, 17].

This study aims to quantifying natural radioactivity, radium equivalent activity, internal and external radiation hazard indexes in the Shatt Al-Arab, Basra sediments. The provided baseline data can be helpful in future research.

2. Analytical technique (study area)

Shatt al-Arab River is a river in southern Iraq that flows into the Persian Gulf and has an approximate latitude and longitude of $30.00°$ N and $47.96°$ E, respectively, which shapes a significant waterway in the Basra region.

The river known as "River of the Arabs," or the Shatt al-Arab, is about 200 kilometers (120 mi) long and begins in the Iraqi town of Al-Qurnah in the Basra Governorate in the southern region, where the rivers Tigris and Euphrates converge.

The river's southernmost location, to the Persian Gulf as it flows out, marks the Iran–Iraq border. The breadth of the

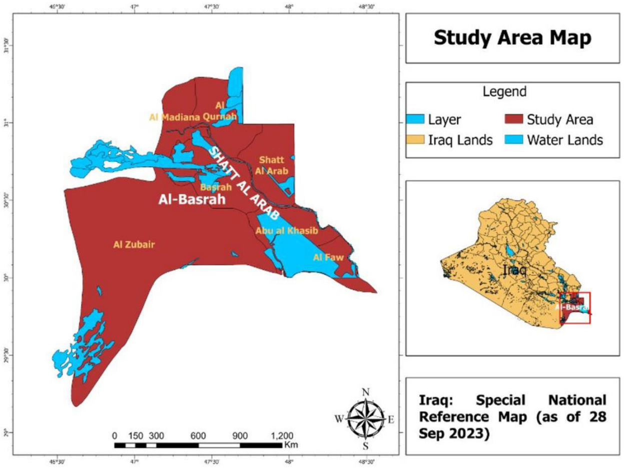

FIGURE 1. Shatt Al-Arab map.

Shatt al-Arab fluctuates, reaching up to 800 meters (2,600 feet) at its mouth from roughly 232 meters (761 feet) in Basra. Based on geological time estimates, the river originated relatively recently. The rivers Euphrates and Tigris were originally drained into the Persian Gulf via a western route. Bubiyan Island in Kuwait is a component of the Shatt al-Arab delta [18]. Figure 1 is a map of Basra Governorate comprising the Shatt al-Arab and the borders that surround it during the sample collection period.

3. Sample collection and measuring methods

A total of twenty sediment samples were obtained through random sampling along the administrative borders of the Shatt al-Arab in Basra. These samples are spread in the study territory. As indicated in Table I, the sampling points were located using the GPS, which symbolizes the Global Positioning System. The longitude and latitude of the sampling locations are shown in Table I. A map of the distribution of the research samples is shown in Fig. 2. The samples were

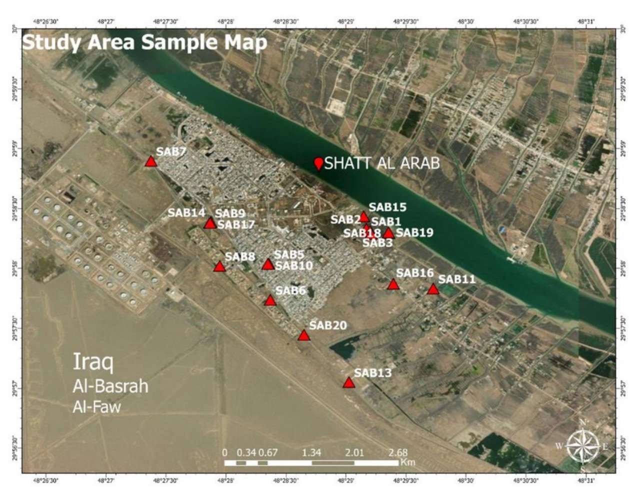

FIGURE 2. A map demonstrating the locations of sampling for sediments of the Shatt Al-Arab, Basra city.

TABLE I. Coordinates of sediment sampling sites.

Sample code	Type of location (sediments)	Location	Latitude	Longitude
SAB1	Coast	Shatt Al-Arab	29.972006	48.486102
SAB2	Coast	Shatt Al-Arab	29.972304	48.486152
SAB3	Coast	Shatt Al-Arab	29.971985	48.486671
SAB4	Coast	Shatt Al-Arab	29.971614	48.486808
SAB5	Water in which waste is collected	Al-Ansar school	29.96742606	48.472606
SAB6	Running water river	Municipal Park	29.962412	48.472814
SAB7	Water in which waste is collected	Al-Faw international road	29.981745	48.456241
SAB8	Running water river	Great victory gate	29.96714	48.46578
SAB9	Water in which waste is collected	Al-Faw international road	29.973131	48.46441
SAB10	From agricultural sediments	Al-Ansar school	29.967407	48.472464
SAB11	Running water river	Kut haj shed	29.963988	48.495437
SAB12	Shatt al-arab coast	Alnakaa	29.98097	49.45974
SAB13	Running water river	Municipal garage	29.95097	48.483737
SAB14	From agricultural sediments	Great victory gate	29.973239	48.464546
SAB15	Shatt al-arab coast	Shatt Al-Arab	29.974017	48.485777
SAB16	Running water river	Kut haj shed	29.964649	48.489904
SAB17	Running water river	Great victory gate	29.973113	48.464439
SAB18	Running water river	Kut haj shed	29.971697	48.48924
SAB19	Running water river	Kut haj shed	29.971781	48.489231
SAB20	Running water river	Municipal garage	29.95756	48.477493

gathered in May 2021. Silt samples were gathered in the form of about 500 g of silt using a small shovel, put in plastic bags, and driven to the University of Kufa's Faculty of Science's physics department laboratory. The samples were ready for measurement once contaminants like leaves, plant roots, and rocks were eliminated. These were then dried by air and then dried in an oven at 80°C until their weight was evaluated and all of the moisture was removed.

Dried samples were ground and then run through a 250-mesh screen. After that, the contents were carefully put into a one-liter Marinelli beaker made of polypropylene and sealed. It took two months of storage for the samples to achieve secular equilibrium between the radium nuclei (^{226}Ra and ^{228}Ra) and their daughters. The radioactivity of natural radionuclides in sediment samples was determined using a gamma-ray spectrometry system manufactured by ORTEC. The system finds extensive application in nuclear physics and environmental research in the detection and measurement of ionizing radiation. It comprises of built-in units such as radiation sensors, signal processing electronics and spectrum analysis software. The systems are highly used in areas like environmental monitoring, nuclear research and health physics because the systems are reliable and accurate in the determination of radioisotopic content. This instrumentation is accurate in identifying and quantifying radionuclides in the samples being studied. A 3×10^{-3} NaI(Tl) detector-based gamma-ray spectrometer, has an energy resolution of 6.8% at 662 keV for ^{137}Cs. The computer was configured with the ScintiVision$^{\text{TM}}$-32 software for the analysis of data, and the calibration of the system's efficiency and energy was performed. The measurement time for each sample was 28,800 seconds. The average background radiation was measured over the same time period using a blank Marinelli apparatus. The radioactivities of the ^{40}K, ^{226}Ra, and ^{232}Th nuclei were calculated at energies of 1460 keV for ^{40}K, 1764 keV for ^{214}Bi, and 2614 keV for ^{208}Tl, respectively.

4. Calculations

The specific activity, measured in Bq/kg, for each isotope was determined using Eq. (1) [19]:

$$A_n = \frac{C_n - C_b}{t\,\varepsilon_\gamma\, I_\gamma\, m_s}, \tag{1}$$

where m_s is the sample mass measured in kg, I_γ and ε_γ are the emission probability and detection efficiency of γ-rays, t is the counting period, and each radionuclide's specific activity, measured in Bq/kg, is abbreviated as A_n. C_n and C_b are the count rates in cps for samples and backgrounds, respectively.

To compare the combined radiological effects of ^{232}Th, ^{40}K, and ^{226}Ra nuclei in sediments and rocks, a common factor was employed due to their non-uniform distribution. The Ra$_{eq}$, symbolizing Radium Equivalent Activity, is the name given to this factor. As suggested by the Economic Cooperation and Development Organization, less than 370 Bq/kg is the acceptable limit for radium equivalent activity values in a safe manner. To compute the Ra$_{eq}$, Eq. (2) was utilized [20]:

$$\text{Ra}_{\text{eq}} = A_{Ra} + 1.43\, A_{Th} + 0.077\, A_K, \qquad (2)$$

where A_K, A_{Th}, and A_{Ra} stand for the corresponding specific activities of ^{40}K, ^{232}Th, and ^{226}Ra. Equations (3) and (4) were utilized to compute the hazard indices, which are exterior (H_{ex}) and internal (H_{in}) [21]:

$$H_{\text{ex}} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}, \qquad (3)$$

$$H_{\text{in}} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \qquad (4)$$

The risks of population health problems may occur in the case when the values of these indices are more than one. The outdoor absorbed dose (D_{out}) is calculated by Eq. (5). The UNSCEAR (2000) study recommends an average value of 51 nGy/h:

$$D_{\text{out}} = 0.462\, A_{Ra} + 0.604\, A_{Th} + 0.0417\, A_K. \qquad (5)$$

The rate of indoor absorbed dose was computed by Eq. (6) [22]:

$$D_{\text{in}} = 0.92\, A_{Ra} + 1.1\, A_{Th} + 0.08\, A_K. \qquad (6)$$

According to WHO guidelines, the suggested rate of indoor absorbed radiation is 70 nGy/h. ELCR (Excess Lifetime Cancer Risk), and AGED (Annual Gonadal Equivalent Dose), were also calculated [23].

The effect of radiation on living cells varies, as it can lead to DNA mutation or cell damage, or there may be no effect. Bone surface cells, bone marrow, and gonads are highly sensitive parts of the human body to radiation, so UNSCEAR attaches great importance to them. The increase in AGED affects the bone marrow, resulting in red blood cell damage. The estimated annual gonadal equivalent dose AGED due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K was calculated using the equation [24]:

$$\text{AGED}(\mu\text{Sv/y}){=}3.09A_{Ra}{+}4.18A_{Th}{+}0.314A_K. \qquad (7)$$

Exposure to radiation carries some risk, even if lower than the dose limit. The term "excess lifetime cancer risk" (ELCR) connotes the risk of dying of cancer over the natural background risk, resulting from a lifetime exposure to carcinogens. Increased cancer risk per unit dose is defined as a risk factor RF. To calculate the excess lifetime cancer risk due to gamma-ray radiation, the following equation was used [25]:

$$\text{ELCR} = D \times D_L \times RF, \qquad (8)$$

where ELCR represents the excess lifetime cancer risk, D is the annual effective dose, D_L stands for average duration of life in years (≈ 70) for an adult, and RF is the risk factor in Sv^{-1}, that is, lethal cancer risk, which is equal to 0.05 for the public, as shown in ICRP [14–17].

TABLE II. The specific activity of (^{40}K, ^{232}Th, and ^{226}Ra) and the counts dose metric for collected sediment samples in the Shatt Al-Arab.

Sample code	**Specific activity (Bq/kg)**			**Counts by dosimeter**
	^{226}Ra	^{232}Th	^{40}K	
SAB1	16.80	4.31	319.66	498
SAB2	3.30	< dl	104.99	546
SAB3	< dl	1.37	279.94	564
SAB4	1.20	< dl	155.03	456
SAB5	10.80	3.24	282.98	534
SAB6	< dl	< dl	192.17	457
SAB7	0.80	2.31	307.71	429
SAB8	< dl	0.52	162.06	484
SAB9	< dl	1.43	243.26	447
SAB10	10.00	0.89	339.58	477
SAB11	< dl	0.42	152.33	473
SAB12	3.30	< dl	104.99	446
SAB13	< dl	< dl	215.37	463
SAB14	< dl	1.61	269.62	523
SAB15	7.30	0.66	142.60	436
SAB16	< dl	0.28	176.82	424
SAB17	1.40	2.15	464.25	466
SAB18	< dl	< dl	152.45	486
SAB19	0.30	0.26	17.58	431
SAB20	0.30	< dl	121.28	479
Max	16.80	4.31	464.25	564
Min	< dl	< dl	17.58	424
Mean	3.29	1.08	213.02	477.59

5. Results and discussion

Table II shows the specific activity values determined for all 20 sediment samples along with their respective ratios.

Table II illustrates that the ^{226}Ra specific activity values for the studied sediment samples fell between the maximum and minimum ranges. Sample SAB1 has the highest reported value of a particular uranium activity. Many samples were below the detection limit for the radionuclide ^{226}Ra, where the mean concentration of this nuclide was 3.29 Bq/kg. Regarding the specific activity of ^{232}Th, sample SAB1 exhibited the highest quantity 4.31 Bq/kg, whereas many samples were below the detection limit for the radionuclide ^{232}Th. The mean of this nuclide was 1.08 Bq/kg.

Focusing on the radioactive potassium nuclide, in the SAB19 sample, it was the smallest value at 17.58 Bq/kg, while the maximum value for the radiation level was 464.25 Bq/kg in sample SAB17. Furthermore, the average value for the radiation level of this nuclide was 213.02 Bq/kg, while the count level for all studied samples of soil sediments, which used a portable dosimeter, was the highest, lowest, and average (564, 424, and 477.590) counts, respectively. Ac-

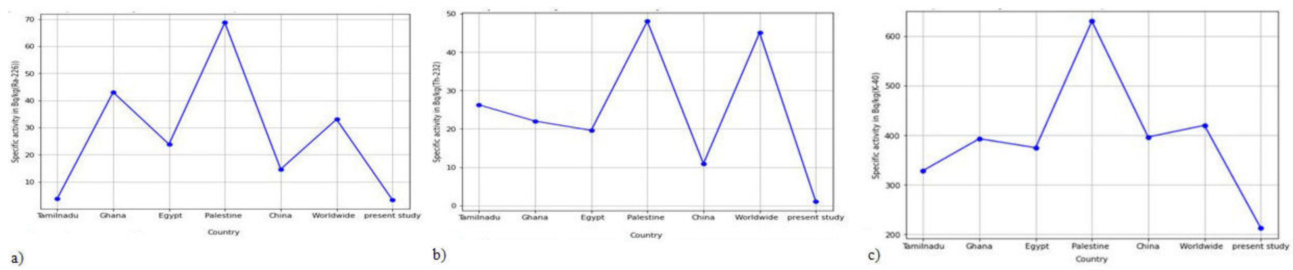

FIGURE 3. Investigation of sediment samples from various countries to compare the specific activity of a) ^{226}Ra b) ^{232}Th c) ^{40}K.

TABLE III. Values of radium equivalent (Ra_{eq}), hazard indices and outdoor, indoor absorbed doses for sediment samples collected from the Shatt Al-Arab, Basra.

Sample code	Ra_{eq} (Bq/kg)	H_{ex}	D_{out} (nGy/h)	H_{in}	D_{in} (nGy/h)
SAB1	47.58249	0.128518	23.77466	0.173925	30.90706
SAB2	11.38434	0.030747	5.923723	0.039666	7.70084
SAB3	23.51642	0.063494	12.94523	0.063494	16.82879
SAB4	13.13695	0.035473	7.178488	0.038716	9.332034
SAB5	37.22328	0.100532	18.92491	0.129722	24.60239
SAB6	14.7971	0.039952	8.263314	0.039952	10.74231
SAB7	27.79081	0.075037	15.09947	0.0772	19.62932
SAB8	13.21736	0.035687	7.310536	0.035687	9.503697
SAB9	20.77762	0.0561	11.40762	0.0561	14.82991
SAB10	37.42694	0.10108	19.46415	0.128107	25.30339
SAB11	12.32635	0.033281	6.826535	0.033281	8.874495
SAB12	11.38434	0.030747	5.923723	0.039666	7.70084
SAB13	16.58358	0.044776	9.260958	0.044776	12.03925
SAB14	23.06354	0.062272	12.65974	0.062272	16.45766
SAB15	19.21875	0.05191	9.683413	0.071641	12.58844
SAB16	14.0131	0.037835	7.787488	0.037835	10.12373
SAB17	40.21764	0.108592	21.98198	0.112375	28.57658
SAB18	11.73843	0.031694	6.555227	0.031694	8.521795
SAB19	2.022935	0.005463	1.054966	0.006274	1.371455
SAB20	9.638419	0.026025	5.34306	0.026835	6.945978
Max	47.58249	0.128518	23.77466	0.173925	30.90706
Min	2.022935	0.005463	1.054966	0.006274	1.371455
Mean	20.75754	0.056054	11.00904	0.064973	14.31175

cording to the findings, the amounts of radioactive elements in coastal silt samples from Shatt Al-Arab are higher compared to their concentrations in the rivers flowing near the Shatt al-Arab. Figure 3 shows the relationship between the studied samples and each nuclide, respectively.

The thorium and uranium nuclei measured in sediment samples were very low in comparison to the world average (45 Bq/kg for ^{232}Th and 33 Bq/kg for ^{226}Ra) that UNSCEAR advised. Additionally, the radium equivalent activities of the sediment samples were calculated, where the average value was 20.75754 Bq/kg, as presented in Table III. The peak value was 47.58249 Bq/kg, and the minimum value was 2.022935 Bq/kg. Every computed value was below the allowable threshold (370 Bq/kg) according to ICRP and UNSCEAR 2000.

The computed values of the internal danger index, outdoor absorbed dose, external hazard index, and indoor absorbed dose are displayed in Table III. These components had maximum values of 0.128518, 23.77466 nGy/h, 0.173925, 30.90706 nGy/h. In contrast, the lowest values were, in order, 0.005463, 1.054966 nGy/h, 0.006274, 1.371455 nGy/h. The computed average values were, in order, 0.056054, 11.00904 nGy/h, 0.064973, and 14.31175 nGy/h.

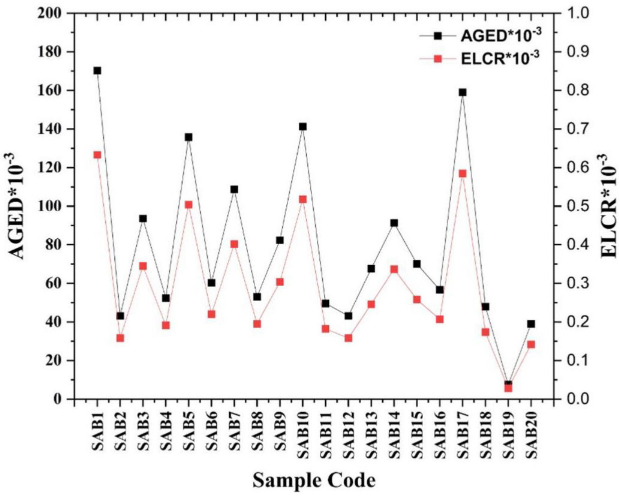

FIGURE 4. A comparison between the AGED and ELCR.

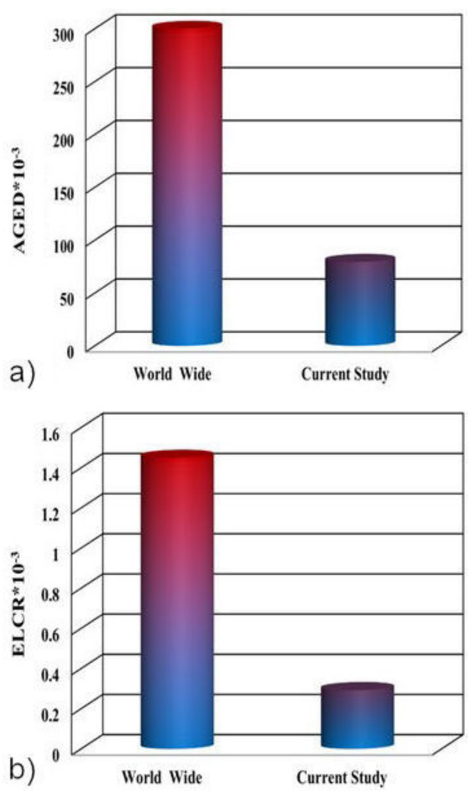

FIGURE 5. A comparison of the present study values of AGED and ELCR with their global counterparts.

Even though the potassium levels in the sediments have significantly increased, the mean values for the indices of internal and external hazards remained below unity. All outdoor-measured absorbed dose mean values were below the 51 nGy/h limit that is allowed by UNSCEAR 2000. With regard to the dose absorbed indoors, this proportionate rise in potassium content in the calculated indoor absorbed dose levels increased considerably due to sedimentation. This meant that the acceptable limit was surpassed in one instance, and the other values were near the limit. As for Table IV, for the

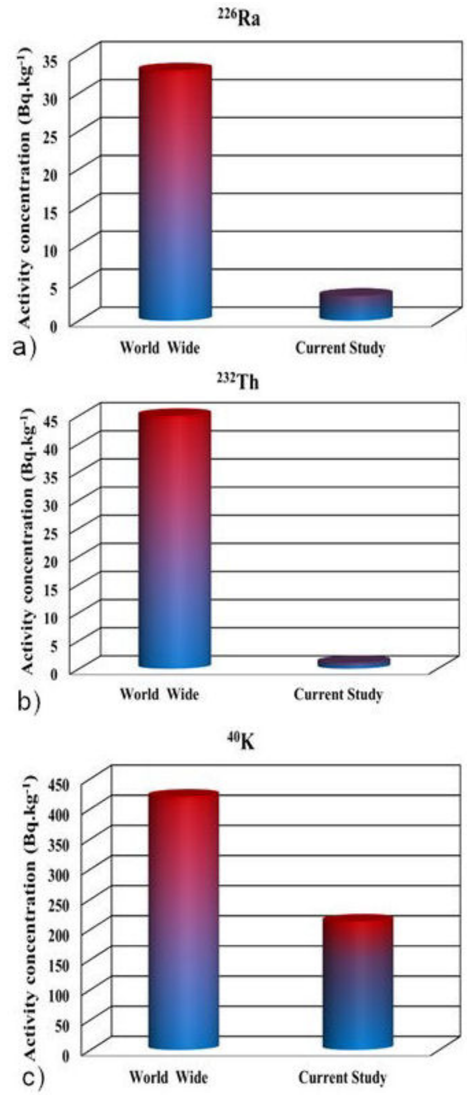

FIGURE 6. Values of activity concentration (Bq/kg) compared to those from past research and the global average (Bq/kg).

other dosimetric quantity AGED and ELCR, according to the UNSCEAR 2000 standards, the average values of all physical variables fell below the internationally acceptable limits.

Figure 4 exhibits a comparison between AGED and ELCR, and Fig. 5 shows a comparison of global and current values from AGED and ELCR studies. According to UNSCEAR 2000, the particular activity levels of ^{226}Ra and ^{232}Th that were computed for this study were significantly lesser than those of the other countries indicated in Table V and the global average, as shown in Fig. 6. Our analysis shows that the value of ^{226}Ra in Tamil Nadu is similar to the values that were obtained in this research.

When the ANOVA between the four groups of sediments was tested using the statistical program SPSS, version 2023, it was discovered that there were no differences in the means of radium equivalents between them because the probability value was greater than 0.05, indicating that there was no statistical significance between the means. However, as the fig-

TABLE IV. Values of hazard indices, AGED and ELCR for sediment samples collected from the Shatt Al-Arab, Basra.

Sample code	AUI	I_α	I_γ	AGED $\times 10^{-3}$	ELCR $\times 10^{-3}$
SAB1	0.234	0.084	0.368	170.317	0.633
SAB2	0.039	0.017	0.092	43.164	0.158
SAB3	0.040	0.000	0.200	93.633	0.345
SAB4	0.024	0.006	0.111	52.386	0.191
SAB5	0.162	0.054	0.293	135.773	0.504
SAB6	0.016	0.000	0.128	60.341	0.220
SAB7	0.060	0.004	0.234	108.730	0.402
SAB8	0.020	0.000	0.113	53.046	0.195
SAB9	0.037	0.000	0.176	82.366	0.304
SAB10	0.131	0.050	0.302	141.267	0.518
SAB11	0.018	0.000	0.106	49.577	0.182
SAB12	0.039	0.017	0.092	43.164	0.158
SAB13	0.018	0.000	0.144	67.627	0.246
SAB14	0.042	0.000	0.196	91.392	0.337
SAB15	0.087	0.037	0.150	70.077	0.258
SAB16	0.018	0.000	0.121	56.685	0.207
SAB17	0.077	0.007	0.340	159.076	0.585
SAB18	0.013	0.000	0.102	47.868	0.174
SAB19	0.007	0.002	0.016	7.526	0.028
SAB20	0.013	0.002	0.083	39.008	0.142
Max	0.234	0.084	0.368	170.317	0.633
Min	0.007	0.000	0.016	7.526	0.028
Mean	0.061	0.016	0.171	79.585	0.293
Worldwide (mean)	1	1	1	300 μSv·y^{-1}	1.45

ure illustrates, the agricultural sediments and the sediments beneath the Shatt Al-Arab's waste are the highest compared to those near the river and the coast.

Table V compares the natural radioactivity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Shatt al-Arab (Basra) sediment samples with those of several global regions, as well as with global averages. The results of this study indicate that the radioactivity values in Iraq (3.29, 1.08, and 213.02 Bq/kg, respectively) are significantly lower than most of the studied regions and also lower than global averages (33, 45, and 420 Bq/kg). For example, regions such as Palestine, Ghana, and the Himalayas record considerably higher values, particularly for thorium and potassium, reflecting the influence of geological structures rich in heavy minerals and igneous rocks. Regions such as Tamil Nadu and the Red Sea region also show intermediate values, but these remain higher than those recorded in this study. The lower concentrations in Iraq are attributed to the nature of the recent river sediments, which are characterized by a lower radioactive isotope content compared to the parent rocks. In general, these results indicate that the studied area falls within safe radiological levels and does not pose a significant environmental risk compared to global averages.

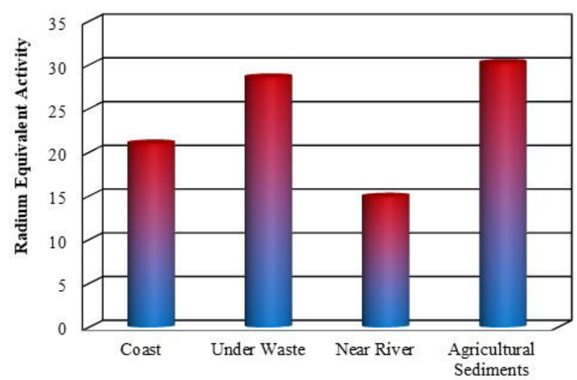

FIGURE 7. A statistical comparison between the sediment areas of the Shatt Al-Arab.

Using a chi-square test, we examined whether the differences in average radium equivalent activity between the four sites (coastal, underground, near the river, and agricultural sediments) were statistically significant. Since the p-value resulting from the test is 0.267, which is greater than 0.05, this means that there are no statistically significant differences between the means as shown in Fig. 7.

TABLE V. International comparison of particular activity measurements obtained from sediment samples.

Country	Activity concentration (Bq/kg)			Reference
	^{226}Ra	^{232}Th	^{40}K	
Tamilnadu	3.8	26.23	328.68	[26]
Ghana	43	22	393	[27]
Red Sea region, Egypt	23.8	19.6	374.9	[28]
Palestine	68.7	48.0	630	[29]
China	14.6	10.9	396.4	[30]
Garhwal Himalaya, India	32	45	410	[31]
Ukhimath area, India	28	36	389	[32]
Worldwide	33	45	420	[33]
Iraq, Sediments of the Shatt Al-Arab, Basra	3.29	1.08	213.02	Present work

6. Conclusion

The study aimed to measure the concentrations of natural isotopes (^{226}Ra, ^{232}Th, and ^{40}K) in the sediments of the Shatt al-Arab (Basra) and evaluate radiometric indicators (Ra_{eq}, D_{out}, D_{in}, H_{in}, H_{ex}, AGED, and ELCR). Spectral analysis results showed that the average concentrations of Ra and Th were within the lower ranges of the global average, whereas K registered comparatively higher values. This was due to the contribution of potassium fertilizers that were used in agricultural areas to the local drainage basin. The calculated values for all radiological hazard indicators (Ra_{eq}, H_{in}, H_{ex}), annual absorbed doses, and ELCR were below the acceptable international limits (compared to UNSCEAR and ICRP reports). This means that external and internal exposure from sediments at the study sites does not pose an immediate radiological risk to the local community according to current standards.

Nonetheless, statistical analyses (ANOVA) show that there is slight spatial variation, with higher values observed in coastal sediments and agricultural areas/near waste collection sites compared to mid-river samples, which demonstrates the importance of geological factors and human activities (irrigation, fertilizers, drainage) in controlling isotopic distributions.

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Ethical approval

All authors have read, understood, and complied as applicable with the statement on ethical responsibilities of authors as found in the Instructions for Authors.

Competing interests

The authors declare no competing interests.

Data availability

All the data and materials in the manuscript are available in the paper.

Author contributions statement

S.A.K. contributed to writing the original draft, formal analysis, software development, and visualization. A.A.A. participated in methodology and investigation. A.A.R. contributed to data curation and validation. Q.S.A. was involved in resources and supervision. H.H.H. contributed to conceptualization and project administration. F.I.S. was responsible for funding acquisition, conceptualization, and overall supervision. All authors reviewed and approved the final version of the manuscript.

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Conflict of interest

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