Environmental Assessment of the Background Radiation in Sediment Samples Selected from Euphrates River in Babil Province, Iraq

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ABSTRACT

This study investigated the natural radioactivity levels in sediment samples collected from the Euphrates River in Babylon Governorate, Iraq, to estimate the potential radiological hazards and environmental concerns. The activity concentration of three natural radionuclides was determined using a 3×3-inch NaI(Tl) gamma-ray spectrometer, including uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K). The results showed average activity concentrations of 46.55 ± 0.68 Bq/kg for ^{238}U, 14.6 ± 0.73 Bq/kg for ^{232}Th, and 293.16 ± 3.83 Bq/kg for ^{40}K. These values were then compared to international safety standards to evaluate their effect on radiological and health risks. Several other radiological hazards indices were performed, including the external hazard index (H_{ex}), Annual Effective Dose Equivalent (AEDE), and Excess Lifetime Cancer Risk (ELCR). The results confirm that the radiation exposure levels in the study area remain within permissible limits, posing no immediate threat to public health or the environment. Future work is essential to further understanding the radiation dynamics.

Keywords-sediment radioactivity; external hazard index; NaI(Tl) detector; annual effective dose; absorbed dose; excess lifetime cancer risk

I. INTRODUCTION

Radiation affects the environment in a significant way, as nuclear particles generate radionuclides that pollute the atmosphere [1]. Several factors influence their behavior, including the abundant release of radionuclides from their source, their chemical characteristics, the limits that can be controlled for the release of radionuclides, and their dispersion through water, soil, or air. Additionally, the physical properties of the affected ecosystem are vital for investigation [2-6].

The majority of rocks and soils that comprise the Earth's crust contain varying amounts of radioactive materials, making them widely distributed [7]. The composition of soil plays a crucial role in determining the concentration of naturally occurring radioactive isotopes in sediments [8]. Soil radioactivity depends on both the radioactivity of the rocks that formed the soil (the origin of the soil) and the overall processes that contributed to its formation [9, 10]. The uranium's concentration in volcanic rocks depends on their silicon content, while it is lower in regions with sandstone and limestone compared to flint. When sedimentary rocks fracture, uranium either dissolves in water or is transported by rock fragments, where it takes the form of carbon compounds in the sedimentary bottom. In this case, uranium becomes abundant in the silt and other sediments at the water's bottom [11-13]. Since uranium is abundant in phosphate rocks, it can be found in all soil types.

Most thorium compounds are either insoluble or take a long time to dissolve in the remnants of broken rocks, and they end up in secondary salts, like monazite, which exhibits significant thorium concentrations [14]. The radioactivity of both uranium and thorium relies on the type and character of the geological and topographical basis of the area where the water is located, with concentration in water being 10^3-10^4 times lower than that of soil and rocks [15]. However, limited research has focused specifically on the Babylon Governorate, despite its significance as a densely populated and economically important region.

A study conducted in Nigeria assessed the possibility of fertility cancer and hereditary risks from the naturally occurring radionuclides using the gamma-ray spectrometry NaI(Tl) detector system. The mean concentrations of key radio nuclides were found to be 645.29 ± 7.32 Bq/kg for ^{40}K, 28.43 ± 4.84 Bq/kg for ^{226}Ra, and 66.84 ± 2.02 Bq/kg for ^{232}Th [16]. The average annual effective dose due to ingestion was calculated 0.36 ± 0.1 µSy/y, 1000 times lower than the global average effective dose. Radium equivalent activity and total cancer risk were observed 161.44 ± 8.08 Bq/kg, 0.142 ± 0.02, and (0.21 ± 0.05) × 10^{-5}, respectively. These values were compared to safety limits established by the UNSCEAR and USEPA, which recommend that radium equivalent activity should not exceed 370 Bq/kg, the alpha index should be below 1, the effective dose should remain under 300 µSy/year, and the total cancer risk should be no more than 1 × 10^$^{-4}$. The findings of this study were well within these recommended thresholds, indicating that the soil in this region does not present a significant radiological risk [17, 18]. This suggests that the ingestion or inhalation of soil in Nasarawa is not associated with any immediate or concerning radiological health risks, as the observed radiation levels within acceptable safety limits [19].

However, there is a research gap in the understanding of radiological risks caused by natural radionuclides in soil, particularly in fertility and hereditary. Additionally, there is a lack of how radionuclides are being transferred from soil to plants, affecting the agriculture and human health. This study aims to evaluate radiation levels in soil samples collected from various locations in the Babylon Governorate, Iraq, and consider whether they are related with internationally accepted safety limits.

II. METHODOLOGY

Figure 1 presents and summarizes the methodology of the current study.

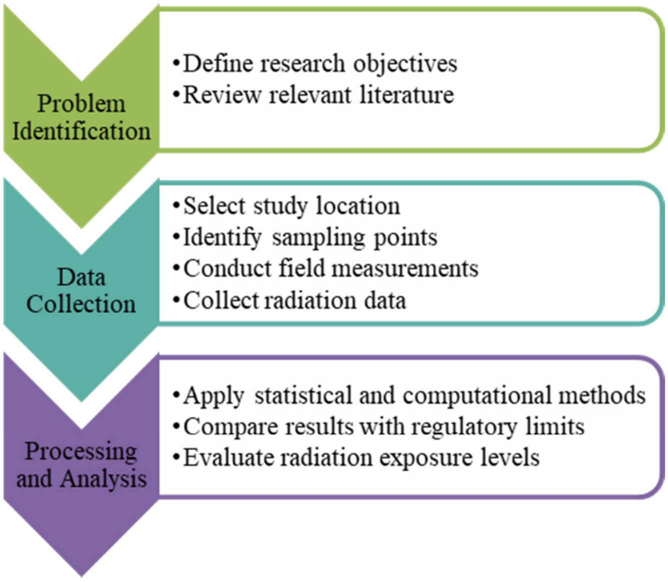

Fig. 1. Methodology of the current study.

A. *Study Area*

The Babylon Governorate is located in the Mesopotamian Plain, an alluvial plain in central Iraq, between latitudes 32.4° and 33.3° north and longitudes 44° and 45.15° east. According to region's geology, it consists of Quaternary sedimentary rocks formed by flat flood sediments, due to river flow. Additionally, stream sediments are observed, gathered by floods, and often containing thin layers of silt, clay, fine sand, and silt-clay. Figure 2 illustrates the precise location of the region, placed in the northern portion of Euphrates, 27 meters above the sea level. The sites and sample codes for the current investigation are displayed in Table I.

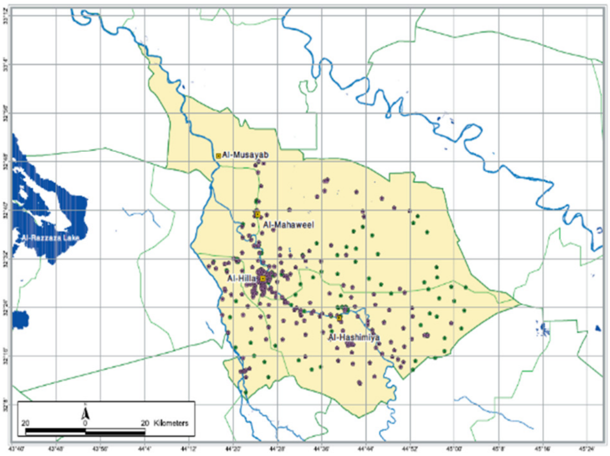

Fig. 2. Map of Iraq viewing the location of Babylon Governorate.

TABLE I. COORDINATES OF LOCATION SAMPLES FOR THE PRESENT STUDY

Sample code	**Coordinates**	
	Latitude (N)	**Longitude (E)**
S1	N 32º,28′, 43. 0″	E 44º,24′,18.0″
S2	N 32º, 32′, 17.0″	E 44º, 24′, 39.3″
S3	N 32º, 28′, 35.6″	E 44º, 24′, 18.2″
S4	N 32º, 31′, 22.0″	E 44º, 24′, 53.2″
S5	N 32º, 32′, 50.6″	E 44º, 44′, 50.0″
S6	N 32º, 31′, 10.35″	E 44º, 25′, 23.9″
S7	N 32º, 28′, 47.6″	E 44º, 25′, 43.0″
S8	N 32º, 31′,00.4″	E 44º, 25′, 52.6″
S9	N 32º, 28′, 25.2″	E 44º, 26′, 18.1″
S10	N 32º, 32′, 50.8″	E 44º, 42′, 18.0″
S11	N32º, 28′, 06.1‴	E 44º, 26′, 20.0″
S12	N 32º, 35′, 00.0″	E 44º, 30′, 18.0″
S13	N 32º, 29′, 02.5″	E 44º, 26′, 23.0″
S14	N 32º, 28′, 30.0″	E 44º, 25′, 00.0″
S15	N 32º, 28′, 43.6″	E 44º, 42′, 18.0″
S16	N 32º, 27′, 35.4″	E 44º, 26′, 18.2″
S17	N 32º, 28′, 30.0″	E 44º, 28′, 20.2″
S18	N 32º, 29′, 32.9″	E 44º, 30′, 18.0″

B. *Sample Preparation and Collection*

Two kg of plastic bags were utilized to collect eighteen sediment samples. These samples were exposed to sun for 72 h to well dry them out for more accurate weight values. An electric grinder was applied for grinding, and then a clamp with millimeter-diameter holes was employed to create uniform samples. After a complete cleaning with diluted hydrochloric acid and distilled water, 1 kg of dry silt was transferred in a 1 L plastic container to quantify the radioactivity.

C. Gamma Spectroscopy System NaI(Tl)

The specific radioactivity of emitting nuclides was measured using a gamma spectroscopy system with a NaI(Tl) detector of 3×3 inches, equipped by Spectrum Techniques, type UCS30 [20], as portrayed in Figure 3. The system was calibrated by identifying the photon energy emitted from the source and its corresponding channel. ^{22}Na isotope (1274 keV), ^{60}Co isotope (1173-1332) keV, and ^{133}Ba isotope (81 keV) were employed for the current process.

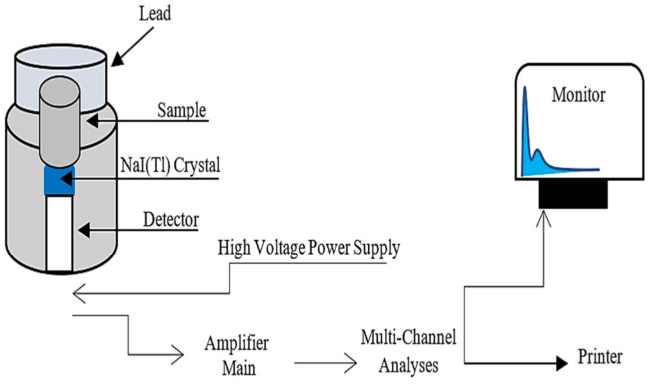

Fig. 3. NaI (Tl) detector system.

III. THEORETICAL APPROACH

The background radiation (A_{BG}) was calculated by [21]:

$$A_{BG}(Bq) = \frac{N}{I_{\gamma} * \xi * T} \tag{1}$$

Using a duration of 18,000 s, the samples' specific radioactivity was measured using [22]:

$$A(Bqkg^{-1}) = \frac{N/T - A_{BG}}{I_{\gamma} * \xi * m} \tag{2}$$

where *m* is the sample's mass (kg).

A number of risk variables, including radium equivalent Ra_{eq}, were measured based on the relative effectiveness of radium, thorium, and potassium. According to (3), the distribution of these three isotopes varied depending on the soil type and can be standardized based on the radiation dose, or the (Ra_{eq})) equivalent [23].

$$Ra_{eq}\left(\frac{Bq}{Kg}\right) = A_{Ra} + 1.43A_{Th} + 0.077A_{K} \tag{3}$$

The maximum value of Ra_{eq} should be within the internationally permitted limit (370 Bq/kg). The absorbed dose rate (*D*) can be used to determine the total radiation dose based on the concentrations of terrestrial radionuclides [24].

$$D(nGy\,h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417\,A_{K} \tag{4}$$

The external hazard index, or H_{ex} evaluates the risk of natural gamma radiation [25]:

$$H_{ex} = \left({A_{Ra}}/{370} + {A_{Th}}/{259} + {A_{K}}/{4810}\right) \leq 1 \tag{5}$$

This parameter should be less than one to follow the standards. When determining the Annual Effective Dosage Equivalent (AEDE), the ratio of the absorbed to the effective dose, as well as the factor of internal preoccupation should be considered. From these considerations, the annual effective dose was calculated using an internal occupation factor of 0.8, which is the ratio of time spent inside to the time spent outside, and a factor of 0.7 Sv/Gy, which converts the air-absorbed dose to the annual effective dose received by adults. Therefore [26]:

$$AEDE_{indoor}\,(mSv\backslash y) = AD\left(\frac{nGy}{h}\right) \times 8{,}760\,(h) \times 0.8 \times 0.7\left(\frac{Sv}{Gy}\right) \times 10^{-6} \tag{6}$$

$$AEDE_{outdor}\,(mSv\backslash y) = AD\left(\frac{nGy}{h}\right) \times 8{,}760\,(h) \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \times 10^{-6} \tag{7}$$

On the other hand, the global annual average effective dosage is 0.48 mSv, and 8,760 represents the number of hours in a year [27]. The following formulas were used to determine the ELCR, or the risk of increasing time life for cancer risk [28, 29]:

$$(ELCR)_{outdoor} = E_{out} \times L_{E} \times R_{F} \tag{8}$$

$$(ELCR)_{indoor} = E_{in} \times L_{E} \times R_{F} \tag{9}$$

where E_{in}, E_{out} is the internal and external annual effective dose, respectively, L_E is the average life expectancy (60 years), and R_F is a risk factor 0.05 (Sv^{-1}).

IV. RESULTS AND DISCUSSION

Table II presents the specific activity concentration of the radionuclides under investigation (^{238}U, ^{232}Th, and ^{40}K) for different sediment samples.

TABLE II. SPECIFIC ACTIVITY CONCENTRATION OF THE STUDIED RADIONUCLIDES (^{238}U, ^{232}TH, AND ^{40}K)

Sample code	**Specific Activity A_{BG} (Bq/kg)**		
	^{238}U	**^{232}Th**	**^{40}K**
S1	15 ±0.73	5 ±0.36	319 ±3.87
S2	10 ±0.62	7 ±0.43	278 ±3.61
S3	22 ±0.9	10 ±0.53	379 ±4.21
S4	14 ±0.71	6 ±0.4	287±3.66
S5	20 ±0.85	8 ±0.46	365±4.13
S6	17 ±0.79	5 ±0.37	263±3.51
S7	9 ±0.57	9 ±0.48	282±3.64
S8	13 ±0.69	5±0.37	277 ±3.6
S9	21 ±0.87	8 ±0.48	336 ±3.79
S10	17 ±0.79	5 ±0.37	364 ±4.13
S11	18 ±0.81	3 ±0.29	234 ±3.31
S12	10 ±0.61	6 ±0.39	280 ±3.62
S13	10 ±0.61	4±0.32	248 ±3.41
S14	11 ±0.63	2 ±0.24	196 ±3.03
S15	14 ±0.71	3 ±0.27	285 ±3.65
S16	14 ±0.72	6 ±0.41	271 ±3.56
S17	14 ±0.71	3±0.27	285 ±3.66
S18	15 ±0.74	4 ±0.32	328 ±3.92
Ave ±SD	14.6 ± 0.73	5.5 ± 0.38	293.16 ±3.83
Max. ±SD	22 ± 0.9	10 ±0.53	379 ± 4.21
Min. ±SD	9 ± 0.57	2 ± 0.24	196 ± 3.03
Global limit [26-27]	35	30	420

The specific gravity of ^{238}U was highest in sample S3 (22 ± 0.9 Bq/kg), while sample S7 exhibited the lowest recorded value (9 ± 0.57 Bq/kg), with an average value of 14.6 ± 0.73 Bq/kg. Given that uranium is found naturally in rocks worldwide, its low radioactivity levels (< 35 Bq/kg) indicate that there is no significant environmental or health impact. Similarly, the highest specific activity of thorium (^{232}Th) was observed in sample S3 (10 ± 0.53Bq/kg) and the lowest value (2 ± 0.24 Bq/kg) in sample S14. Although there was an increase in the measured values for certain locations, the average was 5.5 ± 0.38 Bq/kg, extensively lower than the limit of 30 Bq/kg. In this case, the radioactivity of thorium does not indicate health or environmental hazard. As for potassium (^{40}K), the highest specific activity value of 379 ± 4.21 Bq/kg was observed in sample S3, while sample S14 exhibited the lowest value, 196 ± 3.03 Bq/kg. The average of these values was determined to be 293.16 ± 3.83 Bq/kg, within the acceptable range of 420 Bq/kg. Since potassium is naturally present in most rocks and soils, its radioactivity levels in the sediments indicates that the area did not witness severe geological events or tectonic changes that led to an abnormal increase in its concentration. However, some samples contained a higher percentage of potassium than the rest of the samples, demonstrating that maybe contain a greater percentage of salinity, in addition to their interaction with groundwater.

Table III displays the results of ELCR, total AEDE, absorbed dose rate, external hazard index, and radium equivalent activity. It is evident that sample S3 exhibited the highest values of all parameters while sample S14 had the lowest values. The average values of results were all within the permissible limits.

TABLE III. THE RA_{EQ}, D_{R}, H_{EX}, AEDE TOTAL, AND ELCR RESULTS IN SEDIMENT SAMPLES

Sample No.	**Ra_{eq} (Bq/kg)**	**D (nG/h)**	**H_{ex}**	**Total AEDE, (mSv/y)**	**ELCR ($\times 10^{-3}$)**
S1	46.41	23.13	0.13	0.145	0.508
S2	41.92	20.7	0.11	0.13	0.454
S3	66.86	32.63	0.18	0.205	0.717
S4	44.83	22.13	0.12	0.139	0.486
S5	59.59	29.32	0.16	0.184	0.644
S6	45.85	22.49	0.12	0.141	0.494
S7	43.15	21.19	0.11	0.132	0.465
S8	41.89	20.77	0.11	0.13	0.456
S9	58.87	28.79	0.15	0.181	0.632
S10	52.32	26.13	0.14	0.164	0.574
S11	40.71	20.08	0.1	0.126	0.441
S12	40.33	20.03	0.1	0.126	0.440
S13	35.04	17.49	0.09	0.109	0.384
S14	29.05	14.51	0.07	0.091	0.318
S15	40.5	20.28	0.1	0.127	0.445
S16	44.61	21.92	0.12	0.137	0.481
S17	40.16	20.15	0.11	0.126	0.442
S18	46.06	23.07	0.12	0.145	0.507
Ave ± SD	45.45 ± 0. 6	22.48 ± 0.4	0.12 ± 0.003	0.141 ±0.003	0.49 ±0.006
Max	66.86	32.63	0.18	0.205	0.717
Min	29.05	14.51	0.07	0.091	0.318
Global limit [30]	370	55	≤ 1	0.50	-

A correlation analysis for the relationship between the Natural Occurring Radioactive Materials (NORMs) in soil samples is presented in Table IV. This table provides the Pearson correlation coefficients (r) and p-values for each pair of radionuclides.

TABLE IV. CORRELATION MATRIX OF SPECIFIC ACTIVITIES OF ^{238}U, ^{232}TH, AND ^{40}K IN SOIL SAMPLES

Radionuclide pair	**Pearson correlation coefficient (r)**	**p-value**	**Interpretation**
^{238}U vs ^{232}Th	0.87	<0.05	Strong positive correlation
^{238}U vs ^{40}K	0.22	>0.05	Weak positive correlation
^{232}Th vs ^{40}K	-0.12	>0.05	No significant correlation

A strong positive correlation between ^{238}U and ^{232}Th reveals that these two radionuclides may exhibit similar environmental behavior in the region. This could imply that the factors influencing the distribution of one radionuclide may also affect the other [31]. On the other hand, the weak positive correlation between ^{238}U and ^{40}K is statistically insignificant, indicating that the concentrations of these two radionuclides are not strongly related in the soil samples. Similarly, the negative correlation between ^{232}Th and ^{40}K demonstrates no significant relationship, meaning that different environmental or geological processes may control the distribution of these two elements. Overall, while there are certain correlations between some radionuclides, many of them are weak or statistically insignificant, highlighting the complexity of factors influencing NORM concentrations in the region.

V. CONCLUSION

This study examined the radiation levels in sediment samples taken from different areas of Babylon Governorate, Iraq, focusing on three natural radionuclides: uranium ^{238}U, thorium ^{232}Th, and potassium ^{40}K. The activity concentration of eighteen samples was calculated using a NaI(Tl) gamma-ray spectrometer and compared with global safety standards to evaluate their environmental and health effect. The results showed average activity concentrations of 46.55 ± 0.68 Bq/kg for ^{238}U, 14.6 ± 0.73 Bq/kg for ^{232}Th, and 293.16 ± 3.83 Bq/kg for ^{40}K. All radiation levels were within the acceptable levels, meaning that all areas do not pose any hazard. Additionally, other radiological factors were measured to further assess their impact, including the external hazard index (H_{ex}), Annual Effective Dose Equivalent (AEDE), and Excess Lifetime Cancer Risk (ELCR), with all their average values being within the accepted limits.

Recommendations for future research will include expanding the sample size and incorporating a broader range of environmental and anthropogenic factors. A more detailed investigation of local geology and hydrology, as well as the potential impact of human activities on radiation levels, will provide a more precise understanding of the radiation dynamics. Additionally, long-term studies are proposed to monitor temporal variations in radiation levels and assess their potential health impacts on local communities. Finally, the development of geospatial models for radiation risk assessment would be valuable to predict future trends and to inform targeted environmental management strategies.

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