Mapping of Natural Radioactivity in Soil Samples of Kufa Districts, Iraq Using GIS Technique

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Research Article

Keywords: Natural radioactivity, gamma ray, soil, GIS, and Kufa districts.

Posted Date: September 14th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-862397/v1>

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Mapping of Natural Radioactivity in Soil Samples of Kufa Districts, Iraq Using GIS Technique

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Abstract

The aim from this work is to detect and draw the natural radioactivity of (uranium-238, thorium-232 and potassium-40) levels in soil samples that taken from Kufa districts, Najaf governorate, Iraq. The detection system used in study is NaI (TI) with "3x3" dimension, while maps were drawn by geographic information system (GIS). Some radiological parameters were calculated depending on measuring of specific activity for ^{238}U , ^{232}Th , and ^{40}K . The results of the average value with standard error in all samples of the present study for ^{238}U , ^{232}Th , ^{40}K , and ^{235}U were 6.2 ± 0.74 , 6.41 ± 0.82 , 278.10 ± 19.43 , and 0.28 ± 0.03 Bq/kg, respectively. The specific activity of Uranium-238, Thourium-232, poasium-40 and Uranium-235 found in all soil samples were within the safety limit reported by UNSCEAR, except three samples have poasium-40 higher than safety limit. Also, the results of radiological parameters were all found to be below OECD, UNSCEAR safety limit. Generally, the average of specific activity in soil collected arranged of potassium-40 > thorium-232 > uranium-238. Mapping GIS for natural radioactivity and some radiological parameters were successfully draw for the study area. Finally, natural radioactivity and radiological parameters for soil samples at Kufa districts were safety.

Keyword: Natural radioactivity, gamma ray, soil, GIS, and Kufa districts.

1. Introduction

Today the most important and serious problems that face humanity and other living kinds is environmental pollution. Radioactive materials and radiation pose a major threat to the lives of humans and organisms in general [1]. Radionuclides found in nature are usually categorized into

two distinct forms cosmogenic and terrestrial origin arising from the earth crusts and earth born materials [2]. Among the natural radionuclides, uranium, thorium and their progenies are ubiquitous; mostly contribute to the human radiation exposure. In this study, the focus on gamma-ray that emitting daughter nuclei in the decay series of ^{238}U , ^{232}Th , and ^{40}K [3]. The decay series of ^{238}U and ^{232}Th are characterized more or less by the initial part ruled by alpha decay and a part ruled by gamma-ray emission. This contributes to the difficulty in the radioactive measurements. During a series of radioactive decays, the original radioactive (parent) nucleus decays to another radioactive (daughter) nucleus until the end of the series, where a stable nucleus is formed (^{206}Pb in the case of ^{238}U series and ^{208}Pb for ^{232}Th)[4]. Isotopes which include radionuclides such as ^{238}U , ^{232}Th , and ^{235}U as well as ^{40}K are found in all mutual types of rock and soil. Furthermore, these radionuclides disintegrate into other nuclides that are also radioactive, thus forming a decay chain. Natural and anthropogenic radionuclides in the environment may enter the human body through inhalation and ingestion, therefore; vital to study these radionuclides in each environmental compartment (atmosphere, hydrosphere, lithosphere and biosphere) worldwide and to evaluate the risk hazards on human health among the many investigations concerning naturally occurring isotopes [5]. Because people are exposed to natural radiation with varying amounts depending on natural radioactive minerals prevalent in each location throughout the world, natural environmental radioactivity and radiation in soil have piqued researchers' attention. The principal source of radiation contamination is direct drops from the atmosphere on plants. Finished products of fission are strong maintained and absorbed and by particles of soil, similar to nature radio-actives, which were widely dispersed at various depths of soil. As a result, understanding the distribution of radionuclides in soils is critical for reducing health hazards to the impacted population. A number of studies have determined natural radioactivity in soil and maps using GIS [7-10]. In order to obtain baseline data from nature radiation levels, determine nature radiation at environmental isotopes haven carry out in several nations. As a result, the goal of this study is drawing a map using GIS for the specific

activity of natural radionuclides ^{238}U , ^{232}Th , and ^{40}K in soil samples collected from 40 locations at Kufa districts, Najaf Governorate, Iraq .Which measured by sodium iodide with thallium tainted.

2. Area of Study

Kufa district is located about (8.99) km eastern of AL-Najaf province, it positioned geographically (44020'0"- 44037'30"E and 31058'30"- 32012'30" N) [11] (see Figure 1). The province of AL-Najaf is situated in the south-western region of Iraq, occupying an area of (28537) km^2 , the sub-districts under the district of Kufa are the sub-district of Al-Abbassiya and the sub-district of Al-Huriya. We are studying forty locations that located in Kufa city to measure natural radioactivity and mapping it.

Figure 1. The study area

63

64 **3. Materials and methods**65 **3.1. Collection Samples**

66 40 samples of soil were chosen from Kufa district region, the study area were divided
 67 administratively for the purpose of collecting samples, which collected randomly from various
 68 locations in districts of province. The samples were taken with a depth of 15cm, and determined the
 69 coordinates of the readings as well as drawn using Global Positioning System (GPS) and GIS
 70 (ArcGIS 10.7.1.) as shown in Table 1 and Figure1.

71 **Table 1. Names and locations with Coordinates of Soil samples of present study**

No.	Name of Samples	Sample code	Coordinates	
1	Maysan 1	K1	44°21'21.5"E	32°03'59.5"N
2	Maysan 2	K2	44°21'33.1"E	32°03'30.5"N
3	Maysan 3	K3	44°21'50.4"E	32°02'51.7"N
4	Alwat Alfahal 1	K4	44°21'47.7"E	32°04'13.8"N
5	Alwat Alfahal 2	K5	44°22'06.1"E	32°03'37.2"N
6	Alwat Alfahal 3	K6	44°22'34.3"E	32°03'06.6"N
7	Alzarga 1	K7	44°22'38.1"E	32°03'39.6"N
8	Alzarga 2	K8	44°22'39.7"E	32°03'34.6"N
9	Alzarga 3	K9	44°23'10.0"E	32°03'20.0"N
10	Middle Euphrates Center	K10	44°21'46.0"E	32°02'28.2"N
11	Kufa University 1	K11	44°22'13.7"E	32°01'49.7"N
12	Kufa University 2	K12	44°22'30.3"E	32°01'12.1"N
13	Alsahla	K13	44°22'44.8"E	32°02'22.6"N
14	Palm Street area	K14	44°23'11.4"E	32°02'53.1"N
15	Alaskari	K15	44°22'51.3"E	32°02'07.0"N

16	Alsehilia 1	K16	44°23'31.9"E	32°02'17.0"N
17	Alsehilia 2	K17	44°23'51.1"E	32°02'29.1"N
18	Almutanabi	K18	44°23'02.2"E	32°01'54.4"N
19	Aljamea	K19	44°23'45.8"E	32°02'00.1"N
20	Aljomhoria	K20	44°24'22.6"E	32°01'56.2"N
21	Aljdidaat	K21	44°24'33.2"E	32°02'01.1"N
22	Alshorta	K22	44°23'00.7"E	32°01'30.3"N
23	Kenda 1	K23	44°23'24.2"E	32°01'33.5"N
24	Almolimeen	K24	44°23'29.9"E	32°01'42.8"N
25	Alwakaf	K25	44°24'13.2"E	32°01'50.1"N
26	Alrashadiya	K26	44°24'37.8"E	32°01'50.7"N
27	Industrial District 1	K27	44°22'34.9"E	32°00'56.3"N
28	Industrial District 2	K28	44°22'40.1"E	32°00'32.6"N
29	Almatar	K29	44°22'51.3"E	32°00'24.7"N
30	Tamoz	K30	44°23'04.7"E	32°01'14.3"N
31	Kenda 2	K31	44°23'15.0"E	32°01'07.9"N
32	Maytham Altamaar 1	K32	44°23'23.6"E	32°00'57.3"N
33	Maytham Altamaar 2	K33	44°23'42.9"E	32°01'10.4"N
34	Alsafeer	K34	44°24'11.8"E	32°01'23.4"N
35	Alkareeat	K35	44°24'39.0"E	32°01'48.3"N
36	Alforat 1	K36	44°24'12.1"E	32°01'16.5"N
37	Alforat 2	K37	44°24'30.6"E	32°01'02.6"N
38	Role of cement plant	K38	44°23'36.6"E	32°00'52.9"N
39	Alsadar –Third 1	K39	44°24'21.2"E	32°01'14.8"N
40	Alsadar –Third 2	K40	44°24'31.5"E	32°01'03.0"N

Figure 2. Location of samples in the present study.

3.2. Preparation of the Samples

After the collection of soil process was completed, the samples were transferred to the advance of nuclear laboratory at university of Kufa, Faculty of Science, department of Physics for measurements natural radioactivity. There are several the steps in the preparation of samples for the purpose of measurement such as dried, crushed, sieved, stored, and weighted. Grinding the soil sample using a mill after drying in an oven (100°C) for two hours. Sieve the samples by a 200 sieve (0.063mm). Weight 1kg of the dried samples and put in bags was Marinelli beaker kept for 30 days to obtain radiation of secular equilibrium [12].

85 3.3. Gamma-ray Spectroscopy Detection System

86 In the present study, the detection system radioisotopes (^{238}U , ^{232}Th , and ^{40}K) was NaI(Tl)
87 system with a 3"x3" crystal dimension, that made by ORTEC Company (made in USA). These
88 system content many components such as preamplifier, main amplifier, and multi-channel Analyzer
89 (MCA). Also, Maestro-32 software to setting the gain, high voltage, and MCA as well as to
90 determine area under photopeak of gamma spectrum recorded were setup with a PC. The
91 calibration and efficiency for NaI (TI) detector was determined using five stander sources of
92 radionuclides which is ^{60}Co , ^{137}Cs , ^{22}Na , ^{54}Mn , and ^{152}Eu . Also, resolution of NaI (TI) detector for
93 ^{137}Cs were measured which was equal 7.9%. Gamma energies 1764 keV in ^{214}Bi and 2614 keV
94 ^{208}Tl which are in secular equilibrium with ^{238}U and ^{232}Th , respectively, and directly gamma-line
95 of 1460 keV with ^{40}K were used to measure specific activity in all radionuclides in the present
96 study [8, 10].

97 3.4. Theoretical calculations

98 The specific activities of ^{238}U , ^{232}Th , and ^{40}K (A_U , A_{Th} and A_K) radionuclides were
99 calculated using following equation [13]:

$$100 \quad A \left(\frac{\text{Bq}}{\text{kg}} \right) = \frac{N}{I_\gamma \epsilon M T} \quad (1)$$

101 where, N is net area under photo peak, I_γ is the probability of gamma decay, ϵ is the efficiency of
102 detector, M is the mass of sample, and T is time measured. But, to calculate specific activity of ^{235}U
103 by [14]:

$$104 \quad A_{235\text{U}} = \frac{A_U}{21.7} \quad (2)$$

105 The external hazard index (H_{ex}) was calculated using the following equation [15]:

$$106 \quad H_{\text{ex}} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

107 The internal hazard index (H_{in}) was calculated using the following equation [16]:

108
$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

109 Representative level index (I_γ) was calculated using the following equation [17].

110
$$I_\gamma = \left(\frac{1}{150}\right) A_U + \left(\frac{1}{100}\right) A_{Th} + \left(\frac{1}{1500}\right) A_K \quad (5)$$

111 Alpha index (I_α) was calculated using the following equation [15]:

112
$$I_\alpha = \frac{A_U}{200 \left(\frac{Bq}{kg}\right)} \quad (6)$$

113 Radium equivalent activity (Ra_{eq}) was calculated using the following equation [18]:

114
$$Ra_{eq} \left(\frac{Bq}{kg}\right) = A_U + 1.43 A_{Th} + 0.077 A_K \quad (7)$$

115 The exposure rate ($\dot{X}$) was calculated as the following equation [16, 19] :

116
$$\dot{X} \left(\frac{\mu R}{h}\right) = 1.90 A_U + 2.82 A_{Th} + 0.197 A_K \quad (8)$$

117 The absorbed dose rate (D_r) in air 1 meter was calculated using the following equation [20]:

118
$$D_r \left(\frac{nGy}{h}\right) = 0.462 A_U + 0.604 A_{Th} + 0.0417 A_K \quad (9)$$

119 Annual gonadal equivalent dose (AGED) was calculated using the following equation [21- 23] as:

120
$$AGED \left(\frac{mSv}{y}\right) = 3.09 A_U + 4.18 A_{Th} + 0.314 A_K \quad (10)$$

121 Annual effective dose equivalent (AEDE) indoor was calculated using the following equation [24].

$$122 \quad \text{AEDE}_{\text{indoor}} \left(\frac{\text{mSv}}{\text{y}} \right) = [\text{D}_r(\text{mGy/hr}) \times 8760 \text{ hr} \times 0.8 \times 0.7 \text{ Sv/Gy}] \times 10^{-6} \quad (11)$$

123 Excess lifetime cancer risk (ELCR) indoor according to Duration of Life (DL =70 year) and Risk
 124 Factor (RF=0.05 y/Sv) was calculated using the following equation [13,18]:

$$125 \quad \text{ELCR} = \text{AEDE} \times \text{DL} \times \text{RF} \quad (12)$$

126 4. Results and Discussions

127 The results of specific activity of natural radionuclides (^{238}U , ^{232}Th and ^{40}K as well as ^{235}U)
 128 in soil for Kufa districts were shown in Table 2. While, Table 3 and Table 4 show the results of
 129 radiological parameters (Ra_{eq} , H_{ex} , H_{in} , I_{γ} , and I_{α}) and (Exposure, D_r , AGED, $\text{AEDE}_{\text{outdoor}}$, and
 130 ELCR), respectively. The specific activity of uranium-238 in the studied area were ranged from
 131 0.4 ± 0.1 Bq/kg to 17.9 ± 0.9 Bq/kg, with an average value 6.2 ± 0.74 , from 0.2 ± 0.1 Bq/kg to 24.1 ± 0.6
 132 Bq/kg with an average 6.41 ± 0.82 Bq/kg for thorium-232, from 103.5 ± 2.0 Bq/kg to 708.0 ± 5.9
 133 Bq/kg with an average value of 278.10 ± 19.43 Bq/kg for potassium-40, while the specific activity of
 134 uranium-235 were ranged from 0.018 ± 0.01 Bq/kg to 0.825 ± 0.08 Bq/kg with an average value of
 135 0.28 ± 0.03 Bq/kg. The highest value of the specific activity of ^{238}U , ^{232}Th , and ^{235}U was seen in the
 136 K19 sample (Aljamea district), while ^{40}K was in K17 sample (Alsehilia 2 district). The lowest value
 137 of the specific activity of ^{238}U , ^{232}Th , ^{40}K , and ^{235}U was found in samples K10, K26, K31, and K10,
 138 respectively. Figures 2, 3, and 4 obtain histograms of the specific activities for the frequency
 139 distribution of uranium-238, thorium-232, and potassium-40, respectively. Histograms were divided
 140 into nine parts in terms of specific activity values. From figure 2, the maximum value of specific
 141 activity for uranium-238 in second groups, while for thorium-232 the high value was in first group
 142 as shown in figure 3, and from figure 4, five group was high value of specific activity for potassium-
 143 40. Figure 5, showing the distribution comparing of radioactive isotopes of uranium-238, thorium-
 144 232, and potassium-40 in the soil of the present study which appeared varied in the quantity of these
 145 radionuclides. Also, it is found that Potassium-40 predominant on uranium-238 and thorium-232,

146 but the average quantity of thorium-232 is almost larger than the quantity of uranium-238 in the
147 study area. The difference between concentrations ^{238}U and ^{232}Th indicates the minimum
148 contribution of monazite minerals in the samples. The values are almost less than unity because
149 ^{232}Th activities are usually greater than ^{238}U activities in the crust, which is the origin of the soil.
150 These variations may be because uranium and thorium decay series come from different origins and
151 exist together in nature, whereas potassium is from a different origin [10, 25]. While, the highest
152 distribution of potassium-40 may be because of the increase in the concentration of potassium
153 nuclide in some areas, the reason is due to the existence of agricultural land and areas containing
154 phosphate fertilizers, in which the focus increasingly potassium (^{40}K). The average values of
155 the specific activity of ^{238}U , ^{232}Th , and ^{40}K according to recommendations by UNSCEAR 2008
156 were 33 Bq/kg, 45 Bq/kg, and 420 Bq/kg respectively [20]. Therefore, the specific activity of ^{238}U
157 and ^{232}Th that shown in table 2 in all location sites were within UNSCEAR 2008, while samples
158 K15, K16, and K17 have the specific activity of ^{40}K larger than the world average activity that was
159 recommended by UNSCEAR 2008. Distribution a map (color contour map) of the specific activities
160 in unit of Bq/kg for radioisotopes ^{238}U , ^{232}Th , ^{40}K , and ^{235}U in all soil samples of the present study
161 was shown in Figures 6, 7, 8, and 9, respectively which it is drawn by geographic information
162 system (GIS) technology.

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Table 2. The specific activity for natural radioactivity in soil for Kufa districts

No.	Sample code	Specific Activity (Bq/kg)							
		^{238}U		^{232}Th		^{40}K		^{235}U	
		Average	$\pm$ S.E	Average	$\pm$ S.E	Average	$\pm$ S.E	Average	$\pm$ S.E
1	k1	5.3	0.5	1.3	0.1	109.9	2.2	0.244	0.04
2	k2	4.9	0.5	1.2	0.1	142.4	2.5	0.226	0.04
3	k3	2.3	0.3	0.7	0.1	145.4	2.5	0.106	0.03
4	k4	2.9	0.3	2.2	0.2	176.4	2.7	0.134	0.03
5	k5	2.8	0.3	1.4	0.2	150.0	2.6	0.129	0.03
6	k6	5.4	0.5	6.2	0.3	130.7	2.5	0.249	0.04
7	k7	1	0.2	6.9	0.4	303.0	4.0	0.046	0.02
8	k8	1.1	0.2	1.5	0.1	184.3	2.7	0.051	0.02
9	k9	9.1	0.6	1	0.1	226.5	3.3	0.419	0.06
10	k10	0.4	0.1	2.2	0.2	210.1	3.0	0.018	0.01
11	k11	0.9	0.2	3.1	0.2	167.2	2.8	0.041	0.02
12	k12	6.9	0.5	15.3	0.5	336.8	4.0	0.318	0.05
13	k13	6.6	0.6	6.7	0.3	339.3	4.1	0.304	0.05
14	k14	3.3	0.3	1.6	0.1	109.0	2.1	0.152	0.03
15	k15	4.5	0.5	13.6	0.5	443.3	4.7	0.207	0.04
16	k16	2.1	0.3	6.4	0.3	537.0	5.1	0.097	0.03
17	k17	7.6	0.6	13.2	0.5	708.0	5.9	0.350	0.05
18	k18	14.1	0.8	12.5	0.4	113.8	2.3	0.650	0.07
19	k19	17.9	0.9	24.1	0.6	389.8	4.4	0.825	0.08
20	k20	11.4	0.7	9.1	0.4	303.1	3.7	0.525	0.06
21	k21	1.2	0.2	1.4	0.1	229.3	3.1	0.055	0.02

22	k22	13.1	0.8	8.5	0.4	316.7	3.9	0.604	0.07
23	k23	8.4	0.6	10	0.4	317.9	3.8	0.387	0.05
24	k24	10.2	0.7	11.3	0.4	307.8	3.8	0.470	0.06
25	k25	5.8	0.5	15.4	0.5	396.5	4.5	0.267	0.05
26	k26	0.91	0.2	0.2	0.1	181.6	2.9	0.041	0.02
27	k27	14.2	0.8	8.5	0.4	279.0	3.6	0.654	0.07
28	k28	2.4	0.3	6.6	0.3	395.3	3.9	0.111	0.03
29	k29	14.1	0.8	9.1	0.4	320.6	3.9	0.650	0.07
30	k30	8.4	0.6	2.9	0.2	333.1	4.0	0.387	0.05
31	k31	1.7	0.2	1.5	0.1	103.5	2.0	0.078	0.02
32	k32	13.2	0.7	6.8	0.3	300.8	3.7	0.608	0.07
33	k33	3.5	0.4	8.4	0.4	292.2	3.7	0.161	0.04
34	k34	1.4	0.2	8.1	0.4	425.9	4.6	0.065	0.02
35	k35	3.2	0.4	5.7	0.3	283.9	3.7	0.147	0.03
36	k36	2.4	0.3	5.8	0.3	312.5	3.3	0.111	0.03
37	k37	6.4	0.5	2.2	0.2	241.1	3.0	0.295	0.05
38	k38	6.5	0.6	3.9	0.3	299.3	3.9	0.300	0.05
38	k39	5	0.5	0.6	0.1	238.8	3.4	0.230	0.04
40	k40	15.5	0.9	9.6	0.4	322.3	4.2	0.714	0.07
Average±S.D		6.2±0.74		6.41±0.82		278.10±19.43		0.28±0.03	

Uranium-238

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Figure 2. Histograms of specific activities for ^{238}U in soil of present study.

Thourium-232

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Figure 3. Histograms of specific activities for ^{232}Th in soil of present study.

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Figure 4. Histograms of specific activities for ^{40}K in soil of present study.

Figure 5. Compression of specific activities for natural radionuclide of present study.

Figure 6. Distribution of ^{238}U in soil of study area.

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Figure 7. Distribution of ^{232}Th in soil of study area.

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Figure 8. Distribution of ^{40}K in soil of study area.

Figure 9. Distribution of ^{235}U in soil of study area.

The results of R_{aeq} were ranged from 11.8 Bq/kg to 82.4 Bq/kg, with an average value of 36.79 ± 2.78 Bq/kg, also it is found the minimum and the maximum values of H_{ex} , H_{in} , I_{γ} , and I_{α} in the same sample K31 and K19, as shown in Table 3. The values of H_{ex} and H_{in} were ranged from 0.032 to 0.222, with an average of 0.099 ± 0.007 , and from 0.036 to 0.271, with an average of 0.116 ± 0.008 , respectively. While the results of other parameters such as I_{γ} , and I_{α} were ranged from 0.095 to 0.655, with an average of 0.290 ± 0.021 , and from 0.009 to 0.090, with an average of 0.031 ± 0.003 , respectively. The minimum value of all radiological parameters that shown in Table 3 was in samples K31 (Kenda 2), while, the maximum was found in samples K19 (Aljamea), except value of I_{γ} the maximum was in samples K17 (Alsehilia 2). From the results of radiological parameters (R_{aeq} , H_{ex} , H_{in} , I_{γ} , and I_{α}) in Table 2 for all soil samples under study were less than 370 Bq/kg for R_{aeq} [26] and less than unity for the values of H_{ex} , H_{in} , I_{γ} , and I_{α} [27]. The distribution of a

map (color contour map) of R_{eq} and H_{ex} due to radioisotopes ^{238}U , ^{232}Th , and ^{40}K in all soil samples of the present study was shown in Figures 10, and 11, respectively which is drawn by geographic information system (GIS) technology.

Table 3. The radiological parameters (R_{eq} , H_{ex} , H_{in} , I_γ , and I_a) for nature radioactivity in soil for Kufa districts

No.	Sample code	R_{eq} (Bq/kg)	H_{ex}	H_{in}	I_γ	I_a
1	k1	15.6	0.042	0.057	0.122	0.027
2	k2	17.6	0.047	0.061	0.140	0.025
3	k3	14.5	0.039	0.045	0.119	0.012
4	k4	19.6	0.053	0.061	0.159	0.015
5	k5	16.4	0.044	0.052	0.133	0.014
6	k6	24.3	0.066	0.080	0.185	0.027
7	k7	34.2	0.092	0.095	0.278	0.005
8	k8	17.4	0.047	0.050	0.145	0.006
9	k9	28.0	0.076	0.100	0.222	0.046
10	k10	19.7	0.053	0.054	0.165	0.002
11	k11	18.2	0.049	0.052	0.148	0.005
12	k12	54.7	0.148	0.166	0.424	0.035
13	k13	42.3	0.114	0.132	0.337	0.033
14	k14	14.0	0.038	0.047	0.111	0.017
15	k15	58.1	0.157	0.169	0.462	0.023
16	k16	52.6	0.142	0.148	0.436	0.011
17	k17	81.0	0.219	0.239	0.655	0.038
18	k18	40.7	0.110	0.148	0.295	0.071
19	k19	82.4	0.222	0.271	0.620	0.090

20	k20	47.8	0.129	0.160	0.369	0.057
21	k21	20.9	0.056	0.060	0.175	0.006
22	k22	49.6	0.134	0.169	0.383	0.066
23	k23	47.2	0.127	0.150	0.368	0.042
24	k24	50.1	0.135	0.163	0.386	0.051
25	k25	58.4	0.158	0.173	0.457	0.029
26	k26	15.2	0.041	0.043	0.129	0.005
27	k27	47.8	0.129	0.168	0.366	0.071
28	k28	42.3	0.114	0.121	0.346	0.012
29	k29	51.8	0.140	0.178	0.399	0.071
30	k30	38.2	0.103	0.126	0.307	0.042
31	k31	11.8	0.032	0.036	0.095	0.009
32	k32	46.1	0.124	0.160	0.357	0.066
33	k33	38.0	0.103	0.112	0.302	0.018
34	k34	45.8	0.124	0.127	0.374	0.007
35	k35	33.2	0.090	0.098	0.268	0.016
36	k36	34.8	0.094	0.100	0.282	0.012
37	k37	28.1	0.076	0.093	0.225	0.032
38	k38	35.1	0.095	0.112	0.282	0.033
38	k39	24.2	0.065	0.079	0.199	0.025
40	k40	54.0	0.146	0.188	0.414	0.078
Average ± S.E.		36.79±2.78	0.099±0.007	0.116±0.008	0.290±0.021	0.031±0.003

Figure 10. Distribution of R_{aeq} in soil of study area.

Figure 11. Distribution of H_{ex} in soil of study area.

The results of another radiological parameters that shown in Table 4, Exposure was ranged from 27.8 $\mu R/h$ to 191.1 $\mu R/h$, with an average value of $84.66 \pm 6.21 \mu R/h$, the values of D_r were ranged from 6.0 nGy/h to 41.0 nGy/h, with an average value of 18.33 ± 1.34 nGy/h. While the results of AGED, $AEDE_{outdoor}$, and $ELCR \times 10^{-3}$ were 44.0-301.0 mSv/y with an average value of 133.301 ± 9.70 , 0.007-0.050 mSv/y with an average value of 0.022 ± 0.001 mSv/y, and 0.026-0.176 with an average value of 0.078 ± 0.005 , respectively. The minimum value of all radiological parameters that shown in Table 4 (Exposure, D_r , AGED, $AEDE_{outdoor}$, and ELCR) was in samples K31 (Kenda 2), while, the maximum was found in samples K17 (Alsehilia 2). The results of D_r in-unit nGy/h in Table 3 for all of the soil samples studied were less than the world average value that equal 55 nGy/h [28]. Also, it noted that the results of AGED in-unit mSv/y were lower than the global average value that equal 55 [28, 29], except sample K17, which was higher than the limit permissible. $AEDE_{outdoor}$ in all soil samples in the present study was less than the world average of 0.07 mSv/y [29]. The results of ELCR in all location samples were lower when compared with the world average permissible limit of 0.29×10^{-3} [28], which was shown in the map of Figure 12, as shown in the map in bold color, the highest value was in the area of sample K17 and K19 in the map of dark color.

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Table 4. The radiological parameters (Exposure, Dr, AGED, AEDE_{outdoor}, and ELCR) for

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nature radioactivity in soil for Kufa districts

No.	Sample code	Exposure ($\mu\text{R/h}$)	Dr (nGy/h)	AGED (mSv/y)	AEDE_{outdoor} (mSv/y)	ELCR$\times 10^{-3}$
1	k1	35.4	7.8	56.3	0.010	0.034
2	k2	40.7	8.9	64.9	0.011	0.038
3	k3	35.0	7.5	55.7	0.009	0.032
4	k4	46.5	10.0	73.5	0.012	0.043
5	k5	38.8	8.4	61.6	0.010	0.036
6	k6	53.5	11.7	83.6	0.014	0.050
7	k7	81.0	17.3	127.1	0.021	0.074
8	k8	42.6	9.1	67.5	0.011	0.039
9	k9	64.7	14.3	103.4	0.017	0.061
10	k10	48.4	10.3	76.4	0.013	0.044
11	k11	43.4	9.3	68.2	0.011	0.040
12	k12	122.6	26.5	191.0	0.032	0.114
13	k13	98.3	21.2	154.9	0.026	0.091
14	k14	32.3	7.0	51.1	0.009	0.030
15	k15	134.2	28.8	209.9	0.035	0.124
16	k16	127.8	27.2	201.9	0.033	0.117
17	k17	191.1	41.0	301.0	0.050	0.176
18	k18	84.5	18.8	131.6	0.023	0.081
19	k19	178.8	39.1	278.4	0.048	0.168
20	k20	107.0	23.4	168.4	0.029	0.100
21	k21	51.4	11.0	81.6	0.013	0.047

22	k22	111.2	24.4	175.5	0.030	0.105
23	k23	106.8	23.2	167.6	0.028	0.099
24	k24	111.9	24.4	175.4	0.030	0.105
25	k25	132.6	28.5	206.8	0.035	0.122
26	k26	38.0	8.1	60.6	0.010	0.035
27	k27	105.9	23.3	167.0	0.029	0.100
28	k28	101.0	21.6	159.1	0.026	0.093
29	k29	115.6	25.4	182.3	0.031	0.109
30	k30	89.8	19.5	142.7	0.024	0.084
31	k31	27.8	6.0	44.0	0.007	0.026
32	k32	103.5	22.7	163.7	0.028	0.098
33	k33	87.9	18.9	137.7	0.023	0.081
34	k34	109.4	23.3	171.9	0.029	0.100
35	k35	78.1	16.8	122.9	0.021	0.072
36	k36	82.5	17.6	129.8	0.022	0.076
37	k37	65.9	14.3	104.7	0.018	0.062
38	k38	82.3	17.8	130.4	0.022	0.077
38	k39	58.2	12.6	92.9	0.015	0.054
40	k40	120.0	26.4	189.2	0.032	0.113
Average $\pm$ S.E.		84.66 $\pm$ 6.21	18.33 $\pm$ 1.34	133.301 $\pm$ 9.70	0.022 $\pm$ 0.001	0.078 $\pm$ 0.005

Figure 12. Distribution of ELCR in soil of study area.

The results of the specific activity natural radioactivity (^{238}U , ^{232}Th , and ^{40}K) in soil samples of the present study are compared with the previous studies as presented in Table 5. From Table 5, it is found that the specific activity of natural radionuclides for ^{238}U was less than all previous studies, but for ^{232}Th are lower than Iraq (Baghdad) and Saudi Arabia, and very close form the recorded value in Iraq (Dhi Qar) and Iran, while for ^{40}K are less than all previous studied, except in Iran.

Table 5. Comparison of the average of the specific activity of ^{238}U , ^{232}Th , ^{40}K in this study with previous studies.

No.	Country	The average of the specific activity Bq/kg			References
		^{238}U	^{232}Th	^{40}K	
1	Iraq (Dhi Qar)	10.85	5.81	354.11	[8]

2	Iraq (Baghdad)	16.5	9.7	368	[10]
3	Iran	8	5	250	[20]
5	Saudi Arabia	14.22	14	968.19	[30]
6	Present study	6.2	6.41	278.10	-----

247

248 **Conclusions**

249 The results of the terrestrial gamma radiation (^{238}U , ^{232}Th , ^{40}K , and ^{235}U) as well as
250 radiological parameters (R_{eq} , H_{ex} , H_{in} , I_{γ} , and I_{α} , Exposure, D_r , $\text{AEDE}_{\text{outdoor}}$, and ELCR) in soil
251 samples of Kufa districts were within the world average values according to UNSCEAR 2008,
252 UNSCEAR 2000, OECD, ICRP1993, and another previous studies. Therefore, it may be concluded
253 that the studied area was safe for the population based on natural radioactivity. Also, it is found that
254 the results of specific activity for potassium-40 > thourium-232 > uranium-238 > uranium-235,
255 because of the most area in the present study was clay minerals and agricultural. The geographic
256 information system (GIS) was a good technique suitable for drawing of natural radioactivity with
257 some radiological parameters in soil samples under study area.

258

259 **Data availability statement**

260 The datasets generated during and/or analysed during the current study are available from the
261 corresponding author on reasonable request.

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