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Calculating the risks of the effective annual dose resulting from selected soil samples from the city of Kufa – Iraq

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Abstract:
Research has been done on the naturally occurring radioactivity of the earth formations in the soil of the Kufa city, in the governorate of Al-Najaf Al-Ashraf. Currently, it consists of the historic city's core, the northern and southern portions, to calculate the level of radioactivity present and the degree to which it affects the local population these areas using gamma-ray spectroscopy NaI(Tl) (3"×3"), spectral measurements were obtained by choosing 30 sites for soil samples from the area. The specific activity of ^{232}Th, ^{40}K, and ^{238}U in the investigated ranges between (28.402±1.015) Bq/kg in old city to (5.076±0.368) Bq/kg in south part with average (10.634) Bq/kg to (9.391) Bq/kg , (27.431±0.982) Bq/kg in north part to (5.019±0.415) Bq/kg in south part with average (18.785) Bq/kg to (18.078) Bq/kg, (380.580±3.725) Bq/kg in south part to (103.455±1.982) Bq/kg in old city with average (332.235) Bq/kg to (245.153) Bq/kg. As for the value of the annual effective dose (total) it was it was between (0.214) mSv/y in south part part to (0.100) mSv/y in old city with average (0.214) mSv/y g to(0.100) mSv/y, The radiation levels of the investigated samples were found to be within allowable limits when the current results were compared with the values that are taken into consideration internationally.

Keywords: Nal(TI), Soil, Natural radioactivity, Kufa city-Iraq.

Introduction:

The amount of radioactive activity in soil is one of the primary variables influencing natural background radiation. There are about sixty radionuclides in nature, which can be divided into three main groups: those from space, those made by humans, and both. It is possible to create radionuclides naturally or artificially**.** Radioactive elements are classified as heavy. Any element with an atomic number higher than eight includes radioactive isotopes and is prone to disintegration. The stable form of these radioactive isotopes is indissoluble[1, 2]. Radioactive isotopes are harmful to living things and the environment even though they have considerably assisted humanity in the fields of agriculture, industry, medicine, and soil studies[3]. radioactivity or via radionuclide discharge into the earth, which can affect people and the surrounding biota. For a number of reasons, including the location of nuclear power plants and the development of backup plans to monitor any occurrences of radiation exposure from natural sources, the average quantity of radiation exposure from natural sources is measured in many countries [4,5]. Radioactive emissions into the environment or naturally occurring radioactivity could lead to Because they cause contamination, the excessive concentration of radioactive materials in the environment is dangerous to life, especially for people [6].

Study Area:
One of the holiest historical cities is thought to be Kufa. The year it was founded was 638 AD. Its area is roughly measured as (49,689 km2). The Kufa district's geographic coordinates are (44º20'0"–44º37'30" E and 31º58'30"–32º12'30" N), placing it approximately 8.99 km east of AL-Najaf. [7] One of the cities in the southwest of Iraq, Kufa is located in the eastern portion of the Najaf Governorate and is situated on the western bank of the Kufa River, a significant branch of the Euphrates River and the most valuable water supply in the area. Considering that it serves as a major metropolitan center for the Governorate of Najaf. The following are the separations from its borders: Al-Kifl (Babylon Governorate) is located 20 km to the north, Najaf City's heart is located 5 km to the east, and Al-Manathrah district is located 12 km to the south It is 160 kilometers away from Baghdad. The city of Kufa experiences hot, dry desert weather[8].

Samples Collection and Preparation:
Thirty soil samples were collected from Kufa City between August 15, 2023, and August 30, 2023, in order to carry out this investigation. The GPS device was utilized to record the coordinates of each sample location, which were spaced one kilometer apart throughout the study region. The purpose of gathering the samples was to ascertain the amount of radioactivity that occurs naturally. The samples have been relocated to the physics department research lab at Kufa University's College of Education for Girls. These materials were crushed, dried until a stable weight was reached, and then sieved to a 0.5 mm size in order to obtain homogenous samples. The samples weighed between 600 and 750 grams. The density of the soil will vary due to the various types of soil, some of which are clayey and some of which are sandy. The data from each soil sample was then recorded before being packed into plastic bags. The samples are additionally packed in special measurement containers (Marinelli beakers), which are then tightly sealed with adhesive tape in order to achieve a state of radioactive equilibrium between uranium-238 and thorium-232 and their radioactive daughters. After that, the samples are kept for 30 days in these containers. Adopting a scintillation detector NaI (Tl) (3"x3") for gamma-ray spectroscopy, For 18000 seconds, the isotopes' natural radioactivity—^{238}U, ^{232}Th, and ^{40}k—is monitored. The company (Alpha Spectra, Inc.-12I12/3) installed a multi-channel (MCA) (ORTEC – Digi Base) with 4096 channels, 7.9% energy resolution, and 4.6 efficiency at energy (662) kev. It connects to an analog to digital convertor. This enables the analyst to transform a pulse in relation to the quantity of digital measurements, and the MAESTRO – 32 program is used to do nuclear analysis

Data Analysis and Mathematical Equations:
It is possible to calculate the concentration of any element in any radiation chain in terms of the concentration of another element as all elements in the two radiation chains are active when ^{238}U and ^{232}Th are balanced with their radioactive daughters. For instance, by calculating the activity concentration of bismuth nuclides 214Bi with energy of (1764.539 keV) and potassium radioactive nuclide ^{40}K with energy of (1460.822 keV), one can determine the concentration of 232Th using the energy-producing activity concentration of thallium ^{208}Tl radionuclides (2614.5 keV) and ^{238}U (1)[9].

$$A = \frac{N_{net}}{\varepsilon . I_{\gamma} . m . t} \pm \frac{\sqrt{N_{net}}}{\varepsilon . I_{\gamma} . m . t} [Bq . kg^{-1}] \quad \dots \quad \dots (1)$$

Where $N_{net:}$ is the optical peak's net area under its curve after the radioactive background has been subtracted from it.

ε: the photo peak's estimated efficiency at a specific energy

I_{γ}: The intensity of the gamma rays

m: the sample's mass (kg)

t: duration of measurement (sec)

A: number of radioactive hazard coefficients were computed based on the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K.

The outdoor, indoor and total absorbed dose rate AD $\left(\frac{nGy}{h}\right)$ in air at $1m$ above the ground surface to the population was calculated from the specific activity of the $S.A_U$, $S.A_{Th}$ and $S.A_K$ radionuclides. It is defined by equations (2-4) [10].

$$AD\left(\frac{nGy}{h}\right) Out = 0.463\, S.A_U + 0.604\, S.A_{Th} + 0.0417\, S.A_K \dots \dots (2)$$

$$AD\left(\frac{nGy}{h}\right) In = 0.92\, S.A_U + 1.14\, S.A_{Th} + 0.081\, S.A_K \dots \dots (3)$$

$$AD\left(\frac{nGy}{h}\right) Tot. = D\left(\frac{nGy}{h}\right) Out + D\left(\frac{nGy}{h}\right) In \dots \dots (4)$$

Then the outdoor, indoor and total annual effective dose equivalent(AEDE) to the population can be calculated using the conversion coefficient from absorbed dose in air to effective dose (0.7 Sv/Gy), the outdoor occupancy factor 0.2 and the indoor occupancy factor 0.8 [11] Therefore, the annual effective doses equivalent for outdoor, indoor and total are calculated by using the equations (5),(6) and (7)[12].

$$AEDE_{Out}\left(\frac{mSv}{y}\right) = AD \times 0.7 \times 0.2 \times 8760 \times 10^{-6} \dots (5)$$

$$AEDE_{In}\left(\frac{mSv}{y}\right) = AD \times 0.7 \times 0.8 \times 8760 \times 10^{-6} \dots (6)$$

$$AEDE_{Tot.} = AEDE_{Out} + AEDE_{In} \dots (7)$$

where AD$(nGy.h^{-1})$ is absorbed dose rate. This calculation takes into account that the people spend 20% of their time outdoors and 80 % of their time indoors. The corresponding worldwide values of AEDE $_{out}$ and AEDE$_{in}$ are 0.08 mSv and 0.42 mSv respectively[13].

The risk of Gamma Ray linked with radionuclides in the analyzed samples is computed using the excess lifetime cancer risk (ELCR). It provides the percentage of people who get cancer as a result of their yearly effective doses. This is how ELCR was determined [14].

$$ELCR = AEDE \times DL \times RF \dots (8)$$

Since DL is the estimated life expectancy of roughly 70 years, AEDE is the annual effective dose equivalent, and RF is the risk of fatal damage per Sievert, which is equal to 0.5 for the general public according to ICRP [15].Equations (9) through (11) are then used to compute the outdoor, inside, and total [16].

$$ELCR_{In} = AEDE_{In} \times DL \times RF \dots (9)$$

$$ELCR_{Out} = AEDE_{Out} \times DL \times RF \dots (10)$$

$$ELCR_{Tot.} = ELCR_{Out} + ELCR_{In} \dots (11)$$

Results and Discussion:

The specific activity of ^{238}U, ^{232}Th and ^{40}K radionuclides in thirty soil samples from the kufa city in Al-Najaf Al-Ashraf governorate have been measured. The city of Kufa is considered one of the sacred historical cities have been computed using equation (1) following the samples' preparation for gamma-ray spectroscopy measurement NaI (Tl) (3"x3") It is clear that the highest value of the specific activity of uranium ^{238}U was (28.402±1.015) Bq/kg in old city with average (10.634) in sample (1) as in Table (1) and figure(1), and the lowest value was (5.076±0.368) Bq/kg in south part with average (9.391) Bq/kg in sample (3) in Table (3) and figure(1) It was found that the highest value of the specific activity of thorium ^{232}Th was (27.431±0.982) Bq/kg in nourth part with average (18.785) Bq/kg in sample (2) in Table (2) and figure(1), and the lowest value was (5.019±0.415) Bq/kg in south part with average (18.078) Bq/kg in sample (9) in Table (3) and figure(1) The maximum value of specific activity for potassium ^{40}K was (380.580±3.725) Bq/kg in south part with average (332.235) Bq/kg in sample (9) in Table (3) and figure(1) , and the lowest value was (103.455±1.982) Bq/kg in old City with average (245.153) Bq/kg in sample (9) in Table (1) and figure(1) , As for the highest value of absorbed dose rate in air(total) it was (102.127) nGy/h in S.Part with average (84.215) in sample (4) and the lowest value was (47.896) nGy/h in old City with average (68.310)) nGy/h in sample (10) as in tables (6-4) and figure 2. As for the highest value of the annual effective dose (total) it was(0.214) mSv/y in S.Part with average (0.176) mSv/y in sample (4) and the lowest value was (0.100) mSv/y in old City with average (0.142) mSv/y in sample (10), as in tables (9-7) and figure 2**.** The highest value of the excess lifetime cancer risk (total) it was (0.752) in S.Part with average (0.617) in sample (4), and the lowest value was (0.350) old City with average (0.499) in sample (10), in tables (12-10) and figure 2

Table (1) The specific activity of ^{238}U, ^{232}Th and ^{40}K radionuclides in ten soil samples from old City, Kufa-Iraq, with their locations.

Samples Code	Location	Concentration Bq/kg		
	Latitude(E^0), Longitude(N^0)	$^{238}_{92}U$	$^{232}_{90}Th$	$^{40}_{19}K$
Old City	N 32° 01.000" E 044° 23.173"	28.402±1.0150	16.580±0.771	261.086±3.152
Old City	N 32° 01.621" E 044° 24.035"	9.476±0.569	7.108±0.490	237.809±2.921
Old City	N 32° 01.693" E 044° 24.107"	5.670±0.407	13.417±0.622	194.084±2.439
Old City	N 32° 02.023" E 044° 23.933"	14.972±0.671	10.670±0.563	331.629±3.237
Old City	N 32° 01.998" E 044° 24.143"	8.197±0.516	16.768±0.734	258.923±2.972
Old City	N 32° 02.132" E 044° 24.161"	7.176±0.488	12.820±0.649	275.497±3.098
Old City	N 32° 02.333" E 044° 24.117"	7.841±0.545	14.280±0.731	259.628±3.212
Old City	N 32° 02.339" E 044° 24.435"	13.156±0.740	17.713±0.854	324.444±3.764
Old City	N 32° 02.211" E 044° 24.260"	6.303±0.477	21.503±0.877	103.455±1.982
Old City	N 32° 01.507" E 044° 24.378"	5.146±0.409	9.280±0.546	204.974±2.646
Average		10.634	14.01	245.153

Max.		28.402	21.503	331.629
Min		5.146	7.108	103.455
UNSCEAR (2000)[17]		35	30	400

Table (2) The specific activity of ^{238}U, ^{232}Th and ^{40}K radionuclides in ten soil samples from N.Part, Kufa-Iraq, with their locations.

Samples Code	Location	Concentrations Bq/kg		
	Latitude(E^0), Longitude(N^0)	$^{238}_{92}U$	$^{232}_{90}Th$	$^{40}_{19}K$
N.Part	N 32° 01.324" E 044° 22.805"	9.017±0.587	19.091±0.849	313.875±3.547
N.Part	N 32° 01.810" E 044° 23.046"	5.587±0.445	27.431±0.982	322.980±3.472
N.Part	N 32° 01.740" E 044° 22.809"	14.406±0.652	13.084±0.618	156.447±2.201
N.Part	N 32° 02.466" E 044° 24.050"	6.896±0.467	16.589±0.720	360.120±3.457
N.Part	N 32° 01.749" E 044° 23.173"	8.965±0.582	23.990±0.947	313.633±3.528
N.Part	N 32° 01.919" E 044° 23.329"	10.194±0.558	21.292±0.803	244.107±2.800
N.Part	N 32° 02.113" E 044° 23.246"	7.199±0.471	16.691±0.714	339.721±3.318
N.Part	N 32° 01.808" E 044° 23.608"	7.342±0.488	19.062±0.782	197.278±2.593
N.Part	N 32° 01.428" E 044° 23.299"	8.505±0.541	16.727±0.754	139.783±2.247
N.Part	N 32° 03.008" E 044° 21.977"	16.407±0.692	13.893±0.633	142.102±2.086
Average		9.452	18.785	253.005
Max.		16.407	27.431	360.120
Min		5.587	13.084	139.783
UNSCEAR (2000)[17]		35	30	400

Table (3) The specific activity of ^{238}U, ^{232}Th and ^{40}K radionuclides in ten soil samples from S.Part, Kufa-Iraq, with their locations.

Samples Code	Location	Concentrations Bq/kg		
	Latitude(E^0), Longitude(N^0)	$^{238}_{92}U$	$^{232}_{90}Th$	$^{40}_{19}K$
S.Part	N 32° 01.456" E 044° 23.797"	23.661±0.842	15.636±0.681	311.185±3.129
S.Part	N 32° 01.143" E 044° 23.047"	7.751±0.483	16.441±0.700	339.854±3.279
S.Part	N 32° 01.237" E 044° 23.515"	5.076±0.368	12.451±0.573	293.813±2.870
S.Part	N 32° 01.126" E 044° 23.736"	8.562±0.521	25.853±0.900	379.716±3.554
S.Part	N 32° 01.192" E 044° 23.025"	5.079±0.427	23.276±0.910	341.148±3.591
S.Part	N 32° 01.461" E 044° 23.414"	14.066±0.638	22.066±0.795	295.726±2.999
S.Part	N 32° 01.049" E 044° 23.565"	9.186±0.525	16.663±0.703	324.831±3.198
S.Part	N 32° 01. 000" E 044° 23.173"	8.081±0.527	18.271±0.788	370.852±3.658
S.Part	N 32° 00.851" E 044° 23.498"	6.533±0.476	5.019±0.415	380.580±3.725
S.Part	N 32° 02.540" E 044° 23.274"	5.916±0.434	25.101±0.890	284.647±3.90
Average		9.391	18.078	332.235

Max.		23.661	25.853	380.580
Min		5.076	5.019	284.647
UNSCEAR (2000)[17]		30	35	400

Table (4) The outdoor, indoor and total absorbed dose rate AD in ten soil samples from Old City, Kufa-Iraq, with their locations

Samples Code	$AD_{\ Outdoor}$	AD_{Indoor}	AD_{Total}
Old City	33.202	65.517	98.719
Old City	18.306	35.800	54.106
Old City	18.602	35.696	54.299
Old City	26.748	52.373	79.122
Old City	24.415	46.960	71.376
Old City	22.296	43.019	65.316
Old City	22.799	43.952	66.751
Old City	29.875	57.868	87.744
Old City	19.943	37.833	57.776
Old City	16.350	31.546	47.896
Average	23.254	45.056	68.310
Max.	33.202	65.517	98.719
Min	16.350	31.546	47.896
W . Ave. [18]	59	84	143

Table (5) The outdoor, indoor and total absorbed dose rate AD in ten soil samples from N.Part, Kufa-Iraq, with their locations

Samples Code	$AD_{\ Outdoor}$	AD_{Indoor}	AD_{Total}
N.Part	28.456	54.720	83.177
N.Part	32.336	61.476	93.812
N.Part	20.642	40.319	60.961
N.Part	27.961	53.763	81.724
N.Part	31.357	60.042	91.400
N.Part	27.377	52.572	79.950
N.Part	27.303	52.501	79.805
N.Part	22.846	43.703	66.550

N.Part	19.557	37.547	57.105
N.Part	21.401	41.888	63.290
Average	25.924	49.853	75.777
Max.	32.336	61.476	93.812
Min	19.557	37.547	57.105
W . Ave. [18]	59	84	143

Table (6) The outdoor, indoor and total absorbed dose rate AD in ten soil samples from S.Part, Kufa-Iraq, with their locations

Samples Code	$AD_{\ Outdoor}$	AD_{Indoor}	AD_{Total}
S.Part	32.658	64.174	96.833
S.Part	27.399	52.744	80.144
S.Part	21.924	42.166	64.090
S.Part	35.053	67.073	102.127
S.Part	30.383	57.910	88.293
S.Part	31.682	61.168	92.851
S.Part	27.532	53.093	80.626
S.Part	29.932	57.572	87.505
S.Part	21.725	42.359	64.084
S.Part	29.485	56.111	85.597
Average	28.777	55.437	84.215
Max.	35.053	67.073	102.127
Min	21.72546957	42.16657237	64.08467285
W . Ave. [18]	59	84	143

Table (7) The outdoor, indoor and total annual effective dose equivalent (AEDE) in ten soil samples from Old City, Kufa-Iraq, with their locations

Samples Code	(AEDE)Outdoor	(AEDE) Indoor	(AEDE) Total.
Old City	0.040	0.162	0.203
Old City	0.022	0.089	0.112
Old City	0.022	0.091	0.114
Old City	0.032	0.131	0.164
Old City	0.029	0.119	0.149
Old City	0.027	0.109	0.136
Old City	0.027	0.111	0.139

Old City	0.036	0.146	0.183
Old City	0.024	0.097	0.122
Old City	0.020	0.080	0.100
Average	0.028	0.114	0.142
Max.	0.040	0.162	0.203
Min	0.020	0.080	0.100
W . Ave. [18]	0.026	0.104	0.131

Table (8) The outdoor, indoor and total annual effective dose equivalent (AEDE) in ten soil samples from N.Part, Kufa-Iraq, with their locations

Samples Code	(AEDE)Outdoor	(AEDE) Indoor	(AEDE) Total.
N.Part	0.034	0.139	0.174
N.Part	0.039	0.158	0.198
N.Part	0.025	0.101	0.126
N.Part	0.034	0.137	0.171
N.Part	0.038	0.153	0.192
N.Part	0.033	0.134	0.167
N.Part	0.033	0.133	0.167
N.Part	0.028	0.112	0.140
N.Part	0.023	0.095	0.119
N.Part	0.026	0.104	0.131
Average	0.031	0.127	0.158
Max.	0.039	0.158	0.198
Min	0.023	0.095	0.119
W . Ave. [18]	0.026	0.104	0.131

Table (9) The outdoor, indoor and total annual effective dose equivalent (AEDE) in ten soil samples from S.Part, Kufa-Iraq, with their locations

Samples Code	(AEDE)Outdoor	(AEDE) Indoor	(AEDE) Total.
S.Part	0.040	0.160	0.200
S.Part	0.033	0.134	0.168
S.Part	0.026	0.107	0.134
S.Part	0.042	0.171	0.214

S.Part	0.037	0.149	0.186
S.Part	0.038	0.155	0.194
S.Part	0.033	0.135	0.168
S.Part	0.036	0.146	0.183
S.Part	0.026	0.106	0.133
S.Part	0.036	0.144	0.180
Average	0.035	0.141	0.176
Max.	0.042	0.171	0.214
Min	0.026	0.106	0.133
W . Ave. [18]	0.026	0.104	0.131

Table (10) The outdoor, indoor and total excess lifetime cancer risk (ELCR) in ten soil samples from Old City, Kufa-Iraq, with their locations

Samples Code	(ELCR) Outdoor	(ELCR) Indoor	(ELCR) Total.
Old City	0.142	0.570	0.712
Old City	0.078	0.314	0.392
Old City	0.079	0.319	0.399
Old City	0.114	0.459	0.574
Old City	0.104	0.419	0.524
Old City	0.095	0.382	0.478
Old City	0.097	0.391	0.489
Old City	0.128	0.512	0.641
Old City	0.085	0.342	0.428
Old City	0.070	0.280	0.350
Average	0.099	0.399	0.499
Max.	0.142	0.570	0.712
Min	0.070	0.280	0.350
W.Ave. [18]	0.29	1.16	1.45

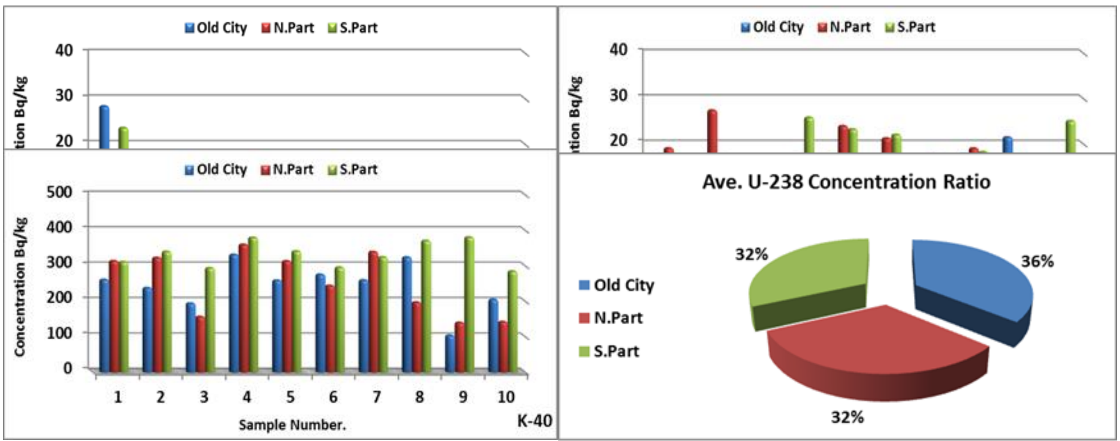
Table (11) The outdoor, indoor and total excess lifetime cancer risk (ELCR) in ten soil samples from N.Part, Kufa-Iraq, with their locations

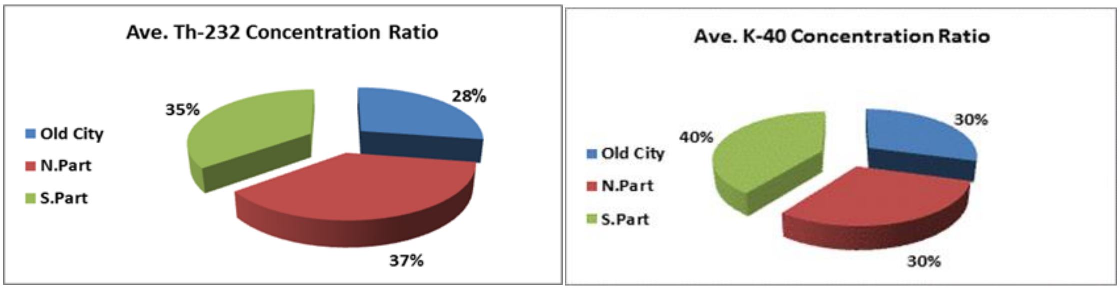
Samples Code	(ELCR) Outdoor	(ELCR) Indoor	(ELCR) Total.
N.Part	0.122	0.488	0.610
N.Part	0.138	0.555	0.693

N.Part	0.088	0.354	0.443
N.Part	0.120	0.480	0.600
N.Part	0.134	0.538	0.673
N.Part	0.117	0.470	0.587
N.Part	0.117	0.468	0.585
N.Part	0.098	0.392	0.490
N.Part	0.083	0.335	0.419
N.Part	0.091	0.367	0.459
Average	0.111	0.445	0.556
Max.	0.138	0.555	0.693
Min	0.083	0.335	0.419
W.Ave. [18]	0.29	1.16	1.45

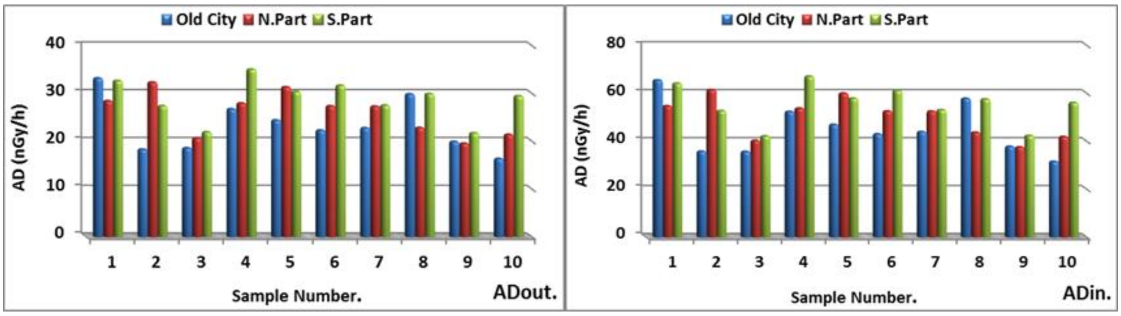
Table (12) The outdoor, indoor and total excess lifetime cancer risk (ELCR) in ten soil samples from N.Part S.Part, Kufa-Iraq, with their locations

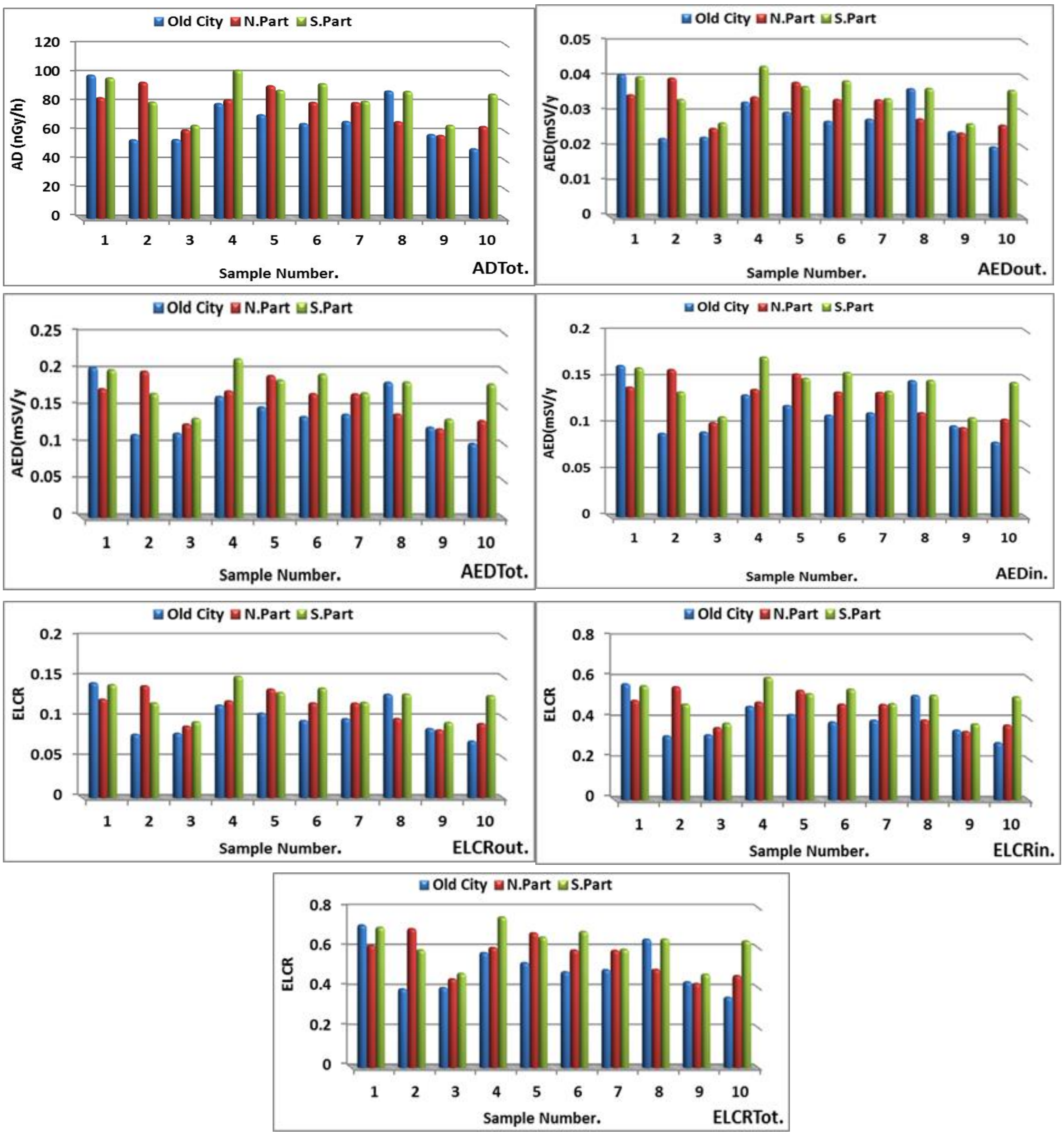
Samples Code	(ELCR) Outdoor	(ELCR) Indoor	(ELCR) Total.
S.Part	0.140	0.560	0.700
S.Part	0.117	0.470	0.588
S.Part	0.094	0.376	0.470
S.Part	0.150	0.601	0.752
S.Part	0.130	0.521	0.652
S.Part	0.135	0.543	0.679
S.Part	0.118	0.472	0.590
S.Part	0.128	0.513	0.642
S.Part	0.093	0.373	0.466
S.Part	0.126	0.506	0.632
Average	0.123	0.494	0.617
Max.	0.150	0.601	0.752
Min	0.093254406	0.373	0.466
W.Ave. [18]	0.29	1.16	1.45





Figure(1) The specific activity of ^{238}U, ^{232}Th and ^{40}K radionuclides and their ratios in thirty soil samples from Kufa.-Iraq.





Figure(2) The absorbed dose rate AD, annual effective dose equivalent (AEDE), and the excess lifetime cancer risk (ELCR) in thirty soil samples from Kufa.-Iraq.

Conclusions:

Because the radioactive isotope natural distribution rates in the three sites under study have converged, Permissible rates include absorbed dose rate (AD), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR). It is determined that the soil in these regions is deemed safe and is within the range of the worldwide average.

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