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Radioactive Levels and Radiological Hazards in Ali Al-Gharbi City Soil

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ABSTRACT

► ***Original article***

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Background: The city of Ali Al-Gharbi in Misan province, Iraq, is known for its agricultural activities, raising concerns about potential soil contamination due to industrial activities, waste disposal, and the use of fertilizers and pesticides. Understanding soil radioactivity levels is essential for assessing health risks to the environment and the local population. ***Materials and Methods:*** A High-Purity Germanium detector was employed to assess the radioactivity of both artificial and natural radionuclides within the soil obtained from twenty-three localities in Ali Al-Gharbi city, Misan. The soil was prepared, dried, and analyzed in the lab. Radiological hazard indices (RHI): annual gonadal dose equivalent (AGDE), radium equivalent activity (Ra_{eq}), absorbed dose rate (D), gamma index ($I\gamma$), external and internal hazard indices (Hex & Hin), excess lifetime cancer risk (ELCR), and outdoor annual effective dose equivalent (AEDE), were computed using established formulas. Statistical analysis provided insights into the radiological risks in the region. ***Results:*** ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs were found to be 32.676±3.684 Bq/kg, 18.150±1.562 Bq/kg, 377.376±15.266 Bq/kg, and 1.906±0.422 Bq/kg, respectively. Radiological hazard parameters, including excess ELCR, I_γ, D, Ra_{eq}, (H_{ex} & H_{in}), AGDE, and $AEDE_{out}$ were found to be 87.091±17.476 Bq/kg, 0.235±0.047, 0.323±0.073, 0.323±0.062, 41.543±8.107 nGy/h, 50.948±9.943 µSv/y, 293.587±56.174 µSv/y, and 1.783±0.348 $\times10^{-4}$, respectively. The findings showed that the ^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs were below the recommended value by the UNSCEAR. ***Conclusions:*** Moreover, all estimated radiation hazard parameters from natural radionuclides were below the recommended limits, suggesting no health risk from radioactivity in the study area.

INTRODUCTION

Background radioactivity originates from both artificial sources and natural. Naturally occurring sources encompass environmental radiation from Naturally Occurring Radioactive Materials (NORMs) like radium (^{226}Ra), thorium (^{232}Th), and potassium (^{40}K) [1-3]. Additionally, artificial radionuclides such as Cesium-137 (^{137}Cs) may be found in the environment. This can occur due to atmospheric nuclear weapons testing, accidents, and routine discharge from nuclear facilities [4-6]. The concentrations of radionuclides, whether artificial or natural, are primarily influenced in geological and geographical conditions, leading to varying levels in the soil across different regions worldwide [7-10]. Assessing the activity of radionuclides in soil is vital because it provides important information for tracking environmental radioactivity [11-13]. In recent times, various radiological surveys have been performed globally to determine radionuclide concentrations in soil and evaluate their potential radioactive hazards [14-17]. Almayahi *et al.,* 2018 examined background radiation exposure rates in various sites within Najaf and Dhi Qar cities, Iraq. They often used a portable Geiger-Müller meter to measure gamma dose rates. Their findings indicated that the absorbed dose rates of background radiation in these areas were consistent with global levels observed in other regions [18]. Mohammed *et al., 2016* conducted research at the University of Kufa in Iraq to examine the biological effects of background radiation on humans. They measured natural background radiation exposure rates at various locations within the university using a G-M survey meter. The results revealed that the recorded gamma-ray dose rates and absorbed dose rates were within the normal range observed in other regions [19]. Albazoni and Almayahi, 2022 developed a biosensor to detect Pb^{+2} and ^{222}Rn (Radium progenitors) in soil and construction materials. The biosensor utilized primers with high guanine content. Chinese and Indian granites were found to exceed acceptable limits for Pb^{+2} and ^{222}Rn [20]. In 2024, Obayes evaluated the radionuclide concentrations in soil samples collected from governmental departments in Al-Nasiriya city, Iraq. The study measured the specific activities of radionuclides including ^{238}U, ^{232}Th, and ^{40}K, and assessed various radiological parameters. The results indicate that the levels of these radionuclides did not exceed the permissible global values, suggesting no significant threat to human health from natural radioactivity in the studied areas [21]. The main goal of this study is to evaluate the activity of both natural and artificial

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radionuclides (^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs) in soil samples collected from Ali Al-Gharbi city in Misan, Iraq. It also seeks to assess the radiological hazard parameters related to natural radionuclides. This research represents the first attempt to measure background radiation levels in Ali Al-Gharbi city, providing a baseline dataset for future studies. The study focuses on determining the radioactivity levels in soil samples from the area and estimating the associated radiological hazard indices. The novelty of this research lies in its contribution as the inaugural investigation into the background radiation levels in Ali Al-Gharbi city. By providing a comprehensive analysis of radionuclide levels and associated hazards, this study establishes a foundational dataset that can be referred to by future research endeavors in Ali Al-Gharbi and nearby locations.

MATERIALS AND METHODS

Area of study

Ali Al- Gharbi is located in a northern and northwestern part of Misan province in Iraq. According to its geographical location, it stands between latitudes (32°11′17″ and 32°51′49″) N and longitudes (46°35′23″ and 46°47′30″) E. The area spans about 3766 km^2 with a population of 53989 as of 2019 [22-24].

Soil collection and preparation

Twenty-three soil samples from multiple locations in Ali Al- Gharbi city was collected, as listed in table 1. Soil was gathered from a depth of 0~5 cm (surface soil) at selected spots and the Global Positioning System (GPS) (Etrex Vista Hcx (GARMIN company, USA) was employed in determining location coordinates (figure 1). The soil samples were filled in a clean zip lock and each one of the collected samples was given a unique code, then transferred to the lab for preparation. The soil was sieved with a 75 µm sized mesh, dried in an oven herfy-28L (DENIKA company, Korea) at 80 ° C for 2 h (remove the moisture). Next, the soil samples were placed in 500 mL plastic Marinelli beakers manufactured by GA-MA company in the USA. These beakers were sealed with plastic tape to ensure no airborne radionuclides could escape and were left undisturbed for a period of 4 weeks. This allowed sufficient time for the secular equilibrium of ^{226}Ra with its decay products in the uranium series to be reached before gamma spectrometry counting took place [25].

Table 1. Geographic site of Ali Al- Gharbi city (Standard Errors= ±3) using GPS.

Sample Code	Sample Location	Latitude	Longitude
S_1	Large Al-Amiya	32.51910	46.52399
S_2	Small Al-Amiya	32.50800	46.54910
S_3	Al-Shuwaimi	32.50076	46.57149
S_4	Al-Wahda	32.51534	46.58139
S_5	Al-Majari	32.49468	46.60120
S_6	Al-Kabsun	32.48557	46.63368
S_7	Al-Majd	32.49478	46.65956
S_8	Al-Nujaydia	32.47274	46.68503
S_9	Al-Batool	32.47456	46.69460
S_{10}	Al-Saadiq	32.47003	46.70237
S_{11}	Al-Hasanain	32.46778	46.67872
S_{12}	Al-Amir	32.45862	46.68974
S_{13}	Umm Shajaj	32.46151	46.71835
S_{14}	Bayt Faeil	32.43939	46.70172
S_{15}	Al-Hura	32.43008	46.68171
S_{16}	Ansar Al-Hussein	32.44066	46.72520
S_{17}	Al-Sabbiha	32.42538	46.72700
S_{18}	Al-Mustafa	32.41039	46.73574
S_{19}	Al-Ghalibia	32.39404	46.72570
S_{20}	Al-Khulud	32.32202	46 .75296
S_{21}	Al-Risala	32.29152	46.71530
S_{22}	Al-Dawieina	32.28428	46.70937
S_{23}	Al-Saadia Al-Sakhria	32.26242	46.71544

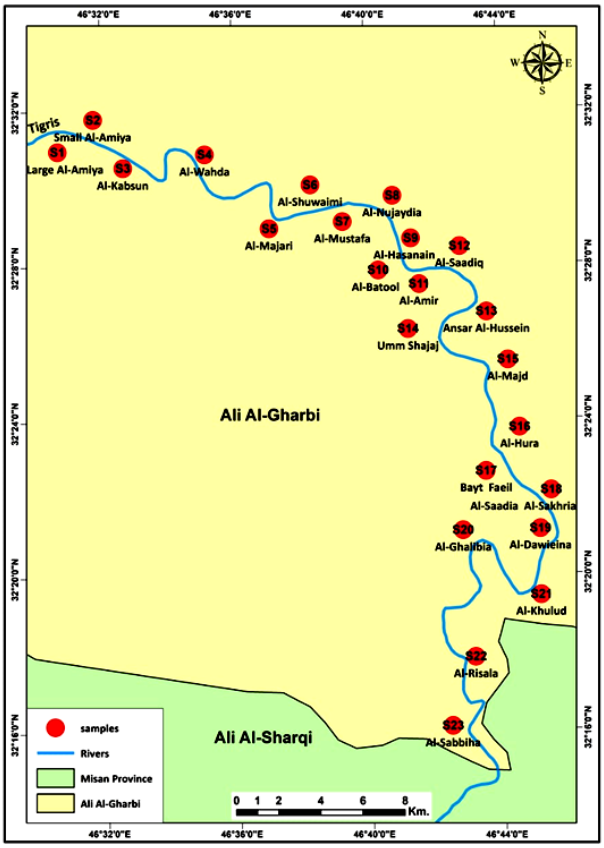

Figure 1. Map of the administrative divisions of the study area.

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Radioactivity measurement

Measurement of activity levels within the soil was done with an HPGe detector (GC4020 Model, CANBERRA company, USA) which has a 40% (relative efficiency) and resolution at 2 keV (Full Width Half Maximum (FWHM)) at 1332 keV gamma ray peak of Cobalt-60 (^{60}Co). To diminish background radioactivity, a 12 cm thick lead shield was employed to cover the HPGe detector. The gamma spectra of all samples were carefully analyzed using Genie-2000 spectra analysis software from Canberra, version 3.1. The detector underwent energy and relative efficiency calibrations utilizing a standard multi-gamma source identified by Certificate Number 1035-SE-40524-16, Type of CBSS 2, Serial number of 280616-1597016, and Date of Certificate issue is 18 July 2016 (Czech Metrology Institute, Czech Republic) which contains 12 radionuclides including Americium-241 (^{241}Am) (59.54 keV), Cadmium-109 (^{109}Cd) (88.3 keV), Cerium-139 (^{139}Ce) (165.85 keV), Cobalt-57 (^{57}Co) (122.06 and 136.47 keV), Cobalt-60 (^{60}Co) (1173.24 and 1332.5 keV), Cesium-137 ^{137}Cs (661.66 keV), Tin-113 (^{113}Sn) (391.69 keV), Strontium-85 (^{85}Sr) (514 keV), Yttrium-88 (^{88}Y) (898.02 and 1836.08 keV), Chromium-51 (^{51}Cr) (320 keV), Manganese-54 (^{54}Mn) (834.8 keV), and Zinc-65 (^{65}Zn) (1116 keV) in the energy range (59.54 to 1836.08 keV) with mass of 441.0 gm, density of 0.98± 0.01 g /cm^3, and volume of 450.0 ± 4.5 cm^3 [26].

The ^{226}Ra was evaluated through the ɣ-ray energies of Lead-214 (^{214}Pb) at 351.92 keV and Bismuth-214 (^{214}Bi) at 609.31 keV, the ɣ-ray lines 911.07 keV of Actinium-228 (^{228}Ac) and 583.19 keV of Thallium-208 (^{208}Tl) were used to evaluate ^{232}Th activities, while the activities of ^{40}K and ^{137}Cs were directly evaluation using peak energies of 1460.80 keV and 661.64 keV, respectively [2]. The ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in each sample were found using equation 1 [27]:

$$A\left(\frac{Bq}{kg}\right) = \frac{N}{\varepsilon\, I_\gamma\, M\, t} \quad (1)$$

In the formula, A the activity (Bq/kg), N stands for a net area below a peak (count per sec.), ε represents the absolute gamma peak detection efficiency, Iγ signifies the absolute gamma intensity of the respective gamma-ray energy considered, M denotes the mass of the sample in kilograms, and t indicates the time of measurement in seconds.

Radiological health hazard indices (RHHI)

The RHHI resulting from natural radionuclide including radium equivalent activity (Ra_{eq}), external and internal hazard indices (H_{ex} & H_{in}), gamma index (Iγ), absorbed dose rate (D), outdoor annual effective dose equivalent ($AEDE_{out}$), annual gonadal dose equivalent (AGDE), and excess lifetime cancer risk (ELCR), were found using the equations 2-9 [1, 2, 28-33].

$$Ra_{eq} = A_{Ra}\ Bq/kg + (1.43 \times A_{Th}\ Bq/kg) + (0.077 \times A_k\ Bq/kg) \leq 370 \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K.

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (3)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (4)$$

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 1 \quad (5)$$

$$D\left(\frac{nGy}{h}\right) = (0.462 \times A_{Ra}) + (0.604 \times A_{Th}) + (0.0417 \times A_K) \quad (6)$$

Where; the conversion factors of ^{226}Ra, ^{232}Th, and ^{40}K, are 0.462, 0.604, and 0.0417 nGy/h per Bq/kg, respectively.

$$AEDE\left(\frac{\mu Sv}{y}\right) = D \times DCF \times OF \times 8760\frac{h}{y} \times 10^{-3} \quad (7)$$

Where; D (calculated absorbed dose rate), DCF (dose conversion factor from absorbed dose rate) in the air to effective (0.7 Sv/ Gy), and OF=0.2 (outdoor occupancy factor).

$$AGDE\left(\frac{\mu Sv}{y}\right) = (3.09 \times A_{Ra}) + (4.18 \times A_{Th}) + (0.314 \times A_K) \quad (8)$$

$$ELCR = AEDE \times DL \times RF \quad (9)$$

Where; AEDE (annual effective dose equivalent, μSv/y), DL (duration of life (70 years)) and RF (risk factor).

Statistical analysis

Statistical software packages such as Genie-2000 (version 3.1) Spectra analysis software were used for analyzing the spectrums of gamma in all samples collected. This software aided in processing the gamma ray spectrometry data obtained from the HPGe detector. Additionally, statistical tests were used to calculate various RHHI, including Raeq, Hex & Hin, Iγ, D, AEDEout, AGDE, and ELCR. These statistical analyses provided essential insights into the radiological hazard levels in the studied area. Data analysis was conducted using SPSS statistical software (IBM SPSS Statistics 26.0). Statistical tests were applied for data analysis, and variations were quantified using p-values.

RESULTS AND DISCUSSION

Table 3 presents the ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs in the samples. The ^{226}Ra,^{232}Th,^{40}K, and ^{137}Cs in soils ranged from an average of 32.676±3.684 Bq/kg, 18.150 ± 1.562 Bq/kg, 377.376±15.266 Bq/kg, and 1.906±0.422 Bq/kg, respectively. The ^{226}Ra was higher than that ^{232}Th for 22 out of 23 samples, and the ^{40}K was greater than that ^{226}Ra and ^{232}Th of all the sites. As shown in table 2, the p-values calculated indicate the level of significance for each radionuclide measured in the samples from Ali Al-Gharbi city. The RHHI obtained in the soil are showed in table 3.

Table 2. Radionuclides (^{226}Ra, ^{232}Th, ^{40}K, and ^{137}Cs) (Bq/kg) with P Value in Ali Al- Gharbi city.

Sample Code	^{226}Ra	P Value	^{232}Th	*P Value*	^{40}K	*P Value*	^{137}Cs	*P Value*
S1	50.416±3.167	0.05	22.815±1.944	0.05	564.325±6.261	<0.0001	2.224±0.501	0.53
S2	41.122±4.322	0.05	16.613±1.452	0.05	345.322±14.458	0.05	1.602±0.416	0.48
S3	42.257±3.127	0.05	18.221±1.745	0.05	362.223±13.324	0.05	3.812±0.721	0.05
S4	45.125±5.241	0.05	21.411±2.235	0.05	439.321±13.652	0.05	1.812±0.423	0.82
S5	2.415±3.516	0.05	18.321±1.658	0.05	357.451±12.762	0.05	0.534±0.025	<0.0001
S6	23.222±2.381	0.05	9.621±1.225	0.05	411.542±17.809	0.05	1.821±0.524	0.87
S7	24.432±2.431	0.05	18.431±2.451	0.05	417.21±13.351	0.1	1.115±0.409	0.1
S8	41.811±3.673	0.05	22.435±1.211	0.05	424.421±11.651	0.05	0.487±0.065	<0.0001
S9	27.321±3.652	0.05	22.414±1.809	0.05	448.424±17.091	0.05	4.623±0.916	0.05
S10	33.811±3.23	0.05	17.811±1.951	0.05	328.256±15.132	0.05	1.223±0.343	0.09
S11	47.137±5.431	0.05	23.417±1.722	0.05	400.221±18.541	0.05	0.591±0.039	<0.0001
S12	29.412±3.361	0.05	12.325±1.531	0.05	271.336±13.114	<0.0001	1.242±0.421	0.15
S13	34.264±3.681	0.05	17.221±1.116	0.05	355.321±15.214	0.05	1.202±0.331	0.1
S14	28.443±3.21	0.05	16.431±1.224	0.05	334.216±19.341	0.05	1.327±0.321	0.13
S15	25.234±4.325	0.05	13.632±1.221	0.05	285.234±14.651	<0.0001	1.132±0.201	<0.0001
S16	36.651±4.761	0.05	18.832±1.975	0.05	273.012±18.108	<0.0001	2.071±0.512	0.73
S17	32.424±3.202	0.05	21.611±1.622	0.05	396.455±18.105	0.42	4.625±0.911	0.05
S18	35.423±3.204	0.05	16.247±1.301	0.05	383.237±19.261	0.39	5.102±0.812	<0.0001
S19	35.624±3.103	0.05	18.227±1.321	0.05	323.412±11.406	<0.0001	0.493±0.062	<0.0001
S20	19.423±3.327	0.05	17.123±1.242	0.05	353.411±11.236	<0.0001	2.424±0.802	0.52
S21	35.351±4.013	0.05	24.854±1.117	0.05	344.822±17.321	0.05	1.601±0.312	0.34
S22	39.424±5.165	0.05	15.211±1.622	0.05	436.252±19.831	0.07	2.211±0.521	0.57
S23	20.823±3.231	0.05	14.232±1.245	0.05	424.242±19.511	0.15	0.564±0.131	<0.0001
Mean Value ± Standard Deviation	32.676±3.684	0.05	18.150±1.562	0.05	377.376±15.266		1.906±0.422	

Table 3. Radiological hazard indices (Ra_{eq}, H_{ex} & H_{in}, I_y, D, $AEDE_{out}$, AGDE, and ELCR) in Ali Al-Gharbi city.

Sample Code	Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	I_y	D (nGy/h)	AEDE (µSv/y)	AGDE (µSv/y)	ELCR (×10^{-4})
S_1	126.494	0.341	0.477	0.470	60.604	74.325	428.350	2.601
S_2	91.468	0.247	0.358	0.335	43.432	53.265	304.940	1.864
S_3	96.204	0.259	0.374	0.352	45.632	55.964	320.475	1.958
S_4	109.570	0.295	0.417	0.403	52.099	63.895	366.881	2.236
S_5	56.137	0.151	0.158	0.218	27.087	33.219	196.283	1.162
S_6	68.668	0.185	0.248	0.262	33.700	41.330	241.195	1.446
S_7	82.913	0.223	0.289	0.312	39.817	48.832	283.540	1.709
S_8	106.573	0.287	0.400	0.393	50.565	62.013	356.242	2.170
S_9	93.901	0.253	0.327	0.352	44.859	55.015	318.917	1.925
S_{10}	84.556	0.228	0.319	0.311	40.066	49.137	281.998	1.719
S_{11}	111.440	0.301	0.428	0.407	52.610	64.521	369.205	2.258
S_{12}	67.929	0.183	0.262	0.250	32.347	39.670	227.601	1.388
S_{13}	86.249	0.232	0.325	0.318	41.048	50.341	289.430	1.761
S_{14}	77.673	0.209	0.286	0.288	37.001	45.379	261.514	1.588
S_{15}	66.690	0.180	0.248	0.247	31.786	38.982	224.518	1.364
S_{16}	84.602	0.228	0.327	0.307	39.691	48.678	277.695	1.703
S_{17}	93.854	0.253	0.341	0.348	44.565	54.654	315.011	1.912
S_{18}	88.165	0.238	0.333	0.327	42.159	51.704	297.705	1.809
S_{19}	86.591	0.233	0.330	0.317	40.953	50.225	287.818	1.757
S_{20}	71.121	0.192	0.244	0.268	34.052	41.762	242.562	1.461
S_{21}	97.443	0.263	0.358	0.357	45.723	56.074	321.398	1.962
S_{22}	94.767	0.255	0.362	0.352	45.593	55.915	322.385	1.957
S_{23}	73.841	0.199	0.255	0.281	35.907	44.036	257.044	1.541
Mean Value ± Standard Deviation	87.689±16.534	0.236±0.044	0.325±0.071	0.325± 0.059	41.796±7.745	51.258±9.498	295.335±53.734	1.794±0.332

^{226}Ra is 35, ^{232}Th is 30, and that of ^{40}K is 400 Bq/kg are the global average in soils [1]. The ^{226}Ra in the location of study is below the global average, although the ^{226}Ra of the S_1 (Large Al-Amiya), S_2 (Small Al-Amiya), S_3 (Al -Shuwaimi), S_4 (Al-Wahda), S_8 (Al-Nujaydia), S_{11} (Al-Hasanain), S_{16} (Ansar Al-Hussein), S_{18} (Al-Mustafa), S_{19} (Al-Ghalibia), S_{21} (Al-Risala), and S_{22} (Al-Dawieina) are slightly above the world average. The ^{232}Th activity value is below the global average and ^{40}K is also lower compared to the

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worldwide average. Nevertheless, the ^{40}K of the S_1 (Large Al-Amiya), S_4 (Al-Wahda), S_6 (Al-Kabsun), S_7 (Al-Majd), S_8 (Al-Nujaydia), S_9 (Al-Batool), S_{11} (Al-Hasanain), S_{22} (Al-Dawieina), and S_{23} (Al-Saadia Al-Sakhria) are slightly higher than the world average value. Moreover, excessive use of artificial fertilizers in soil may lead to elevated activity values of ^{40}K. The artificial radionuclide, (^{137}Cs), is not naturally present in samples. It is rather a byproduct of fallout radioactivity. The probable introduction of these elements into the study area's soil could be attributed to incidents like the Chernobyl nuclear power plant disaster on April 26, 1986, and nuclear weapons testing. A p-value of less than 0.05 typically indicates a statistically significant difference. For instance, the p-value for some radionuclides in several samples was found to be highly significant ($p<0.0001$), suggesting notable variation in concentration levels. Conversely, p-values greater than 0.05 suggest no statistically significant difference, as observed with other radionuclides in specific samples.

Comparison of the radioactivity

The average of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs have been compared to the same studies done in various regions of Iraq and the world, indicated in table 4. Upon comparison, it's noted that the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K are lower in comparison to findings from studies conducted in Malaysia. (Malaysian Peninsula), India (Uttara Kannada), Pakistan (Punjab), Bangladesh (Inani Beach), Palestine (West Bank), Yemen (Sana'a) and Turkey (Rize) [2, 15, 34-38] whereas higher than previous studies reported in Iran (Fars), Kuwait, Qatar, Iraq (LZRB), Iraq (Al-Nahrawan) and Iraq (Najaf) [39-41]. Also, the average activity concentration for ^{137}Cs is lower. The average radioactivity in the investigated soil was below the global average values as documented by UNSCEAR, and variations in soil radioactivity across different regions of the world are influenced by the geological and geographical characteristics specific to each area [1].

Table 4. Comparison of the average soil radioactivity (Bq/kg) in this study with other countries worldwide.

Place	^{226}Ra	^{232}Th	^{40}K	^{137}Cs	Reference
Malaysia (Malaysian Peninsula)	57	68	427	Not measured	Almayahi *et al.*, 2012 [34]
India (Uttara Kannada)	36.13	48.47	415.76	Not measured	Suresh *et al.*, 2022 [15]
Pakistan (Punjab)	58.23	53.60	564.48	2.18	Rahman *et al.*, 2011 [35]
Bangladesh (Inani Beach)	44.39	69.79	1007.25	Not measured	Ahmed *et al.*, 2014 [36]
Palestine (West Bank)	68.7	48	630	Not measured	Dabayneh *et al.*, 2008 [37]
Yemen (Sana'a)	48.2	41.7	939.1	Not measured	Harb *et al.*, 2012 [38]
Turkey (Rize)	85.75	51.08	771.57	236.38	Dizman *et al.*, 2016 [2]
Iran (Fars)	26.3	14.9	271	6.37	Faghihi *et al.*, 2011 [39]
Kuwait	16.99	12.70	333.20	Not measured	Bajoga *et al.*, 2019 [40]
Qatar	23.2	4.5	127.1	Not measured	Nasir *et al.*, 2012 [41]
Iraq (LZRB)	13.8	6.5	276.5	7	Smail *et al.*, 2021 [42]
Iraq (Al-Nahrawan)	16.634	11.693	147.55	Not measured	Essa *et al.*, 2021 [43]
Iraq (Najaf)	11.96	4.99	104.62	Not measured	Hasan *et al.*, 2021 [44]
Worldwide Average	35	30	400	Not measured	UNSCEAR, 2000 [1]
Iraq (Ali Al- Gharbi)	**32.676**	**18.150**	**377.376**	**1.906**	**Present study**

The calculated radium equivalent activity values in the soil ranged from 56.137 Bq/kg (S_5) to 126.494 Bq/kg (S_1) (with average 87.689±16.534 Bq/kg), which is lower than the worldwide value of 370 Bq/kg [1]. The H_{ex} ranged from 0.151 (S_5) to 0.341 (S_1) (0.236±0.044), which is lower than (1) [1]. The H_{in} ranged from 0.158 (S_5) to 0.477 (S_1) (0.325±0.071), which is less than (1) [1]. The gamma index values scaled between 0.218 (S_5) and 0.470 (S_1) (0.325 ± 0.059), which is less than (1) [1]. The D in the air ranged from 27.087 (S_5) to 60.604 (S_1) nGy/h (41.796±7.745 nGy/h, which is lower than the world value (59 nGy/h) [1]. Nonetheless, a little higher level of the D was observed in a sampling site of S1(Large Al-Amiya). The AEDE in the study area ranged from 33.219 (S_5) to 74.325 (S_1) μSv/y (51.258±9.498 μSv/y), which is lower than the world value (70 μSv/y) [1]. However, a slightly higher level of AEDE was noticed in the sampling region of S1(Large Alamiya). The AGDE ranged from 196.283 (S_5) to 428.350 (S_1) μSv/y with a mean value of 295.335±53.734 μSv/y, which is lower than the global value (300 μSv/y) [1]. Nevertheless, slightly elevated AGDE levels were detected in the specific areas, S_1 (Large Al-Amiya), S_2 (Small Al-Amiya), S_3 (Al-Shuwaimi), S_4 (Al-Wahda), S_8 (Al-Nujaydia), S_9(Al-Batool), S_{11}(Al-Hasanain), S_{17}(Al-Sabbiha), S_{21}(Al-Risala), and S_{22} (Al-Dawieina). The ELCR ranged from 1.162×10^{-4} (S_5) to 2.601×10^{-4} (S_1) ($1.794\pm0.332\times10^{-4}$) lower than the worldwide average value of 2.9×10^{-4} [1]. Based on the RHI derived from the study, it can be concluded that the surveyed area exhibits radiation levels within normal ranges, posing no health risks to the population.

Comparison of RHI

The average RHI derived from the study area has been compared with those obtained from regions in Iraq and globally. This comparison is detailed in table 5. Ra_{eq}, H_{ex}, H_{in}, I_γ, D, AEDE, AGDE and ELCR of this study are lower than studies reported in India, Dadri (U.P.), Pakistan (Waziristan), Iran (Tehran), Jordan (northern highlands), Iraq) Nineveh(and Iraq (Abu

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Al Khasib) [45-50] ,while higher than studies reported in Bangladesh (Habiganj), Turkey (Bolu), Saudi Arabia (Dammam), Iraq (Pshdar), Iraq (Al-Sadr), Iraq (Wassit), Iraq (Najaf) [2, 44, 51-55].

Table 5. Comparison of radiological hazard indices from this study with global studies.

Country	Radiological hazard indices								Reference
	Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	I_{γ}	D (nGy/h)	AEDE (µSv/y)	AGDE (µSv/y)	ELCR ($\times 10^{-4}$)	
India (U.P.) Dadri	147.8	0.4	Not measured	Not measured	71.5	80	Not measured	Not measured	Mahur *et al.*, 2013 [45]
Pakistan (Waziristan)	281.272	0.759	0.947	Not measure	100.982	150	Not measured	Not measured	Khan *et al.*, 2020 [46]
Bangladesh (Habiganj)	58.51	0.160	Not measured	Not measured	27.99	33.18	Not measured	Not measured	Ferdous *et al.*,2015 [47]
Turkey (Bolu)	62.8	0.2	Not measured	0.2	29.9	36.6	209.7	1.3	Dizman *et al.*, 2019 [2]
Iran (Tehran)	143.6	0.39	0.49	0.53	69.1	80	Not meas-ured	Not measured	Asgharizadeh *et al.*, 2013 [48]
Jordan (northern highlands)	103.1	0.28	0.39	Not measured	51.5	63.2	334.3	Not measured	Al-Hamarneh and Awadallah, 2009 [49]
Saudi Arabia (Dammam)	63.93	0.17	0.22	0.25	31.68	39	Not measured	1.4	Al-Ghamdi, 2019 [50]
Iraq (Pshdar)	69.83	0.20	0.22	Not measured	33.26	40.79	Not measured	Not measured	Mustafa et *al.*, 2016 [51]
Nineveh (Iraq)	90.75	0.244	0.332	0.656	43.08	Not measured	Not measured	Not measured	Najam *et al.*, 2015 [52]
Iraq (Al-Sadr)	61.434	0.166	0.208	Not measured	29.535	37	Not measured	1.28	Al-Alawy et *al.*, 2023 [53]
Iraq (Wassit)	61.585	0.166	0.219	0.225	28.656	35	Not measured	Not measured	Najam *et al.*, 2017 [54]
Iraq (Najaf)	26.23	0.07	0.1	0.188	11.02	15	80	0.53	Hasan *et al.*, 2021 [44]
Iraq (Abu Al Khasib)	Not measured	Not measured	Not measured	Not measured	50.51	60	Not measured	2	Mohammed and Ahmed, 2017 [55]
World average	370	1≥	1≥	1≥	59	70	300	2.9	UNSCEAR, 2000 [1]
Iraq (Ali Al- Gharbi)	**87.689**	**0.236**	**0.325**	**0.325**	**41.796**	**51.258**	**295.335**	**1.794**	**Present study**

This study reveals that the concentration of ^{226}Ra in most sites is below the global average, although some locations such as S1 (Large Al-Amiya), S2 (Small Al-Amiya), S4 (Al-Wahda), and others show slightly elevated levels. Similarly, the 40K values are generally lower than the worldwide average, except for certain locations where the concentration is slightly higher, likely due to local agricultural practices, including the use of artificial fertilizers. The presence of ^{137}Cs, which is not naturally occurring, is attributed to fallout from nuclear incidents such as the Chernobyl disaster. This long-term presence highlights the impact of historical events on environmental radioactivity.

The results have compared with those from various regions globally, including Iraq, Iran, and other countries, as detailed in table 4. The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the study area are generally lower compared to countries like Malaysia, India, and Pakistan, while being slightly higher than those in regions such as Iran and Kuwait. The calculated radiological health hazard indices also indicate that the values are below the global average, and despite some localized elevations, the overall health risk from radiation exposure is minimal. A statistical analysis was performed to validate the significance of these differences, with p-values supporting the variations observed across radionuclide concentrations. The radioactivity in soil shows variations across the sites, with ^{226}Ra, ^{232}Th, and ^{40}K generally aligning with worldwide averages, though some locations have slightly higher levels due to local geology or human activities like artificial fertilizers. The presence of ^{137}Cs, from fallout events like Chernobyl, highlights long-term environmental impacts. Comparing radionuclide concentrations with other regions shows that while the study area has lower levels than some countries (e.g., India, Pakistan), it is higher than others (e.g., Iran, Kuwait). Despite localized elevations, the calculated radiological health hazard indices indicate that the area poses no significant health risks overall. These variations emphasize the need for localized studies to better understand and manage radiation-related health risks.

CONCLUSIONS

The study revealed that the mean activity levels in the soils were below the recommended standards, from these values, various RHHI were calculated. It was found that the mean values of these indices in the soil were below the global average. And therefore, the results obtained in this research indicate that the soils are considered radiologically

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safe with no associated health risk to the area's inhabitants. This data may be crucial in developing a radioactivity map of the area for monitoring possible radioactivity pollution in future.

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