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Spatial analysis of natural radioactivity in agricultural soils Kufa city and its relation with geomorphological units east of Euphrates River by using remote sensing and geographic information systems (GIS)

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Abstract

The problem of natural radioactivity in agricultural soils is an important environmental problem because the naturally occurring radionuclides may contribute to radiation exposure and enter into the food chain. In this study, the concentrations of naturally occurring radionuclides in agricultural soils collected east of Euphrates River in Kufa City, Iraq were determined. Sixty soil samples were collected systematically from different agricultural sites, along with their geographical coordinates. Prior to the gamma-ray spectrometric analysis the samples were dried, crushed, homogenized and sieved. The activity concentrations of ^{238}U , ^{232}Th and ^{40}K were determined by NaI(Tl) gamma-ray spectrometry system by looking at the proper calibration procedures. The results showed a spatial variability in the concentrations of radionuclides in the analyzed samples. The activity concentrations of ^{238}U ranged from 18.65 to 29.68 Bq kg⁻¹ with a mean of 23.87 Bq kg⁻¹. For ^{232}Th the concentrations varied from 23.48 to 37.12 Bq kg⁻¹ with an average value of 29.72 Bq kg⁻¹. Maximum activity concentrations were determined in ^{40}K and were in the range of 271.4-419.4 Bq kg⁻¹ with a mean of 350.8 Bq kg⁻¹. The variations observed can be explained by the differences in the soil composition, the mineralogical properties and the local environmental conditions. A comparison with the adopted reference values of 33 Bq kg⁻¹ for ^{238}U , 45 Bq kg⁻¹ for ^{232}Th and 420 Bq kg⁻¹ for ^{40}K revealed that the average concentrations of all investigated radionuclides were lower than the corresponding reference levels. The overall results indicate normal levels of natural radioactivity in the investigated agricultural soils and the measured radionuclides did not indicate any significant radiological concern. The present study provides baseline data that can be used in supporting future environmental monitoring and radiological assessment of agricultural soils in Kufa city.

Keywords: Natural radioactivity, agricultural soil, ^{238}U , ^{232}Th , ^{40}K , NaI(tl), gamma-ray spectrometry, Kufa city, Iraq

1. Introduction

Natural radioactivity is an intrinsic component of the terrestrial environment and is mainly associated with primordial radionuclides, particularly uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium-40 (^{40}K). These radionuclides are naturally present in rocks, sediments and soils, and their concentrations depend on geological composition, parent materials, mineralogy, weathering and sedimentary processes [1, 2]. The soil is an important environmental reservoir for natural radionuclides and is a major contributor to terrestrial gamma radiation, therefore, the evaluation of their concentrations is important when trying to determine the natural radiological background of an area [1, 3]. The spatial distribution of ^{238}U , ^{232}Th and ^{40}K in soils is generally heterogeneous due to the influence of different environmental and geochemical processes on each radionuclide. Uranium and thorium are related to certain minerals and fine soil fractions, while ^{40}K is primarily associated with potassium-bearing minerals such as feldspars, micas, and clay minerals [2, 4]. Hence, variations in soil texture, mineral composition, weathering, erosion and sediment transport can produce large differences in natural radioactivity over relatively short distances [2, 5]. In particular, the study of such variations is of great importance for agricultural soils in fluvial environments. Rivers are in a state of constant motion, sorting and depositing sediments from many different geologic sources. Erosion, flooding, sediment transport and alluvial

deposition by the Euphrates River have been important in the formation of the landscape around Kufa City. These long-term processes have led to the formation of a variety of geomorphological environments like alluvial plains, floodplain deposits, natural levees and other sedimentary units with varying textures, mineral compositions and depositional histories. These differences may directly affect the distribution of uranium, thorium and potassium in agricultural soils ^[2, 5]. Many studies have been conducted on the natural radioactivity in soils, however, the traditional assessments that are solely based on mean activity concentrations are not sufficient to consider the geographical variability of radionuclides. Therefore spatial analysis is needed to identify areas of relatively high and low concentrations and to study environmental factors controlling their distribution. Geographic Information Systems (GIS) are efficient tools for the integration of the radionuclides measurements with the data coordinates of the sampling and the environment, allowing the development of continuous maps of the spatial distribution through the use of interpolation techniques and facilitating a more complete interpretation of the radioactivity patterns. ^[3, 6] Remote sensing complements this approach by providing spatial information on land-cover conditions, vegetation, soil surfaces, moisture and geomorphological characteristics. Data and indices derived from satellites can be combined with GIS to describe the environmental setting of agricultural lands and to aid in the interpretation of spatial differences in radionuclide concentrations. In addition, the identification of geomorphological units provides a significant framework for understanding whether differences in natural radioactivity are correlated with sedimentary origin and landscape evolution ^[5, 7]. The simultaneous determination of ²³⁸U, ²³²Th and ⁴⁰K is of particular importance as these radionuclides may exhibit different spatial behaviors. The joint study of them can provide useful information on the geological and environmental processes that affect the radioactivity of the soil. In addition, the measured activity concentrations can be used to estimate the radiological hazard parameters and set a baseline for future environmental monitoring ^[1, 3]. Hence, the present work aims to study the spatial distribution of natural radioactivity in agricultural soils east of Euphrates River, Kufa City by measuring the activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K. The study combines field measurements with Remote Sensing and Geographic Information Systems (GIS) to produce spatial distribution maps and to investigate the relationship between radionuclide concentrations and the main geomorphological units. This integrated approach is expected to provide a better understanding of natural radioactivity controls by environmental and geomorphological factors and to assist in the construction of a complete radiological baseline for the agricultural soils of the study region.

2. Study Area

The present study was conducted in the agricultural areas

lying to the east of Euphrates River inside and around Kufa City, Al- Najaf Governorate, central Iraq. Kufa is located in a significant section of the Euphrates River basin where a large number of agricultural areas have been developed on alluvial deposits which the river has transported and laid down over a long period of time. The study area is characterized by a predominantly flat topography and an agricultural landscape shaped by irrigation, seasonal cultivation and the constant interaction between soil and river processes. The soils of the study area are largely associated with alluvial sediments which may vary in their texture, grain size, mineral composition and depositional history. The Euphrates River has had a great influence on the geomorphological features of this region by erosion, sediment transport, flooding and deposition. These processes have produced several geomorphological units such as alluvial plains, floodplain deposits, natural levees and other fluvial landforms. Such changes of geomorphological conditions can affect the distribution of naturally occurring radionuclides in agricultural soils. The region's climate is generally characterized by hot and dry conditions, with high temperatures during summer and relatively limited precipitation. The main source of irrigation water for agricultural activities is the Euphrates River and its related irrigation networks. The constant use of agricultural land and natural sedimentary processes makes this location suitable for the study of the spatial behavior of uranium-238 (²³⁸U), thorium-232 (²³²Th) and potassium-40 (⁴⁰K). The location east of the Euphrates River was chosen based on the importance of the environment and agriculture and the possibility of the influence of geomorphological variability on soil characteristics. In this study, soil samples were collected from spatially distributed agricultural locations to represent the variability of study area. All sampling sites were geo-referenced and entered into a Geographic Information System (GIS) database. The spatial database was used to analyze and spatialize the distribution of the measured radionuclides and to investigate the relationship with the identified geomorphological units. Remote sensing data were also used to obtain spatial information on the characteristics of the study area and to assist in the delineation and interpretation of land-surface and geomorphological features. The integration of field measurements, geomorphological data, remote sensing and GIS offers a complete framework to assess the spatial variation of natural radioactivity in agricultural soils east of the Euphrates River. All sample sites were geo-referenced with the Global Positioning System (GPS) and imported into a Geographic Information System (GIS) database. The sampling sites distribution is a spatial framework for the mapping and analysis of the concentrations of the radionuclides under investigation and the relationship with the local geomorphological characteristics. Table 1. The geographical coordinates and sample codes of the 60 agricultural soil sampling sites used in this study.

Table 1: Geographic coordinates of agricultural soil sampling locations east of the Euphrates River, Kufa City, Iraq

S. No.	Sample Code	Latitude (N)	Longitude (E)
1	KS-01	32°02'19.79376756"	44°25'17.23349388"
2	KS-02	32°02'19.48081812"	44°25'18.98948784"
3	KS-03	32°02'19.11571044"	44°25'19.77186144"
4	KS-04	32°02'18.75060276"	44°25'20.60639328"

5	KS-05	32°02'19.63312008"	44°25'16.77450144"
6	KS-06	32°02'19.57748460"	44°25'17.78706660"
7	KS-07	32°02'19.58861184"	44°25'18.42131100"
8	KS-08	32°02'19.34381580"	44°25'19.37824068"
9	KS-09	32°02'18.89873196"	44°25'20.07924744"
10	KS-10	32°02'18.77633412"	44°25'21.14744808"
11	KS-11	32°02'19.67762832"	44°25'17.45325408"
12	KS-12	32°02'19.75551828"	44°25'16.94140788"
13	KS-13	32°02'19.61086596"	44°25'18.69948804"
14	KS-14	32°02'19.63312008"	44°25'18.06524400"
15	KS-15	32°02'18.79858824"	44°25'20.34629760"
16	KS-16	32°02'14.22469500"	44°25'17.10265260"
17	KS-17	32°02'14.67134556"	44°25'16.74715548"
18	KS-18	32°02'15.34132104"	44°25'16.43267712"
19	KS-19	32°02'16.02952692"	44°25'16.09085280"
20	KS-20	32°02'16.94245020"	44°25'16.08601260"
21	KS-21	32°02'17.75959620"	44°25'16.05124056"
22	KS-22	32°02'18.59412804"	44°25'16.05124056"
23	KS-23	32°02'14.41896504"	44°25'16.90980672"
24	KS-24	32°02'15.08213976"	44°25'16.54083228"
25	KS-25	32°02'15.82765476"	44°25'16.18476564"
26	KS-26	32°02'16.58429700"	44°25'16.04011332"
27	KS-27	32°02'17.38544784"	44°25'16.10687604"
28	KS-28	32°02'18.20885244"	44°25'15.96222372"
29	KS-29	32°02'18.93211332"	44°25'16.31829072"
30	KS-30	32°02'16.33950096"	44°25'16.05124056"
31	KS-31	32°02'18.85491924"	44°25'21.59739984"
32	KS-32	32°02'18.54196980"	44°25'22.62317880"
33	KS-33	32°02'17.49880500"	44°25'22.53624816"
34	KS-34	32°02'16.32036264"	44°25'21.58140468"
35	KS-35	32°02'16.02126636"	44°25'21.80928756"
36	KS-36	32°02'15.55837944"	44°25'21.94459320"
37	KS-37	32°02'18.76520688"	44°25'22.19339496"
38	KS-38	32°02'17.97518364"	44°25'22.70524116"
39	KS-39	32°02'17.20741416"	44°25'22.34917416"
40	KS-40	32°02'16.57317012"	44°25'21.41449824"
41	KS-41	32°02'18.26448792"	44°25'22.71636804"
42	KS-42	32°02'18.80971548"	44°25'21.89296344"
43	KS-43	32°02'16.81885608"	44°25'21.28942992"
44	KS-44	32°02'17.09764548"	44°25'22.04443092"
45	KS-45	32°02'17.03961780"	44°25'21.67398228"
46	KS-46	32°02'14.11531116"	44°25'19.63215192"
47	KS-47	32°02'13.98769692"	44°25'19.38603864"
48	KS-48	32°02'13.80994836"	44°25'19.05788748"
49	KS-49	32°02'13.61852664"	44°25'18.53831460"
50	KS-50	32°02'13.53648876"	44°25'17.83643520"
51	KS-51	32°02'13.58662308"	44°25'17.49916884"
52	KS-52	32°02'13.82362116"	44°25'17.19836328"
53	KS-53	32°02'15.35186040"	44°25'21.53867664"
54	KS-54	32°02'15.05276412"	44°25'20.96184828"
55	KS-55	32°02'14.88897348"	44°25'20.49896136"
56	KS-56	32°02'14.73942552"	44°25'20.13577320"
57	KS-57	32°02'14.51154264"	44°25'19.67288592"
58	KS-58	32°02'13.57152576"	44°25'18.18452640"
59	KS-59	32°02'14.63705628"	44°25'19.89008688"
60	KS-60	32°02'13.72463484"	44°25'18.75512352"

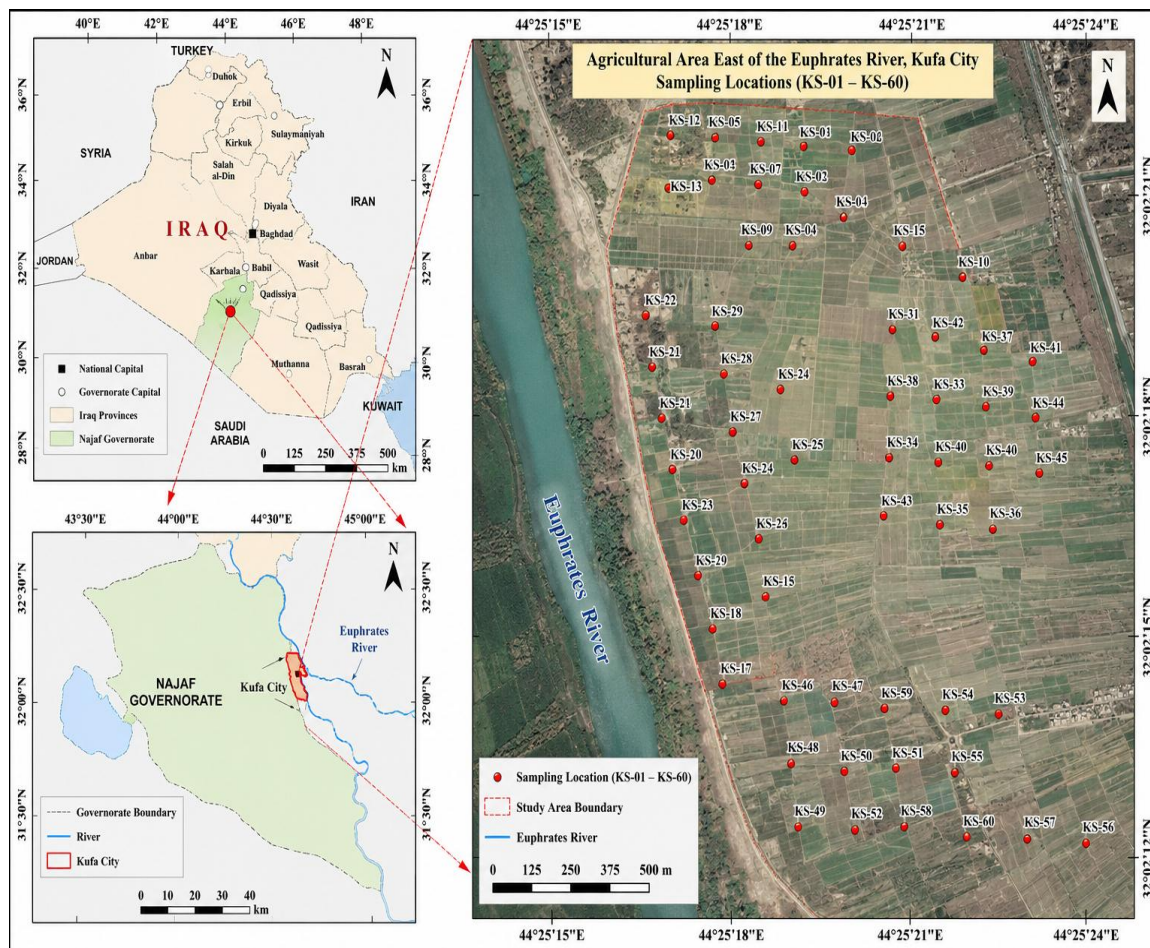


Fig 1: Location of the study area and spatial distribution of agricultural soil sampling sites (KS-01-KS-60) east of the Euphrates River, Kufa City, Al-Najaf Governorate, Iraq

3. Practical aspect

3.1 Soil Sampling

The gathering of representative soil samples is a basic step in environmental radioactivity studies because the reliability of the radiological and spatial analyzes that follow depend strongly on the quality and geographical distribution of the sampling network. In the present study, the agricultural soil samples were systematically collected from an open agricultural area east of the Euphrates River in Kufa City, Al-Najaf Governorate, Iraq. The study area was considered as a single and continuous geographical unit, and the sampling strategy was oriented to the representative coverage of the spatial variability in the investigated agricultural landscape. The study area was divided into different sites and a total of 60 soil samples were collected from different sites. The sampling sites were spatially distributed to cover the entire agricultural area, and to account for possible variations in the natural concentrations of ^{238}U , ^{232}Th and ^{40}K . This distribution was of special importance since the study area is linked with an alluvial environment, influenced by the Euphrates River, in which long-term processes of sediment transportation, deposition, flooding and soil development could lead to differences in mineralogical composition and, consequently, in natural radioactivity levels. Prior to the collection of each sample, the surface was carefully inspected and any foreign materials (plant residues, stones, roots and other visible foreign materials) were discarded. Then soil samples were taken from representative sites to obtain samples that were representative of the local characteristics of the agricultural

soil. Each sample was collected in clean polyethylene bags and assigned a unique identification code (from KS-01 to KS-60) for accurate identification during sample preparation, measurement and data-analysis. The geographical position of each sampling site was recorded by using Global Positioning System (GPS). The latitude and longitude coordinates were then entered into a Geographic Information System (GIS) database. This procedure allowed to establish an accurate spatial framework to associate the radiological results obtained through gamma-ray spectrometry with their respective geographic locations. Then, the recorded coordinates were used to generate the map of the sampling locations, to produce spatial distribution maps of the investigated radionuclides, and to study the relationship between natural radioactivity and the geomorphological features of the study area. The availability of a dense sampling network over the agricultural landscape enabled the study to go beyond an average assessment of radionuclide concentrations. Thus, the sampling design allowed us to analyze the spatial variability and geographical patterns of ^{238}U , ^{232}Th and ^{40}K . Therefore, the collected samples represent an important environmental data set for the assessment of natural radioactive background of agricultural soils in the east of the Euphrates River and for the investigation of possible correlations between the distribution of radionuclides, sedimentary conditions and geomorphological units.

3.2 Sample Preparation

All soil samples were collected, transported to the

laboratory and processed through a standard preparation protocol prior to analysis by gamma-ray spectrometry. The sample preparation plays an important role in the measurements of natural radioactivity, since the moisture content, the particle size, the homogeneity of the sample and the differences in the counting geometry may influence the accuracy and reproducibility of the measured gamma-ray spectra. Therefore, all the 60 agricultural soil samples were prepared using the same procedure to maintain the measurement condition. The samples were initially dispersed individually on clean and dry surfaces to decrease the natural moisture of the samples. Samples were then dried to a stable and sufficiently dry state under controlled conditions. Drying was carried out to minimize the effect of variable soil moisture and to allow consistent reporting of radionuclide concentrations on a dry-mass basis. Each sample was then gently crushed and ground after drying to break down aggregates and to obtain a more homogeneous material. The samples were then thoroughly mixed to ensure homogeneity because natural radionuclides may not be uniformly distributed in untreated soil. The homogenized soil was then sieved to remove coarse particles, stones, roots and other undesired materials. This step produced a relatively homogeneous grain-size fraction suitable for reproducible gamma-ray spectrometric measurements. The prepared samples were then placed into standardized measurement containers of identical geometry. When using a NaI(Tl) gamma-ray spectrometry system it is particularly important to measure all the samples in the same container size, sample geometry and filling conditions as the detection efficiency depends on the geometry and physical arrangement of the sample relative to the detector. Samples

were filled, sealed and labeled with the sample code for each container. The sealed samples were kept for an appropriate time before measurement in an effort to establish secular radioactive equilibrium between radium-226 (^{226}Ra) and its short-lived decay products especially when the indirect determination of the uranium series was based on gamma emissions from the daughter radionuclides. Once the samples were prepared and the equilibration period was over, the radiological analysis could take place. Then activity concentrations of ^{238}U , ^{232}Th and ^{40}K were measured by a thallium-doped sodium iodide (NaI(Tl)) gamma-ray spectrometry system. Prior to the sample measurements, the spectrometry system was properly energy-calibrated and efficiency-calibrated using appropriate reference sources and standard procedures. All soil samples were measured with the same counting geometry and experimental conditions in an effort to make the results comparable. The measured gamma-ray spectra were analyzed to identify the characteristic energy peaks of the investigated natural radionuclides and their decay products from which the activity concentrations were derived. The 60 agricultural soil samples were prepared under comparable conditions by following a standardized procedure (drying, homogenization, sieving, sealing, equilibration, and gamma-ray measurement). Thus, the collected radiological data could be reliably integrated with GPS coordinates and GIS environment for later statistical analysis, spatial interpolation and assessment of the relationship between natural radioactivity and the geomorphologic units of the agricultural area east of the Euphrates River.



Fig 2: Collection and preparation procedures of agricultural soil samples for natural radioactivity analysis

3.3 Gamma-Ray Spectrometric Measurements Using NaI(Tl)

The prepared samples of agricultural soil were analyzed using thallium-activated sodium iodide [NaI(Tl)] gamma-ray spectrometry. The NaI(Tl) detector is a scintillation detector. The incident gamma photons interact with the crystal to produce flashes of light proportional to the deposited energy. These light signals are converted into electrical pulses and then processed by the corresponding electronic system and multichannel analyzer to obtain the gamma-ray energy spectrum. The NaI(Tl) detector is widely used for the determination of naturally occurring radionuclides, including the uranium and thorium decay series and potassium-40 [8, 9], due to its relatively high detection efficiency, suitability for environmental measurements and ability to record gamma radiation over a wide energy range. The gamma-ray spectrometry system was energy-calibrated with suitable standard gamma-emitting reference sources of well-defined photon energies before measuring the soil samples. The channel number versus gamma ray energy relationship was found to be able to properly identify the characteristic photopeaks in the measured spectra. Repeated measurements of appropriate reference sources were also used to verify the stability and the energy resolution of the system, since proper calibration

is necessary for accurate peak identification and reliable radionuclide determination [8]. Efficiency calibration was also done to relate the detector efficiency to the gamma-ray energy. This calibration was done using appropriate reference materials or standard sources counted under the same counting geometry as the soil samples investigated. Since the gamma-ray detection efficiency depends on the source geometry, sample density, matrix composition and photon energy [8, 10], it is important to keep the same sample containers, sample geometry and measurement conditions. The use of certified reference materials and standard calibration procedures also improves the accuracy, comparability and quality assurance of environmental radioactivity measurements [11]. Each sealed soil sample was positioned at a fixed distance from the NaI(Tl) detector and counted for the same predetermined counting time. The sample spectra were corrected by subtracting a background radiation measured separately under the same experimental conditions. This procedure minimized the contribution of environmental and instrumental background radiation to the recorded net count rates. The resulting spectra were analyzed to determine the net areas of the characteristic gamma-ray peaks associated with the investigated radionuclides and their progenies [8, 12].

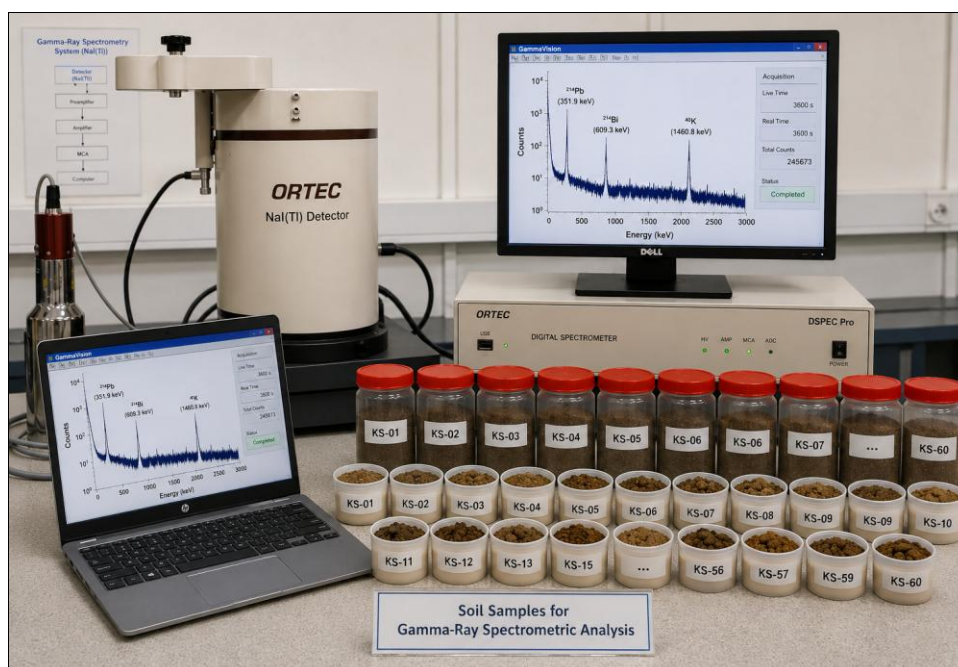


Fig 3: NaI(Tl) gamma-ray spectrometry system and prepared agricultural soil samples (KS-01-KS-60) used for natural radioactivity measurements

4. Calculations

4.1. Specific Activity (A)

Specific activities of radionuclides ^{238}U , ^{232}Th and ^{40}K (denoted as AU, Th and K respectively) were calculated from: Where N is net area under a photopeak, I_γ corresponds to the probability of gamma emission, ϵ is detector efficiency, M is the sample mass and T is the measurement time [13-15].

$$A(\text{Bq/kg}) = N / (I_\gamma \epsilon M T) \dots \dots \dots (1)$$

5. Results and Discussion

Table 2 shows the activity concentrations of the naturally

occurring radionuclides ^{238}U , ^{232}Th and ^{40}K in the 60 agricultural soil samples collected from east of Euphrates River in Kufa City. The results showed significant differences between the sampling locations, suggesting that the distribution of natural radioactivity was not uniform in the studied agricultural area. Such variations are expected, since soil radioactivity depends on several natural factors, such as the mineralogical composition of the parent materials, the origin of the sediment, the weathering, the grain-size distribution, the fluvial deposition processes, etc. [14, 15]. The spatially referenced measurements therefore provide an important basis for subsequent GIS analysis and for study of the relationship between radionuclide

distribution and the geomorphological characteristics of the study area. The activity concentration of ^{238}U ranged from 18.65 Bq kg⁻¹ in the sample KS-50 to 29.68 Bq kg⁻¹ in KS-41 with a mean value of 23.87 Bq kg⁻¹. This average was lower than the reference value of 33 Bq kg⁻¹ that was used for comparison. The relatively higher values observed in some of the samples like KS-31, KS-37, KS-41 and KS-42 may be linked to localized differences in the distribution of uranium bearing minerals and the composition of deposited alluvial sediments. Conversely, lower concentrations in samples KS-46 to KS-52 may indicate soils with lower contents of uranium-associated minerals. Uranium concentrations in soils have previously been shown to vary widely depending on local geology and soil forming processes [14-16]. For ^{232}Th concentrations ranged from 23.48 Bq kg⁻¹ in KS-50 to 37.12 Bq kg⁻¹ in KS-41 with an overall average of 29.72 Bq kg⁻¹. All samples were lower than the reference value of 45 Bq kg⁻¹. The ^{232}Th distribution was generally similar to that of ^{238}U , indicating that variations in the mineralogical and sedimentological characteristics of the soils may affect both radionuclides. Thorium is commonly associated with resistant minerals and is strongly bound to soil particles, thus its spatial distribution may reflect differences in sediment provenance and depositional history [15, 17]. The highest activity concentrations were observed for ^{40}K , ranging from 271.4 Bq kg⁻¹ in KS-50 to 419.4 Bq kg⁻¹ in KS-41, with the mean value of 350.8 Bq kg⁻¹. The dominance of ^{40}K over ^{238}U and ^{232}Th is expected since potassium is naturally present in many common soil-forming minerals. The average concentration was found to be below the adopted reference value of 420 Bq kg⁻¹ and the maximum value recorded was very close to this reference value [14, 15]. Variations in ^{40}K

activity could thus be indicative of variations in abundance and spatial distribution of potassium bearing minerals within the agricultural soils. A comparison of the sampling locations shows that relatively high activities of the three radionuclides were generally confined to samples KS-31 to KS-45, while comparatively lower values were recorded in several samples, notably in samples KS-46 to KS-52. For example, the highest activity was in KS-41 combined, while the lowest concentrations were in KS-50 combined. This distribution pattern may be indicative of the effect of the differences in the properties and origin of the alluvial sediments forming the soils on the natural radioactivity. The study area is located in the environment of the Euphrates river where sediment transport, deposition and geomorphological processes may play an important role in the control of these spatial differences [16-18]. To summarize, the findings indicated that the natural radioactivity levels in agricultural soils in the eastern side of Euphrates River are low to moderate. The average values for ^{238}U , ^{232}Th and ^{40}K were all less than the world reference values used in this study [14, 15]. The general trend of the radionuclides was $^{40}\text{K} > ^{232}\text{Th} > ^{238}\text{U}$ which is in agreement with the expected natural composition of terrestrial soils. The spatial variations observed do not indicate abnormal radioactive enrichment but seem to reflect natural variations in the mineralogy of the soils, the origin of the sediment and the geomorphological conditions. Thus, the integration of these results with GIS interpolation, remote sensing data and geomorphological units maps will give a better understanding of the spatial distribution of natural radioactivity and its relation with the physical features of the agricultural landscape [20-18].

Table 2: Activity concentrations of natural radionuclides in agricultural soil samples east of the Euphrates River, Kufa City (Bq kg⁻¹)

o.N	Sample Code	^{238}U (Bq kg ⁻¹)	^{232}Th (Bq kg ⁻¹)	^{40}K (Bq kg ⁻¹)
1	KS-01	21.45	27.30	315.6
2	KS-02	22.18	28.15	328.4
3	KS-03	20.96	26.74	304.8
4	KS-04	23.12	29.06	341.2
5	KS-05	21.78	27.85	322.5
6	KS-06	24.36	30.42	356.8
7	KS-07	23.85	29.74	348.6
8	KS-08	25.14	31.28	372.4
9	KS-09	22.94	28.96	337.5
10	KS-10	24.68	30.86	361.7
11	KS-11	26.32	32.45	386.3
12	KS-12	25.47	31.76	374.8
13	KS-13	24.95	30.94	365.2
14	KS-14	23.68	29.38	351.6
15	KS-15	26.84	33.12	392.7
16	KS-16	19.85	25.16	286.4
17	KS-17	20.42	25.84	294.7
18	KS-18	21.16	26.35	306.2
19	KS-19	22.04	27.68	318.5
20	KS-20	21.74	27.12	312.8
21	KS-21	22.68	28.46	326.9
22	KS-22	23.35	29.15	339.4
23	KS-23	20.14	25.62	291.6
24	KS-24	21.05	26.48	303.7
25	KS-25	22.47	27.94	321.8
26	KS-26	23.08	28.72	334.6
27	KS-27	22.86	28.36	329.5
28	KS-28	24.12	29.86	347.8
29	KS-29	23.74	29.24	342.1

30	KS-30	21.96	27.54	315.9
31	KS-31	27.18	33.86	398.4
32	KS-32	28.42	35.24	412.6
33	KS-33	27.65	34.48	405.3
34	KS-34	26.94	33.52	391.8
35	KS-35	28.16	34.96	408.7
36	KS-36	27.38	34.15	401.2
37	KS-37	29.24	36.48	418.5
38	KS-38	28.76	35.86	414.2
39	KS-39	27.92	34.72	406.8
40	KS-40	26.58	33.28	389.6
41	KS-41	29.68	37.12	419.4
42	KS-42	28.94	36.24	415.7
43	KS-43	26.76	33.64	393.5
44	KS-44	27.46	34.36	402.8
45	KS-45	28.05	34.84	410.4
46	KS-46	18.94	23.85	278.6
47	KS-47	19.36	24.42	284.3
48	KS-48	20.18	25.36	297.5
49	KS-49	19.72	24.86	289.8
50	KS-50	18.65	23.48	271.4
51	KS-51	19.24	24.15	281.6
52	KS-52	20.06	25.04	295.2
53	KS-53	22.84	28.68	336.7
54	KS-54	23.56	29.42	345.8
55	KS-55	24.18	30.15	358.4
56	KS-56	23.82	29.74	349.6
57	KS-57	22.96	28.85	338.2
58	KS-58	20.54	25.96	301.4
59	KS-59	21.68	27.24	316.8
60	KS-60	20.85	26.68	308.5
Average		23.87	29.72	350.8
Reference value (Bq kg ⁻¹)		33	45	420

To provide a clear visual interpretation of the obtained results, the activity concentrations of the investigated natural radionuclides were illustrated in Figures 3-5. Figure 3 presents the distribution of ²³⁸U activity concentrations among the agricultural soil samples in comparison with the reference value, while Figure 4 shows the corresponding

variation in ²³²Th concentrations. Figure 5 illustrates the activity concentrations of ⁴⁰K and their comparison with the reference level. The graphical presentation confirms the results discussed above and clearly demonstrates that the measured concentrations of all investigated radionuclides remained below their respective reference values.

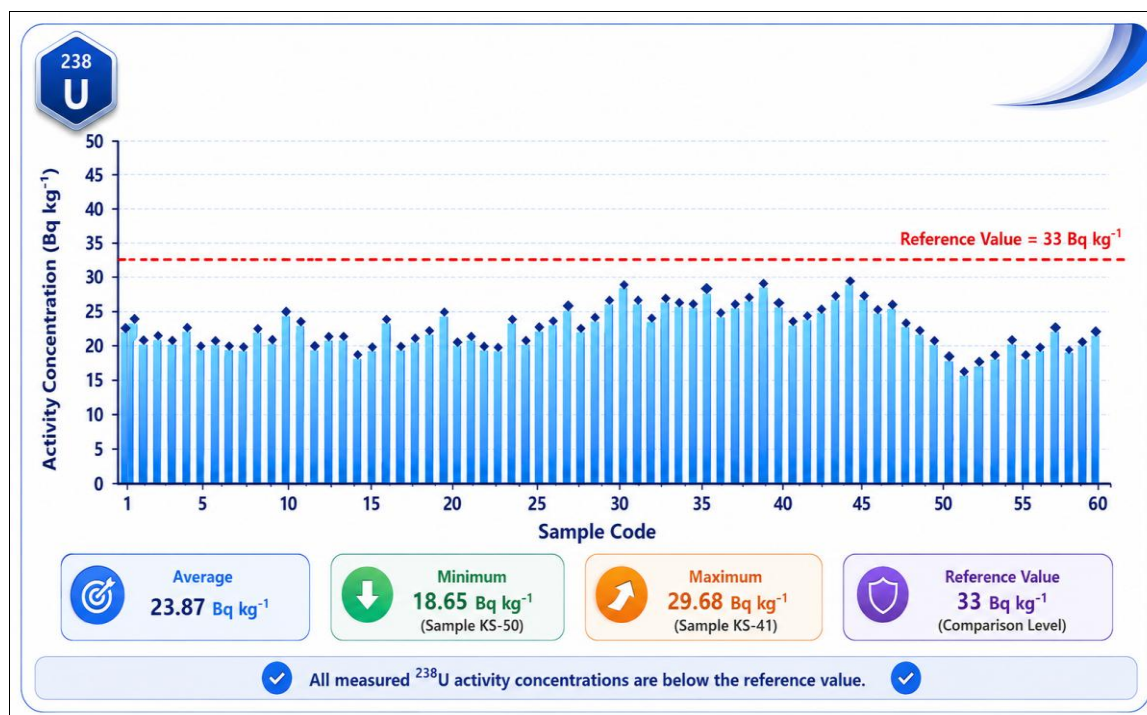


Fig 3: Activity Concentration of ²³⁸U in Agricultural Soil Samples Compared with the Reference Value

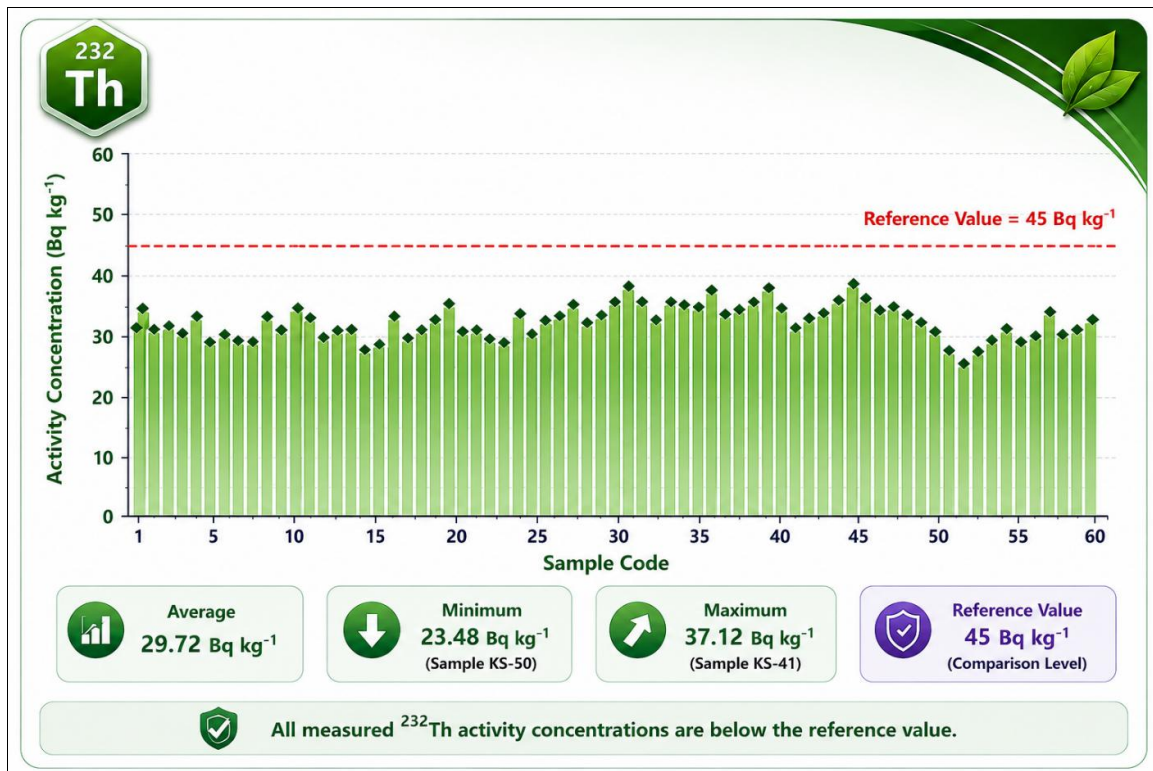


Fig 4: Activity Concentration of ^{232}Th in Agricultural Soil Samples Compared with the Reference Value

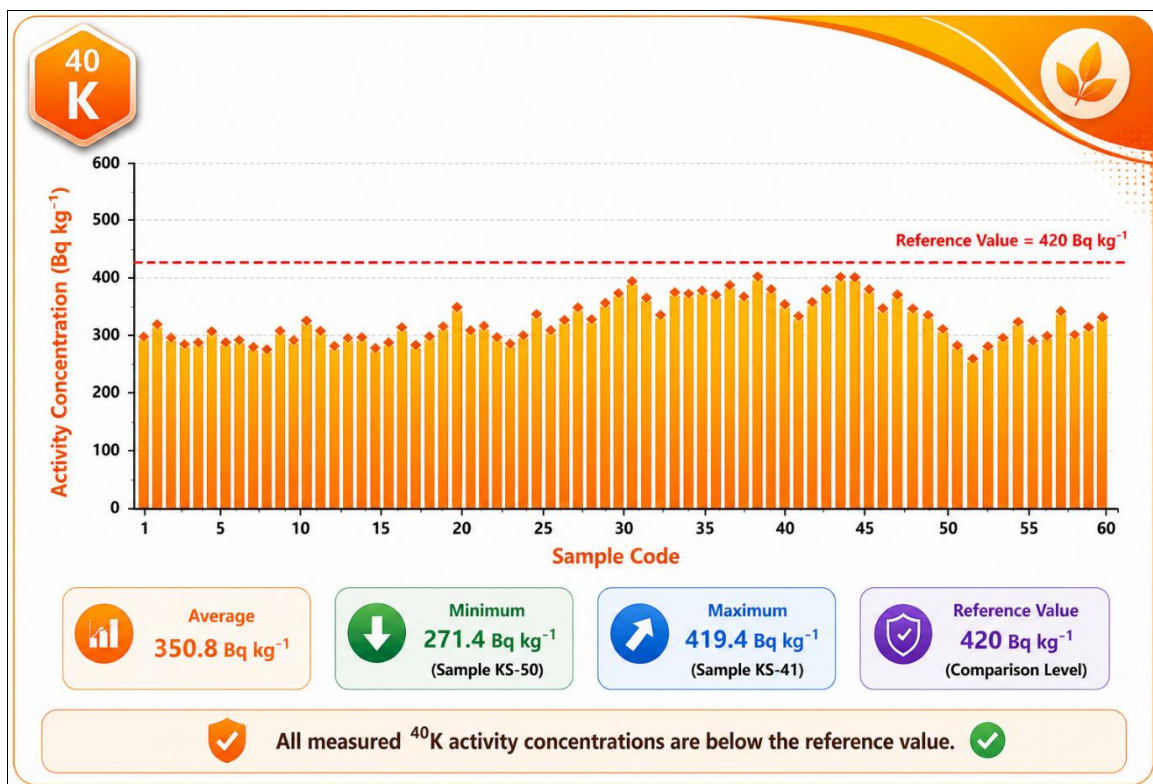


Fig 5: Activity Concentration of ^{40}K in Agricultural Soil Samples Compared with the Reference Value

Conclusion

The present work showed that the agricultural soils collected from the east side of Euphrates River in Kufa City contain detectable levels of the natural radionuclides ^{238}U , ^{232}Th and ^{40}K . Analyzes showed spatial variations between the samples, but all measured activity concentrations were lower than their reference values. Therefore, it can be stated that the agricultural area under study has a normal range of natural radioactivity and does not represent a radiological

concern of significance considering the radionuclides evaluated.

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