

Assessment of ^{39}K , ^{232}Th , and ^{238}U isotopes in soil samples with ICP-MS in El-Obied, Sudan

Amar Belly^{1,2}, Abdelrazig M. Abdelbagi^{3,4}, Abdelaziz A.M. El Shokali^{1,3}, Ahmed Elfaki¹

¹Physics Department, College of Science, Sudan University for Science and Technology, Khartoum, Sudan

²University of Sennar, Physics Department, Education College, Sennar, Sudan

³Physics Department, College of Science and Humanities, Al-Dawadmi, Shaqra University, Riyadh, KSA

⁴Omdurman Islamic University, Faculty of Science, Omdurman, Sudan

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Abstract: The main objective of the present study was to determine the concentrations of the radioisotopes potassium- ^{39}K , thorium- ^{232}Th , and uranium- ^{238}U in soil samples collected from selected areas around El-Obeid City, Sudan. Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) analysis was employed to quantify these isotopes. Soil samples were obtained from five locations surrounding El-Obeid, specifically from two regions in the southern and western parts of the city within North Kordofan State, in areas located away from residential zones. High correlation coefficients between ^{232}Th and ^{238}U indicate that these isotopes likely originate from the same source. Principal component and factor analyses further confirm that ^{232}Th and ^{238}U share common sources in the soil samples collected from various locations around El-Obeid City. In addition, the measured concentrations of ^{238}U and ^{39}K are in reasonable agreement with values reported in the literature. The concentration of ^{232}Th observed in this study is relatively high compared to values reported from other regions worldwide, suggesting possible local geological or anthropogenic influences.

Keyword: Radioactive elements, Potassium; Thorium; Uranium; ICP_MS spectrometer, Data Analysis, Elobied, Sudan

I. Introduction:

Natural terrestrial background radiation in the environment originates from various sources, including gamma, alpha, and beta radiation emitted by naturally occurring radionuclides found in soil, rocks, water, and air. The natural terrestrial background radiation primarily comes from naturally occurring radionuclides in the Earth's crust, soil, and atmosphere (1). These originate from radioactive elements present in the soil, rocks, and building materials (2). The level of environmental radiation pollution provides essential radiological information on radiation levels in soils, building materials, water, food, and air. Uranium is the most abundant naturally occurring element, which is primordially radioactive and decays until it reaches a stable nucleus (3).

Moreover, uranium in the earth's crust is mainly found in soil, beach sand, and rocks, with the highest concentration in phosphate rocks, which represent an estimated abundance of 0.5 to 5 ppm. A significant natural radionuclide found in the Earth's crust is the uranium isotope (4). After decaying into thirteen radioactive daughter isotopes and emitting alpha radiation, the parent atom ^{238}U eventually becomes stable lead (^{206}Pb). Uranium-238 is the most abundant of the three natural uranium origins in the Earth's crust and is an important radionuclide since Earth's formation, continuously emitting alpha radiation (5). Uranium can be leached from source rocks and redeposited in reducing environments such as sandstones, clays, and organic-rich layers. Concentrations are usually lower unless secondary enrichment occurs. Two isotopes of uranium, uranium- ^{238}U , are found (6). The province under study, located within the uranium province district, aligns with the geological features typical of sub-Saharan African countries where uranium ore has been discovered. The natural presence of uranium in soil and human activities are the main sources of trace levels of uranium in the human environment. Both natural and external sources of irradiation emit gamma radiation (7). Terrestrial environmental radiation, which originates from naturally occurring radioactive elements in the Earth's crust, can indeed have negative impacts on both the environment and human health (8). An essential step in assessing the radiation dose exposure to individuals in the area, as a basis for the environmental pollution from ^{39}K , ^{232}Th , and ^{238}U radioactive sources, is determining the natural radioactivity of the elements in the soil in the study district (9). Potassium is an abundant element essential to life, and ^{39}K is found in the Earth's crustal rock in three isotopes: ^{39}K , ^{40}K , and ^{41}K . Potassium-39 (^{39}K) is a stable isotope that naturally occurs in soil, typically at concentrations ranging from 1 to 2 milligrams per kilogram (ppm) (10). This isotope contributes to the overall potassium content in geological materials but is not radiogenic. The stable isotope ^{39}K constitutes 93.258% of the total of potassium isotopes in nature. (Steno Wang; Morgan et al., 2018).

In the Earth's crust, thorium is frequently found in the thorium-phosphate minerals, which can contain up to 12% thorium oxide, ThO_2 . Since thorium is likewise radioactive, the parent isotope's typical decay cycle results, and many of the daughters are gamma emitters. The predominant isotope, thorium-232, is a naturally occurring radioactive metal that is concentrated mainly in acidic igneous rocks such as granites. Also, the average thorium concentration is 16.19 ppm (11).

Assessing the natural radioactivity in the soil of the study area is a critical step in evaluating the potential radiation dose to human exposure. This assessment provides a scientific basis for understanding the extent of environmental pollution arising from naturally

occurring radioactive materials, particularly ^{39}K , ^{232}Th , and ^{238}U . Monitoring naturally occurring radionuclides in the environment is essential for accurate radiological risk evaluation and effective long-term environmental health management (12).

Study Area:

El-Obeid, located in central-western Sudan, is the capital of North Kordofan State. Its approximate geographical coordinates are $13^{\circ}11' \text{ N}$, the latitude, and $30^{\circ}13' \text{ E}$. El-Obeid is situated within the semi-arid Sahel region, not far from the border between North and South Kordofan, and is distinct from Sudan's Eastern Desert, which lies much farther east (9). The western and southern regions of El Obeid are primarily composed of sand and sediment. A total of thirty-seven (37) soil samples were collected from various locations throughout the province, including sites near residential. The Eastern Desert lies to the east of the Nile, while El Obeid is well to the west, in the Sahelian belt of central-western Sudan. The region around El Obeid experiences a semi-arid. In terms of natural resources, five zones have been identified in the area for their sample collections. The surrounding area shows extensive agricultural cultivation and animal husbandry, highlighting the city's deep connection to the land. These activities are crucial not only for subsistence and the local economy but also serve as a fundamental aspect of the native cultural identity within the region. The zones' qualitative analysis of samples from selected locations indicated promising elemental signatures, suggesting the potential radioactive enrichment that warrants further investigation. The qualitative analyses of samples from chosen locations revealed encouraging elemental signatures, indicating the potential radioactive enrichment, which requires further examination.

Experimental and Methods:

Soil samples were collected from five sites located around El-Obied City in western Sudan. These sites were selected to evaluate trace elements in the local environment. Due to the nature of the samples, soil extracted from the underground area at a depth of 0.5 meters can be analyzed with minimal or no pretreatment. Inductively Coupled Plasma Mass Spectrometry ICP-MS is a highly sensitive and precise technique for detecting trace and ultra-trace elements across a wide range of scientific fields (13). The capability to measure both concentrations and low detection limits makes it a go-to method in environmental and nuclear sciences. In this study, the concentration of trace elements in soil samples was measured using ICP-MS at the Atomic Energy Authority Nuclear Research Center, Center Laboratory for Elemental and Isotopic Analysis, Cairo, Egypt. Inductively Coupled Plasma Mass Spectrometry was employed for precise concentration measurements, aiding in the exploration of the isotopic analysis of elements. In this study, the analysis focused on the radioactive elements Potassium (^{39}K), Uranium (^{238}U), and Thorium (^{232}Th).

II. Results and Discussion:

The preliminary outcomes of the study highlighted the value of using ICP-MS to detect potassium, thorium, and uranium, as well as for assessing the spatial distribution of other elements in the area. The resulting data were subjected to various assessment methods and statistical analyses to ensure accuracy, reliability, and meaningful interpretation of the elemental concentrations. Samples are typically prepared in a soluble form for accurate analysis. Qualitative analysis of the soil samples indicated the presence of ^{39}K , ^{232}Th , and ^{238}U , with the corresponding peak concentrations presented in Figure 1. Distribution patterns, particularly of uranium multiplied by 1000 at the value, appear in the graph of the soil samples collected from the Elobied, Sudan. Figure 2 displays the factor analysis distribution of nuclear isotope concentration values, indicating that ^{232}Th and ^{238}U varied across all samples and were different from ^{39}K . The factors of variable concentration in one part of the graph, and the factors of variable ^{232}Th and ^{238}U from similar sources in all sites.

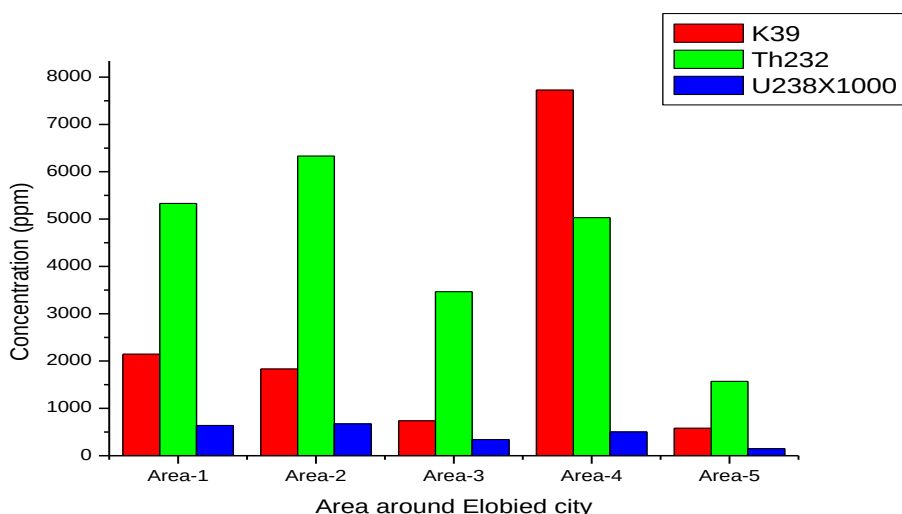


Fig. 1 Average radionuclide element concentration in Elobied.

Table 1: Correlation is significant at the 0.01 level.

Isotopes	^{39}K	^{232}Th	^{238}U
^{39}K	1	.401	.319
^{232}Th	.401	1	.983**
^{238}U	.319	.983**	1

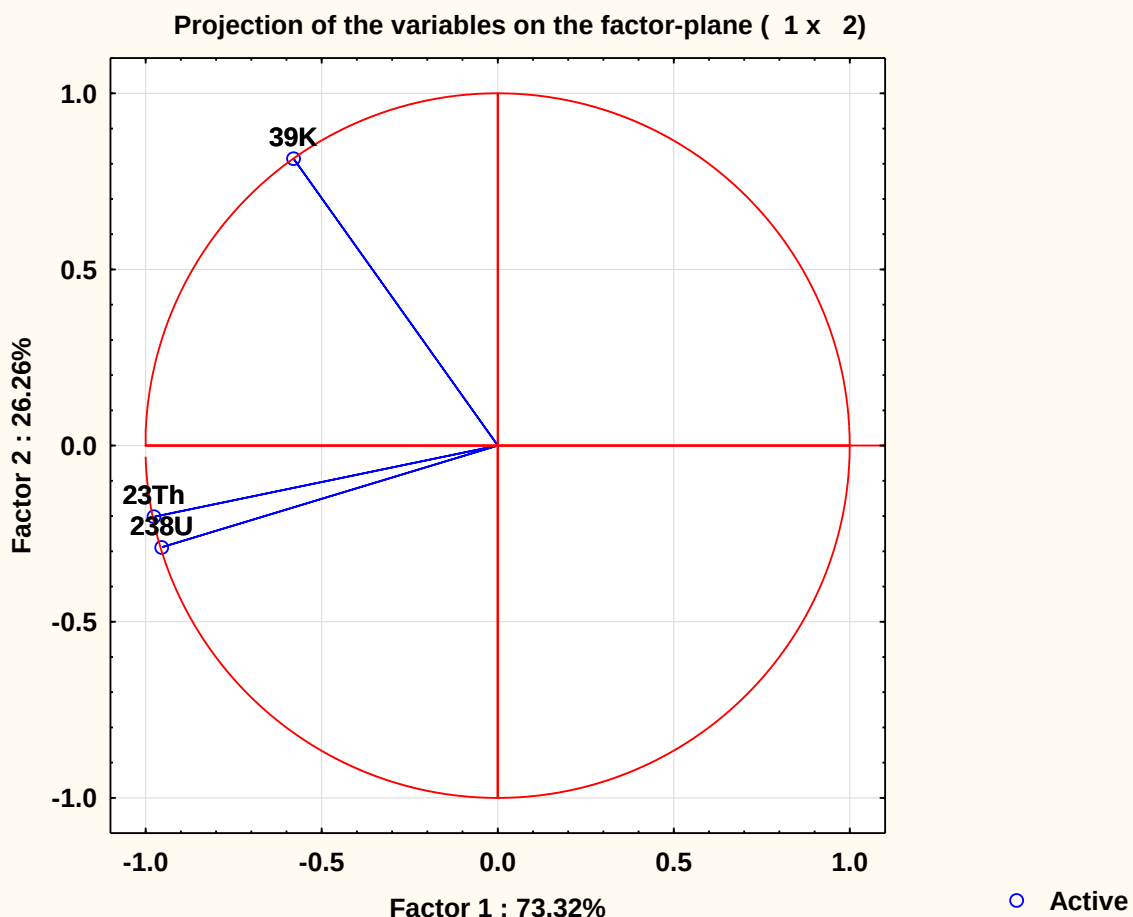


Figure 2: The Factor Analysis Distribution of Nuclear Isotope Concentration Values.

Table 2: t-test of the location

Element	Area-1	Area-2	Area-3	Area-4	Area-5
Isotope	t	T	t	t	t
39K	5.601	4.251	10.369	7.148	4.064
232Th	6.185	8.142	5.323	7.556	10.425
238U	5.595	7.584	4.524	7.561	13.499

Table 3: Factor Analysis

Extraction Method:		Principal Component Analysis	
	Location east ELobied		Location south ELobied

Isotopes elements	Communalities Extraction	Component Matrix ^a	Communalities Extraction	Component Matrix ^a
³⁹ K	.013	.113	.317	.563
²³² Th	.918	.958	.853	.924
²³⁸ U	.920	.959	.873	.935

Table 4. International reference data on the soil.

Region	Th(ppm)	U(ppm)	K (%)	Reference
IAEA-326-soil-Reference	9.71	2.38	1.91	Bajanowki-2001
United state	8.9±4.2	3.0± 2.5	-	Myrick et al 1983
Amman, Jordan	7.1	4.6	1.7	Ahmed et al(1997)
Istanbul, Turkey	9.1	1.7	1.1	Karahan and Bayulken-(2000)
Coastal area, Greece	17.5±6.2	7.5± 3.5	2.9 ± 1.2	Florouand Kritidis (1992)
Taiwan	10.8	2.4	1.4	Yu.Ming et al (1987)
Italy	18-21	4.6- 5.7	1.9 – 2.5	Bellia et al (1997)
Spain	3.2-20.9	1.6-57.6	1.0-2.3	Martinez-Aguirre and Garcia-Leon. 1992)
Rajasthan India	10.6- 26.1	2.4-6.3	0.2-0.5	Nageswara et al (1996)
Worldwide average	7.4	2.8	1.3	UNSCEAR report (2000)
El Obied, Sudan	1572.2-6331.47	0.1499-0.6741	0.0581- 0.7723	Present study

III. Discussion

The results of the soil analysis from the collected samples in the province under study, conducted using an ICP-MS spectrometer, are presented in the accompanying graph. Among the samples, the soil from **El-obeid** shows the highest concentrations of ²³²Th and ³⁹K. The graphical representation highlights factors contributing to concentration variability, with ²³²Th and ²³⁸U displaying similar distribution patterns, suggesting a common source is based on their relative percentage variations across all sampling sites. Table 1 shows the correlation coefficients among the element concentrations of these isotopes across the different sampling locations. The observed data suggest a direct relationship between ²³²Th and ²³⁸U concentrations, whereas ³⁹K shows notable variations among the study areas, reflecting differences in soil composition or mineral content (14). The results are summarized in Table 2, which presents the t-test values for the elements ³⁹K, ²³²Th, and ²³⁸U in soil samples collected from the five study sites, indicating identical values for ²³²Th and ²³⁸U. Table 3 presents the results of the principal component analysis (PCA), including the communalities extraction and component matrix for the isotopes ³⁹K, ²³²Th, and ²³⁸U in soil samples collected from two locations, the western and southern sites of El-Obied. The communalities extraction and component matrix values for ²³²Th and ²³⁸U show almost identical results across the sites, with noticeable differences observed for ³⁹K in the area (15). Table 4 presents international reference data on soil alongside the average results from this study, which were obtained from locations characterized by lower ²³⁸U concentrations, ³⁹K values within a similar percentage range, and higher ²³²Th levels.

IV. Conclusion:

This study presents the first evaluation of the concentrations of the radioactive isotopes ³⁹K, ²³²Th, and ²³⁸U in soil samples collected from various locations around Elobied, Sudan. The investigation detected the isotopes in a province surrounding Elobied city, located in North Kordofan State, Sudan, in areas situated away from residential zones. A significant difference in the concentrations of thorium ²³²Th and uranium ²³⁸U was observed; however, statistical analyses, including principal component analysis (PCA) and factor analysis, indicated that a considerable portion of the data exhibited nearly constant values. The uranium ²³⁸U concentration obtained in this study was lower than the international reference values presented in Table 4 and those reported by UNSCEAR (2000). In contrast, the concentration of ²³²Th was relatively high in all 37 soil samples collected from the five study areas, compared with international reference data. Furthermore, the ³⁹K concentration exceeded the optimum level; however, the total potassium

values remained within acceptable limits when compared to global reference data from previous studies (Table 4). Moreover, the findings of this study provide a valuable baseline for future environmental monitoring and research in the region. These results, particularly the elevated levels of thorium, highlight the critical importance of establishing local guidelines and regulatory policies to accurately assess and mitigate the risks associated with heavy metal exposure.

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