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Investigation of Relative Abundance of Radioelements Concentration over the Southern Part of Sokoto Basin, Northwestern Nigeria

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ABSTRACT
Aero-radiometric datasets (sheet 72, sheet 73, sheet 95, and sheet 96) from the Southern part of the Sokoto Basin in Northwestern Nigeria were analyzed to determine the likely mineral potential zone of the study area. The data which was obtained from the Nigeria Geological Survey Agency (NGSA) were analyzed using Oasis Montaj 8.4 and ArcGIS software. The radiometric data results reveals that the minerals (thorium, potassium and uranium) solutions cluster around the region where geological structures responsible for hosting these radioelements are located. The average depths range from -12, 242.7 to 12,100.5 meters, indicating the depth of the geological features associated with the concentration of radioelements. The depth values clearly indicate the presence of minerals in both shallow and deep-seated regions, with the Ka'oje and Shanga axes being notably deeper and having higher depth values. Conversely, the Giru and Fokku axes exhibit sources at both deeper and shallow depths. The result further revealed the predominance of potassium concentration relative to the other minerals throughout the study area. The concentration of potassium ranged from 0.108 to 2.064%. Uranium exhibits low concentration ranging from 0.82 to 5.05 ppm, in Giru, Fokku, Ka'oje, and Shanga areas. These observations are likely associated with the presence of sedimentary rocks such as carbonates and sandstones in the study area. Uranium emerges as the second most prevalent element in the region, showcasing activity concentrations ranging from 0.82 to 5.05 ppm. In contrast, Thorium, exhibits the lowest abundance, with concentrations ranging from 4.23 to 18.18 ppm. Interestingly, the anticipated prominence of potassium is not evident in the map. The eastern and western flanks of the study area predominantly consist of sedimentary rocks, hosting various economically significant minerals. Within this mineral composition, uranium emerges as the second most abundant element, while potassium stands out as the most plentiful. This high potassium concentration is highly advantageous for agriculture in the research area.

Keywords: Aero-radiometric datasets, Potassium, Shanga, Thorium andUranium

I. Background of the Study

Airborne radiometric surveys focus on measuring naturally occurring radioelements in rocks and soil, specifically Uranium (U), Thorium (Th), and Potassium (K). These elements, present as trace elements, naturally decay and emit gamma rays. The primary objective of radiometric surveys is to determine the relative or absolute abundance of U, Th, and K in rocks and soil by measuring the percentages of Potassium (%K), equivalent Uranium (eU), and equivalent Thorium (eTh).

In Nigeria, the initial phase of large-scale exploration for radio-elements began with the implementation of high-sensitivity aero-radiometric surveys in 1975. These surveys, conducted by Fairly Surveys Ltd. and Hunting Geology and Geophysics Ltd. on behalf of the Federal Ministry of Mines and Power, covered the lower Benue area, the middle Niger, and the Sokoto region. Subsequently, intensive ground follow-up surveys were carried out in certain areas since 1977, including efforts by entities such as the Nigeria Uranium Mining Company (NUMCO), the Nigerian Mining Corporation, the Geological Survey of Nigeria, and the University of Ife. Despite these efforts, there is limited information available on uranium occurrences in Nigeria (Adamu, 2019).Given the existing gap in the nation's energy needs, there is a favorable opportunity for uranium mining and development projects. This gap could be addressed through further research on the concentrations of radioelements, especially uranium. The current study investigates the relative abundance of radioelement concentrations in the southern Sokoto

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basin in Northwestern Nigeria using radiometric measurements. This research aims to determine the concentration and abundance of radioactive elements associated with different rocks in the region. Additionally, it contributes to the development of a ternary map illustrating the radioelement concentration in the research area.

According to Akpan and Uwah,. (2016), Radioactivity is the process in which the nucleus of unstable atoms loose energy by emitting tiny bursts of high frequency and consequently, very energetic electromagnetic radiations. These terrestrial radiations can be dangerous to both human and environmental health although the danger depends on the amount and type of energy released by the atoms. The actual amount of these terrestrial radiations in the environment depends on many factors including the local geological composition of the soils/rocks.

Ngwaka *et al.*, (2023) highlight the increasing popularity of airborne radiometric surveys over the past few decades, driven by advancements in acquisition, processing, and interpretation techniques. This has led to the expansion of its applications beyond the traditional direct detection of mineral deposits to indirect exploration for minerals. The method involves measuring the energy and intensity of emitted radiations to easily detect mineral substances.

II. Materials and Method

Location

The study area falls within the Sokoto Basin, spanning longitudes 4° 00″ E to 4° 50″ E and latitudes 11° 10″ N to 11° 50″ N, with an average elevation of 450 meters above mean sea level (Fig. 1.1). Geographically situated in the semi-arid region, it features savannah-type vegetation and is part of the sub-Saharan Sudan belt in West Africa. The area experiences a tropical continental climate, with a mean annual rainfall ranging from 800 mm to 1000 mm and a mean annual temperature fluctuating between 26.5°C and 40°C, as reported by Silviconsult in 1992. Night temperatures tend to be lower, with the highest temperatures occurring between April and July and the lowest in August, during the rainy season. Relative humidity is generally low, around 40%, for most of the year, except during the wet season when it increases to an average of 80%. This characteristic contributes to the dry nature of the environment, which stands in stark contrast to the hot and humid conditions prevalent in the southern parts of Nigeria.

Figure (1) Location map of the area

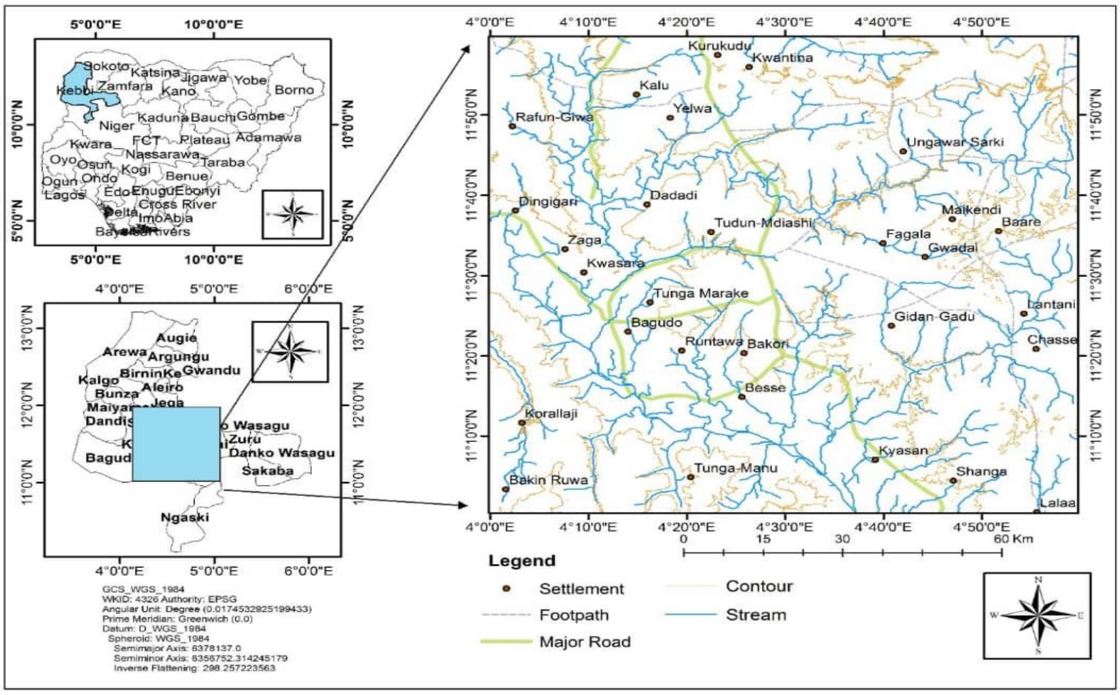

Figure (2) Location map of the area

Geology of the study area

The geological composition of the study area is characterized by two main formations: the Precambrian Basement complex dominating the southern to southeastern regions and young sedimentary rocks prevalent in the north. The basement complex region comprises ancient volcanic and metamorphic rocks, including granites, schist, gneisses, and quartzite, belonging to the Gwandu, Illo, and Rima groups with ages ranging from the Cretaceous to the Eocene (Ahmed *et al.*, (2022).The Gwandu group is characterized by massive interbedded clay and sandstone, while the Illo and Rima groups consist of pebbly grits, sandstones, and clays, as well as mudstones and siltstones, respectively. The area hosts various minerals, such as quartz, kaolin, photolytic bauxite, clay, potassium, silica sand, and salt. It is considered a combination of sedimentary terrain and basement complex terrain, featuring predominantly clay, granites, pebble beds, feldspathic sandstones, siltstones, quartz, granite, and migmatite.

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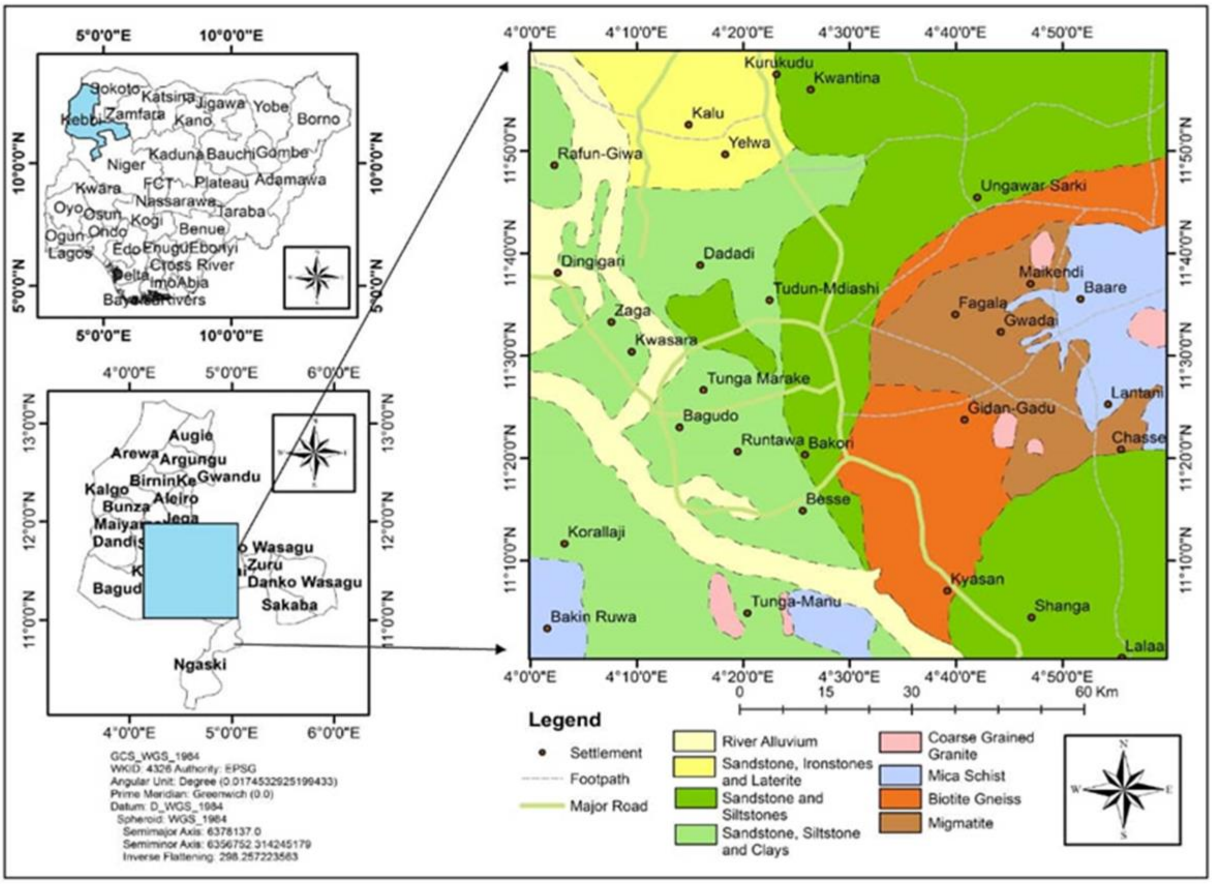

Figure 3: Geology of the study area

Materials
The materials consulted for the sole purpose of this research involves the following.

i. Location map of the study area
ii. Geological and topographic maps of the study area
iii. Recent Aero radiometric data grids covering the study area from NGSA
iv. Personal Computer and Accessories
v. Software Packages for Interpretation of the Data (Arc-GIS V.13, Oasis-Montaj V8.4.3, Microsoft Excell, Surfer V.13)

Method
Data collection

The data utilized in this research were derived from high-resolution airborne radiometric data provided by the Nigeria Geological Survey Agency (NGSA). These data were acquired across various regions of Nigeria in 2008 by Fugro Airborne Surveys Limited include four half-degree radiometric data sheets (specifically, sheet 72, sheet 73, sheet 95, and sheet 96).These data were presented in digital format as a composite grid at a scale of 1:100,000, at a flight elevation of 80 meters, with line spacing set at 500 meters and tie line spacing at 2000 meters.The primary objective of the acquisition was to obtain geological and geophysical information to enhance the understanding of the solid mineral potentials in different parts of the country.

Data analysis

The four acquired data sheets were consolidated into a unified composite sheet using Microsoft Excel, forming the study area that spans approximately 12,100 km^2. Subsequently, the merged data were imported into Oasis Montaj 8.4 for gridding, employing the minimum curvature method. This process aimed to generate an improved radiometric distribution depicting the count rate of the primary radioelements (Potassium, Thorium, and Uranium). The resultant images served as representations of the radiometric signatures associated with mineralization in the region.Additionally, composite maps of Potassium, Thorium, and Uranium radioelements were created using the radiometric ratios of the respective

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nuclides. The Potassium composite map integrated the K map in red, K/eTh map in green, and K/eU map in blue. Similarly, the Thorium composite map combined the eTh map in red, eTh/eU map in green, and eTh/K map in blue. The Uranium composite map was generated by merging the eU map in red, eU/eTh map in green, and eU/K map in blue.

Results and interpretation

High resolution Map were created from the analysis of Aero radiometric datasets in the study area. In order to obtain the concentration of each of the radioelements (i.e., Uranium (U), Thorium (Th) and Potassium (K), maps. were presented in figures below.

Uranium Concentration Distribution Map

The map (Figure 3) shows the shaded uranium count map with activity concentrations of 0.82 to 5.05 ppm with major anomalous uranium count evenly distributed across the surveyed area.

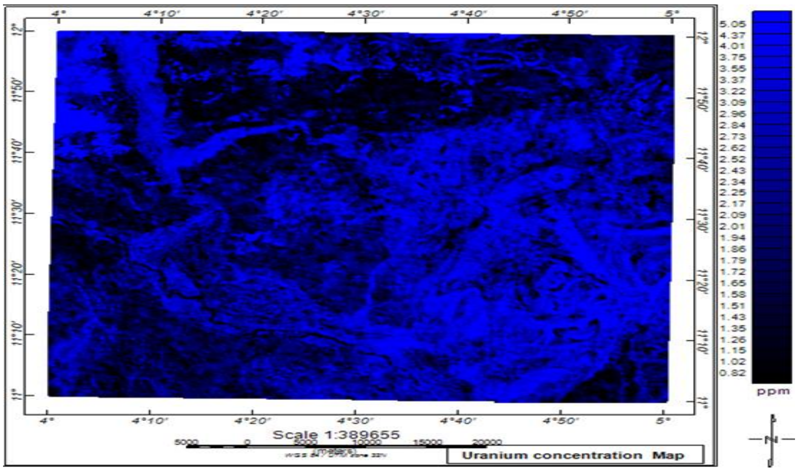

Figure (3) Uranium Concentration Map

From figure (3), was able to reveal areas of high and low concentration of relative abundance of uranium as it can be seen from the legend, and also in most southern eastern part of the map due the probable presence of Sandstone and siltstones. This shows that, the area of Shanga and most part of Fukko (sheet 96) recorded high Uranium signatures, but low between Giro (sheet 95) and Fukku area and moderate to low between Ka'oje (sheet 73) and Giro (sheet 95) as evident in figure (3) above.

Thorium Concentration Distribution Map

The map (Figure 4) shows the thorium count map with the activity concentration of 4.23 to 18.18 ppm with major anomalous thorium count evenly distributed across the surveyed area.

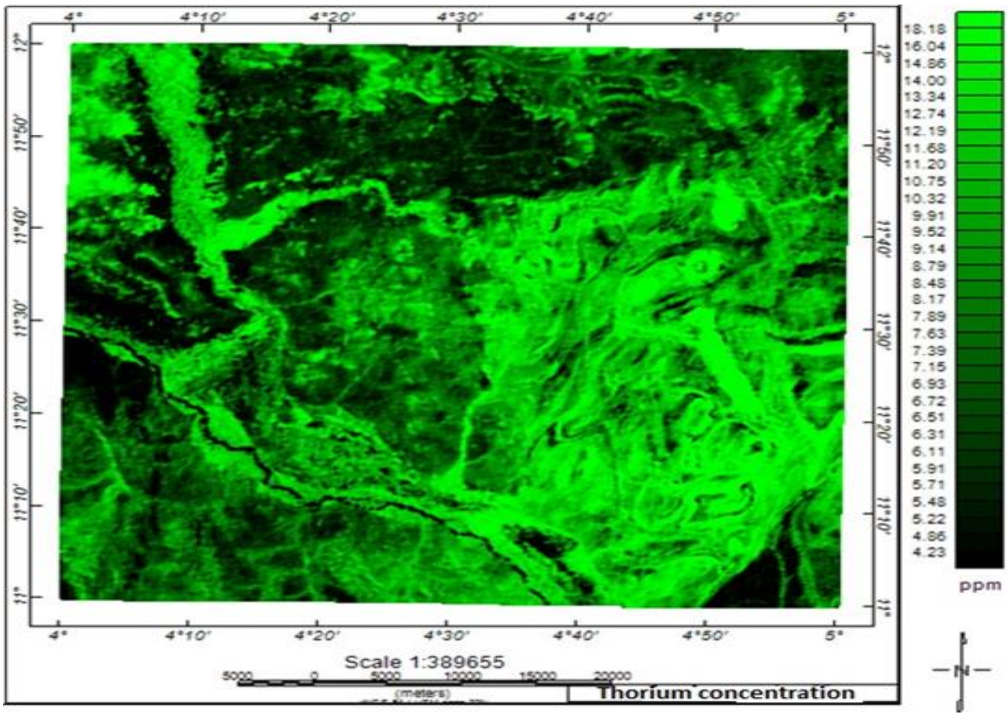

Figure (4) Thorium Concentration map

High Th concentrations are closely related to felsic minerals and low Th concentrations are related to mafic minerals (Shives et al., 2000). Thorium is generally considered very immobile (Silva et al., 2003), thus the regions with low thorium concentration suggest Thorium was mobilized in hydrothermally altered systems.

Figure(4), was able to show areas of high and low Thorium concentration distribution as it can be seen from the legend (4.23 to 18.18 ppm with major anomalous thorium count evenly distributed across the surveyed area.).

Potassium Concentration Distribution Map

The map (Figure 5) shows the shaded potassium count map with activity concentrations of 0.108 to 2.064 percent. With major anomalous potassium concentration along the eastern end.

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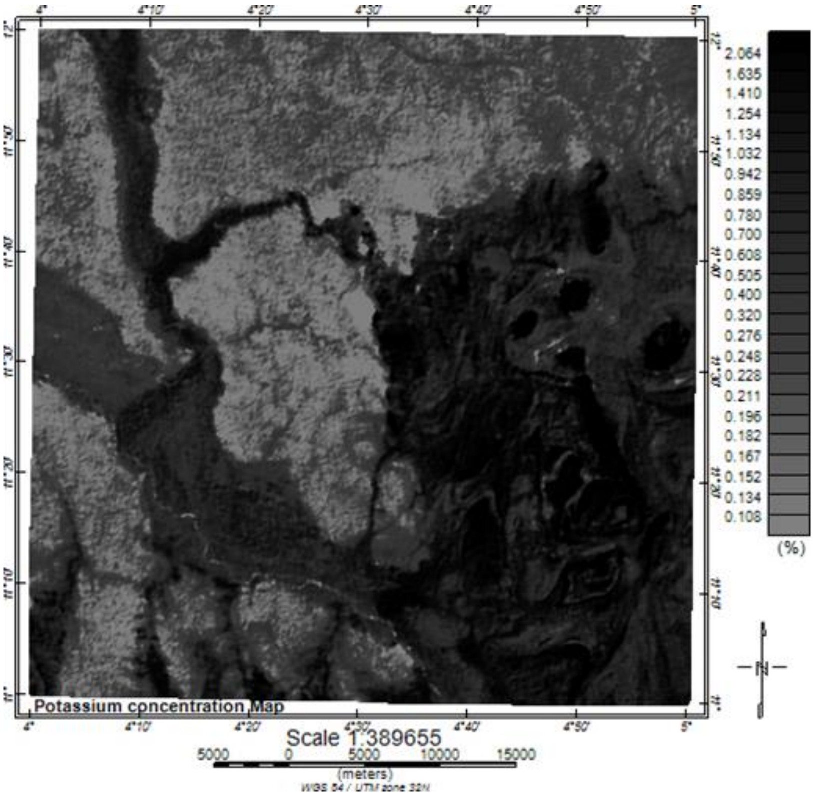

Figure (5) Potassium concentration map

The above mapshow the Concentration of Potassium (K) within the Study Area. Potassium radiation essentially comes from K feldspar, predominantly microcline and orthoclase or micas such as muscovite and biotite which are common in felsic igneous rocks (e.g. granite) and are low in mafic rocks (e.g. basalts and andesite) but virtually absent from dunite and peridotites.From Figure (5), areas of high and low potassium (K) concentration can be seen as it was directed by the legend (the shaded potassium count map with activity concentrations of 0.108 to 2.064 per cent. With major anomalous potassium concentration along the eastern end.). The high concentration is from 0.505 to 2.064 percent and low concentrations is from 0.108 to 0.505 percent. According to figure (5), 98% of Shanga area recorded relative abundance of Potassium Concentration. And most part of Fukku, Giru and Ka'oje recorded low concentration of potassium in the study area.

Uranium Composite Map

The map (Figure 6) represents a composite map depicting the abundance of the equivalent uranium concentration (eU) in ppm with radioelement abundance of uranium prominently found within the eastern and central half with concentrations ranging from 0.774 to 5.225 ppm.

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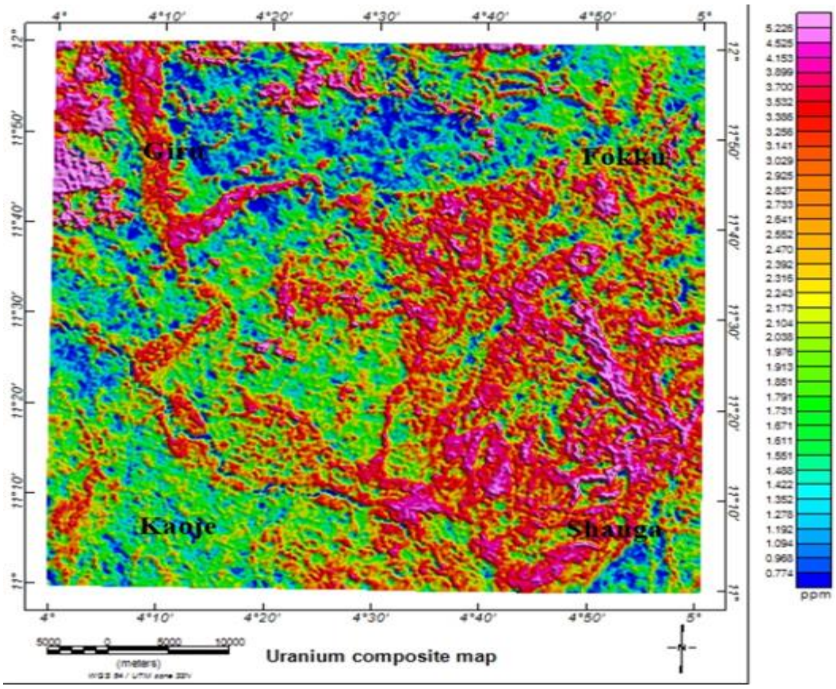

Figure (6) Uranium Composite Map

Lineament analysis map

The map figure (7), represents the lineament analysis map across the surveyed region, this was obtained from the analysis performed on the digital elevation model map, with probable mineralized locations equally spread across all locations as in the case of CET. With both the Giru, Fokku, Kaoje and Shanga towns having their own structural setup which might play host to minerals sufficiently present in the locations.

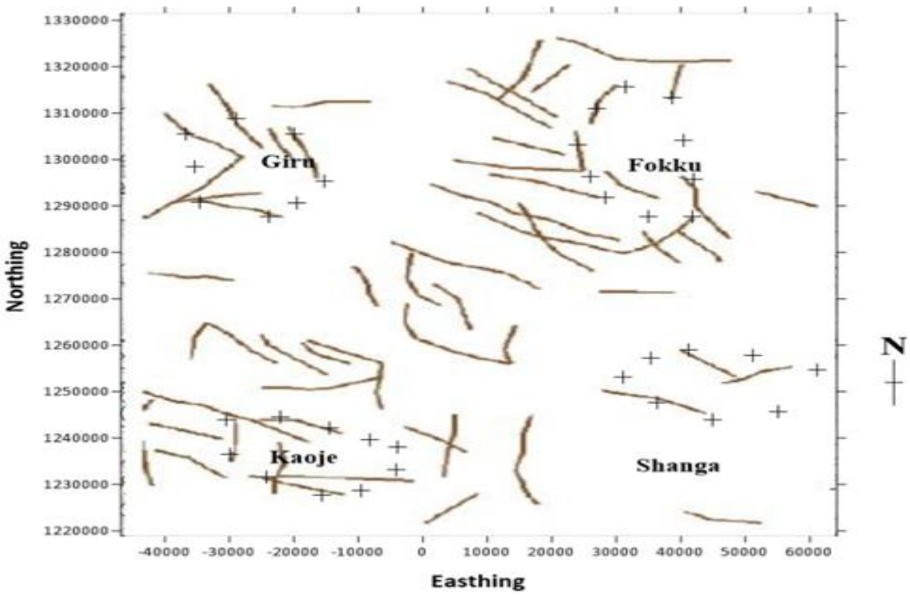

Figure (7) Lineament analysis map

Euler depth Profile for Radio elements.

The map (Figure 8) shows a depth profile for radioelement concentration in the surveyed region with depth values ranging from -12242.7 to 12100.5 meters. These values clearly shows that the region upon which the minerals are present are both shallow and deep seated, with both Kaoje and Shanga axis considered to be deeper with higher depth values, while the Giru and Fokku axis are both having deeper and shallower sources.

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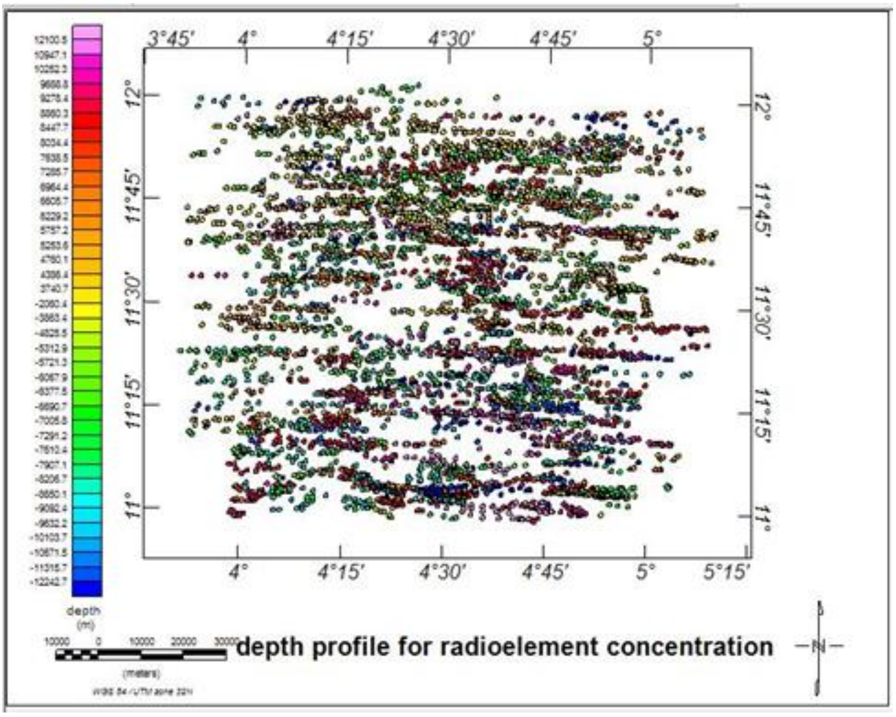

Figure (8) Euler depth Profile for Radio elements.

Ternary radio-elements concentration map

The map (figure 9) shows a ternary radioelement concentration map obtained from a high-resolution gamma ray spectrometry survey acquired over a portion along Kebbi Northwestern Nigeria. This region considered covers an area of approximately 200 square kilometers comprising Giru, Fokku, Kaoje and Shanga of aero radiometric data sheets.

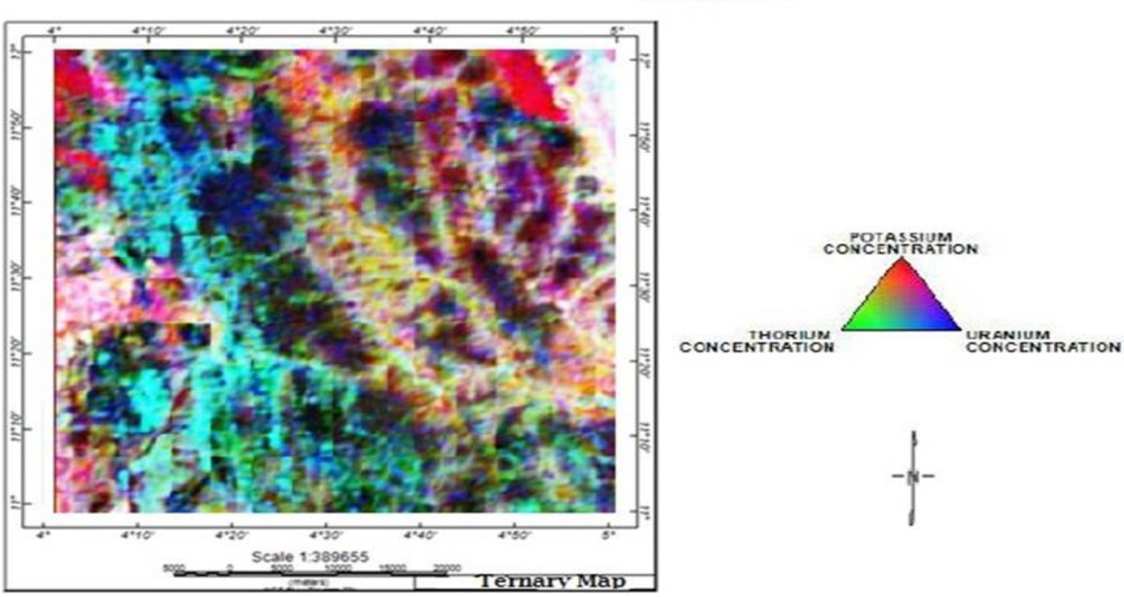

Figure (9) Ternary Radio element concentration Map

From the result obtained (figure 9), the red/cyan color grid depicting potassium that was supposed to be more pronounced as illustrated in the map is being superimposed by the uranium content depicting (blue) with only but a few (green) depicting thorium. The eastern and western flanks of the study area are regions dominated by sedimentary rocks, which play host to economic minerals with potassium the most abundant and uranium the second most abundant across the area.

The values presented in table 1 below illustrate how the various colors that appear in a ternary image can be interpreted. Red areas are high in Potassium, green areas are high in Thorium and blue areas high in Uranium. Cyan areas are high in Thorium and Uranium; magenta areas are high in Potassium and Uranium and yellow areas are high in Potassium and Thorium. White areas have high levels of all three radio-elements and black areas have low levels of all the three radio-elements of interest (U, Th and K).

Table 1. Preparation and Interpretation of Ternary Images of Spectrometry data (Cranfield University, UK 1990).

Radio-element	Uranium	Thorium	Potassium
Red	Low	Low	High
Green	Low	High	Low
Blue	High	Low	Low
Cyan	High	High	Low
Magenta	High	Low	High
Yellow	Low	High	High
Black	Low	Low	Low

Ternary image (figure 9) is one of the most commonly used approach for displaying and interpreting the relative intensities and interactions among the three major radio-elements (K, Th, and U) recorded by gamma ray spectrometric surveys.

III. Discussion

The analysis performed on the digital elevation model map, clearly shows probable mineralized locations for exploration target sources. With both the Giru, Fokku, Ka'oje and Shanga towns having their own structural setup which might play host to minerals sufficiently present in the locations, this is important as studies of this nature are best explained using the structural morphology of mineralization. In this work, we therefore utilized and applied the Euler method on the aero radiometric grid using the Euler 3D extension module of the Oasis Montaj software for Euler solutions. Since the result of the structural analysis shows the bodies or setup responsible for hosting such minerals in the location. The best clustering solution was obtained by selecting a structural index of one (i.e. SI = 1) (figure 8). shows that the solution plotted clustered around the region where the geological structures responsible for hosting such radioelements are located with average depths range of -12242.7 to 12100.5 meters. These depth values clearly shows that the region upon which the minerals are present are both shallow and deep seated, with both Ka'oje and Shanga axis considered to be deeper with higher depth values, while the Giru and Fokku axis are both having deeper and shallower sources.

Results from statistics and map analysis have shown that the concentration of potassium is dominant in almost all parts of the study area with activity concentrations from 0.108 to 2.064 % and is of great advantage to agriculture in the area. Also, from the analysis of the maps, the relative lower values of uranium abundances in Kebbi axis comprising Giru, Fokku, Kaoje and Shanga towns is roughly related to the presence of sedimentary rocks such as carbonates and sandstones in the study area. Uranium is the second most abundant element in the region with activity concentrations between 0.82 to 5.05 ppm. Thorium is the least abundant of the three elements with concentrations between 4.23 to 18.18 ppm. These values obtained correlate with the findings of (Usman *et al.*, 2022) and (Uwa, 1984), along Birnin Yauri axis which indicate the sparse distribution of radioelement concentration, with potassium being the most abundant and thorium the least abundant since both Giru, Fokku, Kaoje Shanga and Yauri are all regions around Kebbi in Northwestern Nigeria.

IV. Conclusion

Airborne radiometric data over southern part of Sokoto basin along Kebbi Northwestern Nigeria covering Giru (sheet 95), Fokku (sheet 96), Shanga (sheet 72) Ka'oje (sheet 73) and axis were analyzed and interpreted with the aim of unravelling the relative abundance of radioelements. The result obtained reveal regions within the study area where radioelements can be located and extracted. The eastern and western flanks of the study area are regions dominated by sedimentary rocks, which play host to economic minerals like the radioelement confined along the identified structures, fractures and veins. In view of the economic importance of these radioelements, potassium contents and a host of other uranium contents are sufficiently available across this region particularly along the western flank for uranium and mid central portion of the surveyed region depicting potassium abundance across the vicinity under study. Conclusively, the result obtained can serve as a baseline for further exploration of uranium and potassium content across the area due to the vast abundance visibly portrayed on the map for potassium and uranium content, with only but a few of the thorium content.

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