



ORIGINAL RESEARCH ARTICLE

INTERPRETATION OF AIRBORNE RADIOMETRIC DATA OF A TYPICAL BASEMENT COMPLEX, NORTHWEST NIGERIA.

O. Ologe, A.M. Moyi*, F. Sanusi U.H. Tsafe, and S. Umar

Department of Applied Geophysics, Federal University Birnin-kebbi.

*Corresponding author's email address: Abdulhameed.muhammad@fubk.edu.ng

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ABSTRACT

Interpretation of High resolution airborne radiometric data over Funtua-Tsafe Northwest Nigeria was carried out with the aim of delineating geological structures and mineral potential of the basement terrain. The data were interpreted quantitatively using the radiometric ratio and ternary radioelement signatures. Analysis of the radiometric data enabled the estimation of relative abundances of natural radioactive elements (Uranium, Thorium and Potassium) concentrations revealing distinct anomalies indicative of hydrothermal alteration and the structural styles (shear zones and fault systems) of the area. The count rate range of Uranium (2.0 to 7.6ppm), Thorium (10.6 to 40.0 ppm) and Potassium (0.5 to 3.1 %) were estimated within the area. High concentrations of the two radioelements (U,Th) are predominant in the western part of the area and are possible site for radiogenic heat exploration and geothermal alteration. From the qualitative analysis of the relative abundance of the radioactive elements and the ratio map analysis, rock bearing minerals such as pegmatite, schists were suggested to be present, which could serve as raw materials for many industries in Nigeria.

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1.0 Introduction

Airborne radiometric survey has become increasingly popular in mineral explorations, especially in large exploration areas of complex terrain or inaccessible regions. This geophysical technique is used to estimate the concentration of radioelements in rocks by measuring the gamma rays emitted by the radioactive isotopes of these elements undergoing radioactive decay (Adonu *et al.*, 2022; Ani *et al.*, 2023; Ngwaka *et al.*, 2023). There are many naturally occurring elements possessing radioactive isotopes but only Uranium, Thorium and Potassium decay series have radioisotopes that produce gamma rays of sufficient energy and intensity which can be measured by gamma-ray spectrometry (Galbraith & Saunders, 1983). The gamma rays from the decaying unstable nuclei of the rocks are recorded during radiometric surveys. The radioelement composite image recorded therefore gives a single display of the three radioelement concentrations which reveal the distribution of certain rock bearing minerals of interest. The Uranium, Thorium, and Potassium maps show regions where the specific radioelement has high or low concentration (Abdulsalam *et al.*, 2023). Aeroradiometric method provides useful information for detecting and mapping natural radiometric emanations of gamma rays by measuring the naturally occurring radioactive elements that exists in rock forming minerals. The method is a passive geophysical process because it measures a natural source of energy and evaluates the mineralization in the area from the relative abundance of these three radionuclides of potassium (K), uranium (U) and thorium (Th). Historically, the main use of radiometric in mineral prospecting was detection of anomalies caused by outcropping, highly radioactive, uranium deposits. The radiometric method has several characteristics that make it unique amongst the geophysical methods. Firstly, the measured radioactivity originates from only the top few centimeters of the Earth's crust, unlike other geophysical methods, radiometric has only a very limited ability to see into the subsurface. Secondly, it is possible to identify the elemental source of the radiation from the energy of the γ -rays emitted, radiometric data are used to map variations in the chemical rather than the physical characteristics of the survey area. Interpretation of radiometric data straddles the boundary between geochemistry and geophysics. This may explain why the methodologies for interpreting radiometric are less well-developed than those of other geophysical methods

(Airo, 2002). The measurements of radioactivity of rocks of the crust can be used to estimate the concentration of heat producing elements. The decay of radioactive elements is essential for geothermal resources.

Augustine *et al.*, (2021) successfully employed aeromagnetic and airborne radiometric data to provide information on the structural settings and inter possible location of mineralization in parts of Zamfara, North-West Nigeria. Radiometric data was proceeded and interpreted in the middle Benue Trough to ascertain the relative quantity of natural radioactive elements (Uranium, Thorium and Potassium) (Ani *et al.*,2023). The outcome of both researchers concluded on areas with possible sites for radiogenic heat exploration and rock bearing minerals. The use of aeroradiometric data to determine the relative abundance of natural radioelements in the study area is uncommon; hence, this study is geared towards estimating the abundance of these elements and identify prospective minerals if any that might be present in the study area by interpreting airborne radiometric data.

2. Materials and Method

2.1 Study Area

Figure 1 shows the location map of the study area obtained from Q-GIS version 3.0

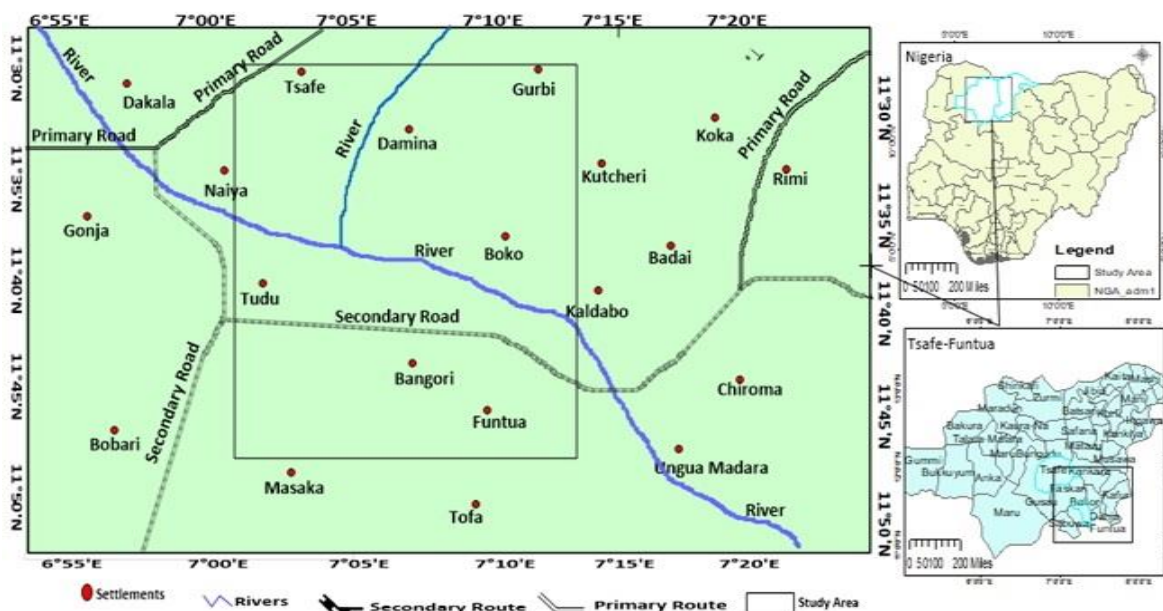


Figure 1: Location map of the Study Area (Adopted from Q-GIS V 3.0)

The study area is situated within the boundary of Zamfara and Katsina States, Northwest Nigeria (Figure 1). The areas geographical coordinates are: Latitude 11°45'0" N - 12°15'0" N and Longitude 7°15'0" E - 7°45'0" E. Funtua-Tsafe is characterized by gently undulating terrain, tropical savanna climate, and Guinea savanna vegetation, with elevation ranging from 300-600 meters above sea level. The area is drained by the Sokoto River and its tributaries. Funtua-Tsafe falls within the Precambrian Basement Complex and the Younger Granite Province of Nigeria, making it a significant location for geological and mineral exploration target area. The climate of the study area Funtua-Tsafe boundary is characterized by high temperatures and moderate rainfall, influencing the vegetation and agricultural practices in the area. The area's climate is marked by an average temperature ranging from 25°C to 30°C (77°F to 86°F), and moderate rainfall, with an annual average of 800-1,000 mm (31-39 in). The vegetation is primarily Guinea savanna, characterized by scattered trees, including species like *Acacia*, *Bauhinia*, and *Vitex*, grasslands with tall grasses, such as *Hyparrhenia* and *Loudetia*, woodland savannas, featuring trees like *Anogeissus* and *Terminalia*.

2.2 Geology of the Study Area

Figure 2 shows the geological Map of the study area obtained from ARC GIS 8.5

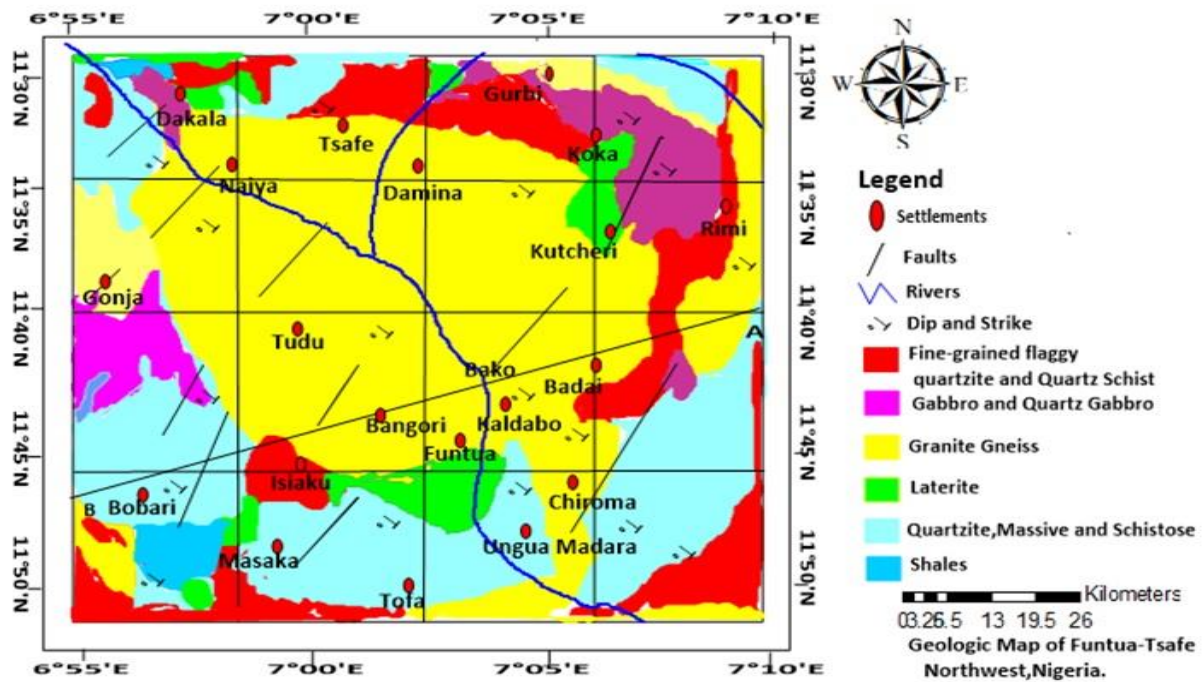


Figure 2: Geological Map of the Study area (Adopted from ARCGIS 8.5)

The basement complex is one of the three major litho-petrological components that make up the geology of Nigeria (Figure 2). The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Cratons and south of the Tuareg Shield (Danbatta, 2010; Obaje, 2009). The study area is located between Katsina and Zamfara States, Northwest Nigeria which lies within the part of North central Nigeria basement and it is situated within the Precambrian Basement Complex and the Younger Granite Province of Nigeria (Alaku et al., 2017). The area's geologic setting is characterized by ancient rocks formed during the Pan-African orogeny, and granitic rocks emplaced during the Jurassic to Cretaceous periods (Danbatta, 2010). The Precambrian Basement Complex comprises gneisses, schists, and quartzites, while the Younger Granite Province consists of granitic rocks (Danbatta, 2010). Geologically, it features a mix of granitic, gneissic, and sedimentary rocks. Inselbergs (isolated hills) and ridges, such as the Katsina-Alkalawa ridge, are prominent. Faults and fractures, including the Sokoto Fault Zone, are also present. Alluvial plains and valleys, drained by the Sokoto River and its tributaries, are characteristic of the area. The Precambrian Basement Complex in Funtua-Tsafe has undergone multiple tectonic events, including the Pan-African orogeny and the Nigerian-Beninian orogeny (Ajibade and Wright, 1989). The Younger Granite Province has been affected by Jurassic-Cretaceous magmatic activity in which the Sokoto-Niger Basin has experienced multiple phases of sedimentation, including the deposition of sedimentary rocks during the Cretaceous and Tertiary periods (Danbatta, 2010; Ajibade and Wright, 1989).

2.3 Method

As part of a nationwide high-resolution airborne geophysical survey for geological studies in Nigeria, radiometric data were acquired by Furgo Airborne Survey Limited for the Nigeria Geological Survey Agency (NGSA). The very high-quality sheets of aero-radiometric data that cover the study area were acquired from Nigerian Geological Survey Agency, Abuja (NGSA), which carried out airborne radiometric survey of Nigeria between the years 2002 - 2009. The aero-radiometric data were acquired with data flight elevation of 80m, line spacing and tie-lines spacing were 500 m and 5000 m respectively. The data were collected systematically by dividing the country's landscape into geological blocks with the eventual production of radiometric map categorized as sheets for the whole country. The radiometric data applied in this study were re-projected to WGS 84 Zone 32°N of Equator using the Geosoft Oasis Montaj software since the survey area falls within 0° to 6° N of Equator. Figure 3 shows a workflow applied in the data processing.

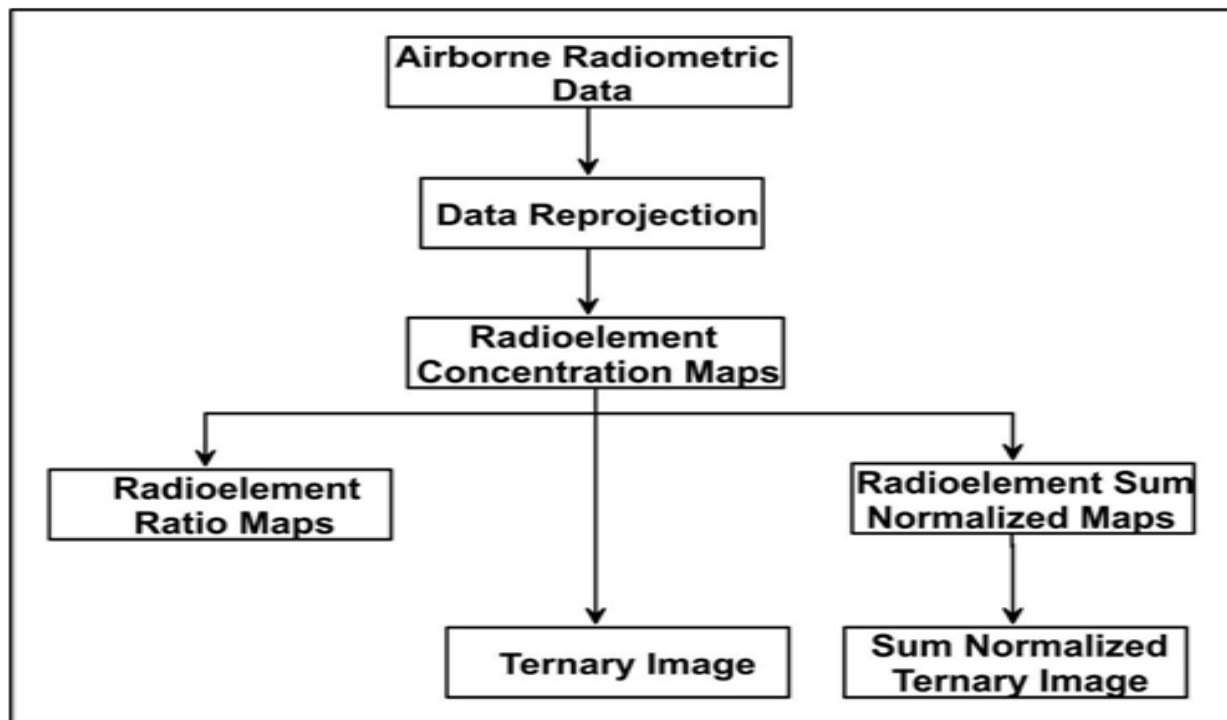


Figure 3: Diagram of Workflow Adopted for Radiometric Data Processing

The airborne radiometric data acquired over the study area had a projection of zone 32°N of equator. To correct this anomaly, the data was re-projected to zone 31°N of Equator which is the geographical projection of the study area. The re-projected data consisting of three radioelement soft thorium, potassium and uranium concentrations were mapped individually to show concentration dominance. A standard way of displaying the Potassium (K), Thorium (Th) and Uranium (U) data is as a ternary image where a composite image is generated by proportioning colours, red, green and blue to the radio-element concentration values of K, Th and U respectively.

In the event of excessive large population of radio-element over others, an approach to overcome this effect is to create separate grids (images) of the radio-elements from selected ranges taken from the total count image. Computing the arithmetic ratio of radio-element grids is away to suppress the effects of environmental factors such as soil moisture, vegetation and topography on the radiometric response to the actual geologic unit.

3. Results and Discussion

3.1 Radioelement

There are over 50 naturally occurring radioactive elements, but terrestrial radiation is dominated by the emission products from just three elements: potassium (K), uranium (U) and thorium (Th) Henderson (1983). The half-lives of their radioactive isotopes are of the same order as the age of the Earth (5×10^9 years) and are sufficiently long that they remain comparatively abundant. The other naturally occurring radioactive elements are too rare and/or too weakly radioactive to be of significance. The γ -ray spectrum recorded in geophysical surveying comprises radiation from a number of different sources in varying proportions. Of these, radiation originating from one or more of the three common radioelements present in the ground, i.e. potassium (K), uranium (U) and thorium (Th), is the signal of interest, and all other sources of radiation form unwanted noise. Spectra are obtained by locating the survey spectrometer (the survey aircraft) over the synthetic sources (the pads), and the effects of different survey heights simulated by partial shielding of the detector. The spectra so obtained are converted to pure K, U and Th spectra based on the known elemental concentration soft the samples (the pads), and the stripping ratios obtained for the various simulated survey heights. The height-corrected stripped counts in each of the three energy channels, K, U and Th, are linearly related to the ground concentrations of their respective elements. The integration of the three elemental concentration channels, potassium (K), uranium (eU) and thorium (eTh), with the total-count (TC) channel and other datasets, such as terrain and multispectral scanner data, is an important aspect of the geochemical/geological interpretation of radiometric data.

3.1.1 Potassium (%K) Map

Figure 4 shows the concentration map of potassium obtained from Oasis montaj software.

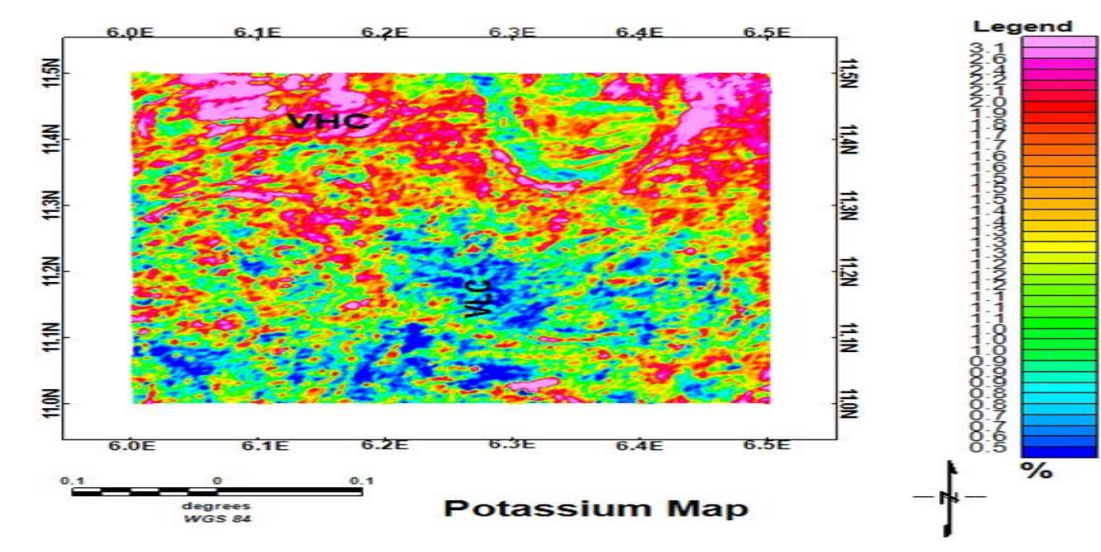


Figure 4: Potassium Concentration Map

The potassium (%K) map (Figure 4) shows different degrees of potassium concentrations ranging from 0.5 to 3.1% that reflects different lithological units and alterations in the area. Alteration, weathering, climatic conditions and hydrothermal processes can affect the concentration of the radioelements. Potassium often increases during signature alterations, but weathering usually decreases the intensity of signature alterations (Blatt, H. 1992). Several potassium anomalies are evident in the radiometric image the color blue corresponds with low K values whilst pink corresponds with very high K values. The color red represents moderately high to high K values and the shades of orange to yellow color represent or are associated with moderately low K values. pegmatite, granite, Gneiss, migmatite, quartzite, phyllite and could be associated with gold deposit in the study area while some part of the map are showing low potassium concentration which could be attributed to the destruction of potassium source during weathering processes resulting to presence of gabbro, diorite, basalt, marble and clastic sediments.

3.1.2 Thorium (Th) Map

Figure 5 shows the concentration map of thorium obtained from Oasis montaj software.

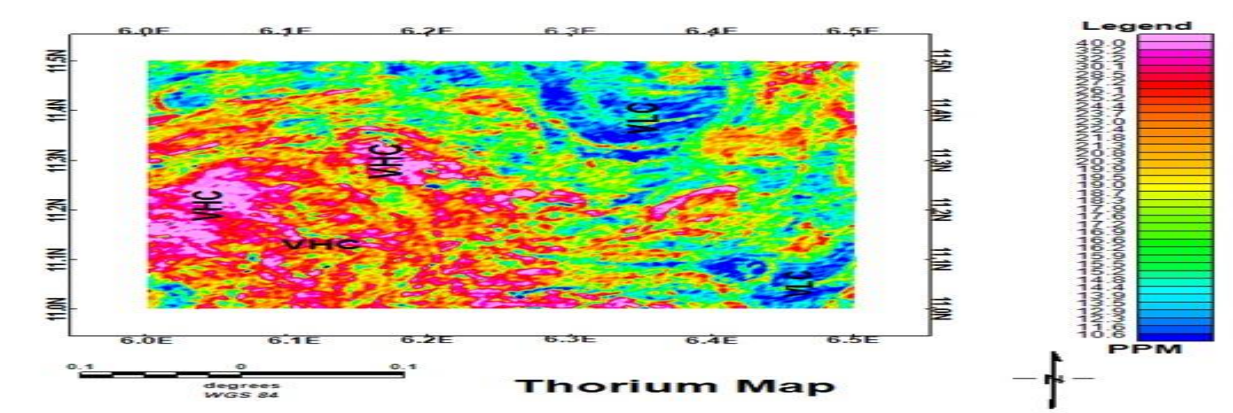


Figure 5: Thorium Concentration Map

Thorium generally is not affected by alteration processes because it is typically immobile in mineralization processes (Taylor *et al.*, 1995.) or it can only partly be depleted in areas of intense K-alteration and silicification. However, the distribution map (figure 5) of thorium has concentration ranging from 10.6 to 40.0ppm. The thorium concentration in the study area was grouped as high (VHC) (>22.4ppm), moderately high (19.9-22.4ppm), moderately low (15.2-19.9 ppm), and low (VLC) (<15.2ppm). The high concentrations of thorium

are marked by red to pink colorations and are observed in the West, towards southern edge of the study area. Areas of very high to high eTh (Red and Pink) concentrations are attributed to Older granite suite, Pegmatitic activity granulites and schists, while zones of low thorium (Green, blue) concentration are regarded as zone embedded with Younger Granite, lower grade metamorphism, Quartzite formation.

3.1.3 Uranium (eU) Map

Figure 6 shows the concentration map of Uranium obtained from Oasis montaj software.

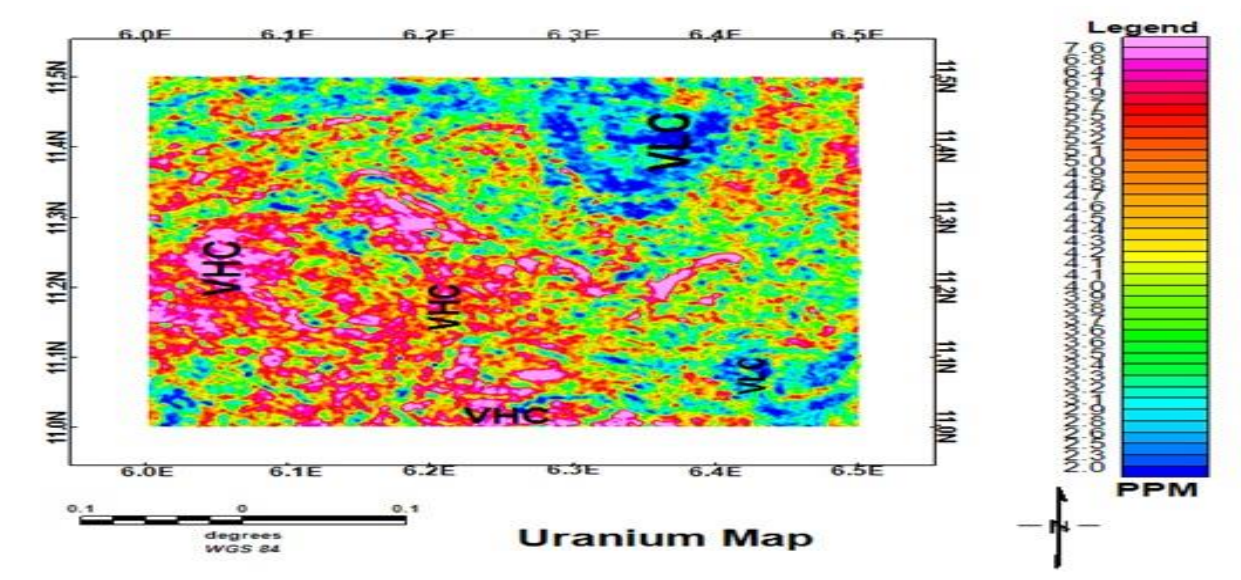


Figure 6: Uranium Concentration Map

Figure 6 also displays the eU concentration. An enrichment of uranium may or may not be accompanied by an enrichment of potassium as Uranium is very mobile in hydrothermal and other geological processes (Kerrick *et al.*, 2017). The map shows various anomalous signatures with total eU concentrations varying between 2.0 to 7.6 ppm. The eU concentrations can be relatively grouped as high (>5.3), moderately high (4.0-5.3), moderately low (3.3-4.0) and low (< 3.3). The areas with high eU concentrations (Figure 6) as observed in Figure 5 are often associated with structures that could be serves as host to minerals emplacement while the lower zone (green and blue) is Attributed to unfaulted areas with lower grade gneisses (Figure 6).

3.1.4 Potassium to Thorium (K/Th) Ratio Map

Figure 7 shows the concentration map of potassium to thorium ratio obtained from Oasis montaj software. The map in Figure 7 displayed %K/eTh. As potassium is more mobile than thorium, K/eTh ratio anomalies can be distinguished to areas of hydrothermal alteration which are characterized by K enrichment. However, depending on the fact that the ratio between potassium and thorium is rather constant in most rocks as reported by Abdulsalam *et al.*, (2023), typically varying from 0.02 to 0.17 (K/Th in %/ppm). So, the zones characterized by the high K/eTh ratio values are strong indicator of hydrothermal alteration and high radiogenic heat production, this was corroborated by the work of Abdulsalam *et al.*, (2023). From the K/eTh ratio map (Figure 7), it is observed that the areas affected by the hydrothermal process with a touch of older granite are featured by pink color and observe in northeastern and eastern of the study area of about 0.09 of K/eTh ratio. An alteration zones suggested to be medium to coarse-grained biotite granite are observed at the South and north central portion of the study area (Figure 7). This is also observed within the western edge portion in which thorium is of high concentration and is symbolized by blue coloration which is attributed to be minerals enrichment suggested to be younger granite origin.

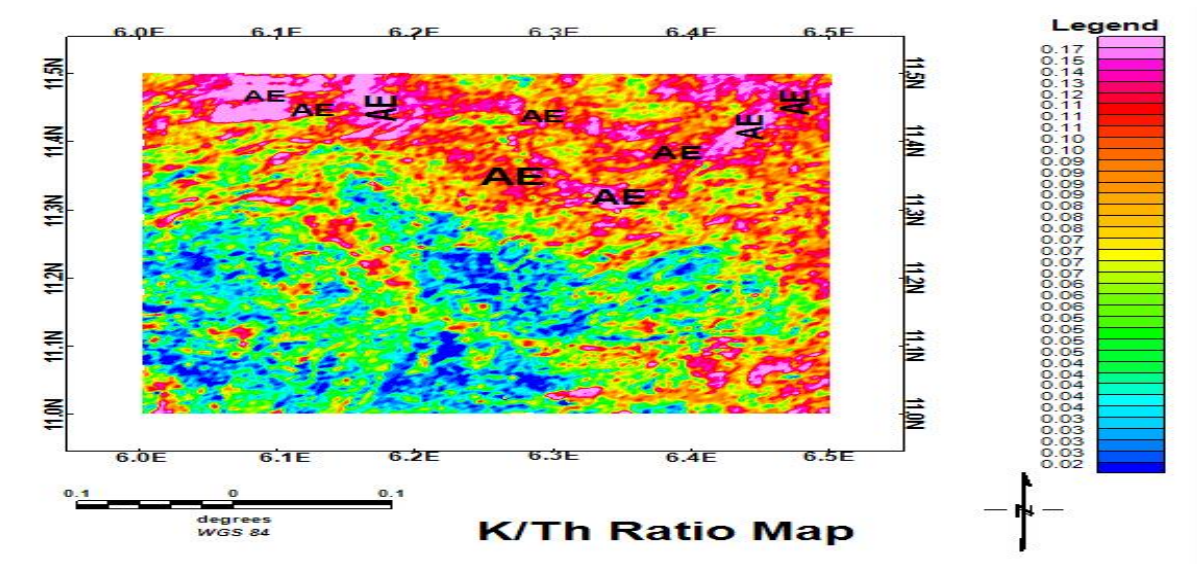


Figure 7: Ratio Potassium to Thorium Concentration Map

3.2 Ternary Map

Figure 8 Shows the ternary concentration map obtained from Oasis montaj software

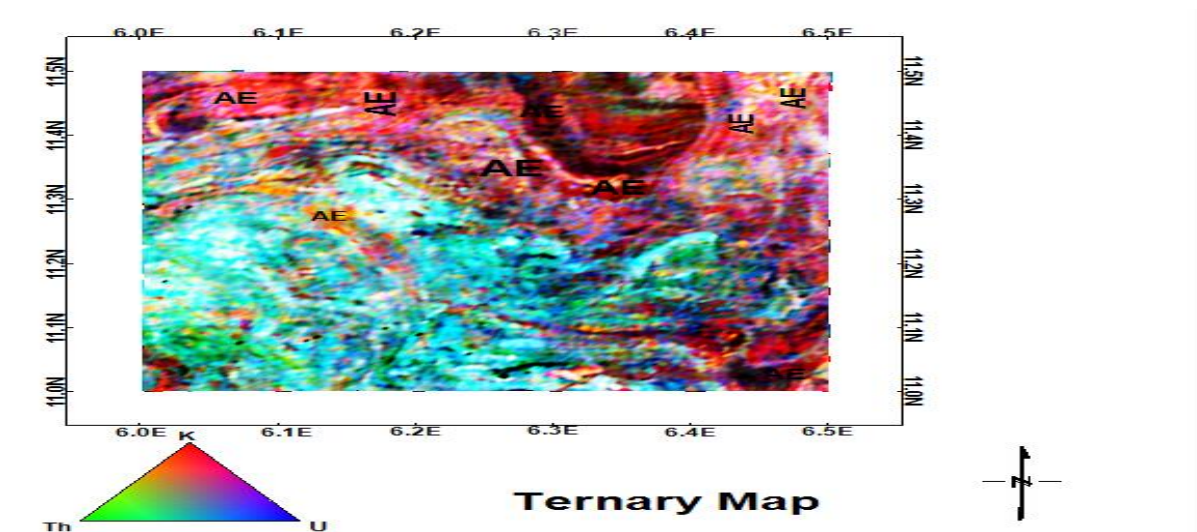


Figure 8: Ternary Concentration Map

The Ternary Map is the triangular plot of the radio-elements which displays a ternary image by combining the three radio-elements. Largely, ternary plots of the radio-elements usually give a superior image of the geology (Salem *et al.*, 2005). The ternary map (Figure 8) indicates uranium, thorium, and potassium distribution within the basement complex. Uranium-rich areas (blue) suggest granite emplacement, hydrothermal activity within the Younger Granite Province and potential uranium mineralization. The uranium-rich zone also reveals pegmatite and hydrothermal veins while Thorium-rich zones (green) indicate crustal thickening, high-grade metamorphism, and potential thorium mineralization. This implies that thorium-rich minerals like monazite or thorite within the Older Granite Complex is suggested to be present in the area. Potassium-rich areas (red) represent felsic rocks and crustal melting. This suggests potassium-rich minerals like orthoclase or biotite within the area. Areas with high uranium and thorium concentrations indicate elevated radiation levels, and possible association with gold, copper, and silver mineralization (Abdulsalam *et al.*, 2023). These zones may also represent hydrothermal activity where tectonism is pronounced.

3.3 Total Count Map

Figure 9 shows the total count map of the study area obtained from Oasis montaj software

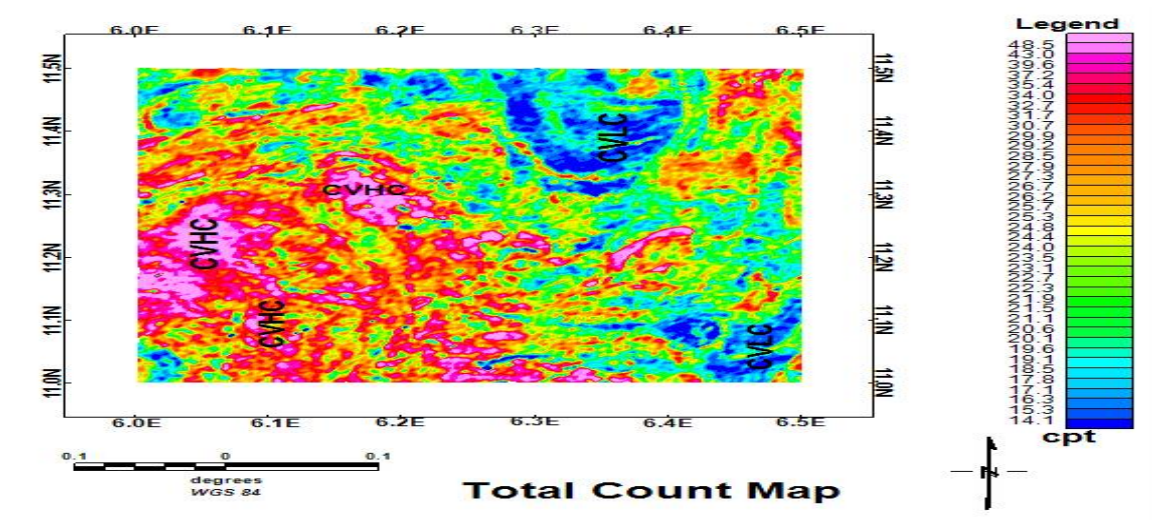


Figure 9: Total Count Map

Figure 9 shows the total radiometric anomalies count map of the study area. It showcases the total count of the three radio-elements (Uranium (ppm), Thorium (ppm) and Potassium (%)) present in the area of study with total count of about 14.1- 48.5cps. The area shows high concentration of total count values in parts of the study area mostly around southwestern part (Figure 9). There is low concentration of total count values around north and some part of the southeast. Low radiation (14.1-20 cps in blue-green color) suggested as areas with low radioactive mineralization, moderate radiation (20-30 cps in yellow-orange color) indicating moderate radioactive mineralization, while high radiation (30-40 cps in orange-red color) indicates significant radioactive mineralization with intense hydrothermal activity and Very high radiation (40-48.5 cps in deep red color) represents intense radioactive mineralization suggested to be corresponding to high-grade uranium deposits.

4. Conclusion

The analysis and interpretation of airborne-radiometric data over Funtua-Tsafe and its environs, North-western Nigeria was carried out. The interpreted radiometric data delineated hydrothermal alteration zones of mineral enrichment in an area to include uranium, thorium and potassium. The coincidence areas of the alteration zones in the area indicated a high possibility for the occurrence of mineralization. Based on the delineated hydrothermal alterations, it is recommended that the study area should be subjected to further investigation using active integrated geophysical methods to ascertain the occurrence of economically rich minerals in the study area that could contribute to the growth of the Nigerian economy.

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