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Investigation of an aerospectrometric anomaly using ground gamma ray spectrometry sheet 81, Dutse North-Western Nigeria

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ABSTRACT

Ground radiometric survey carried out at Gaya North-Western Nigeria using Portable Gamma-ray Spectrometer confirmed, characterized the observed anomalies in Aero-spectrometric map and then correlated with Geological map. The area lies between Longitude 9° 21′ 5.63″-9° 21′ 38.57″ and Latitude 11° 44′ 10.59″-11° 44′ 43.53″. Twenty one profiles each 1 km long and 50 m apart were laid having total of 441 stations. Station coordinates were identified by global positioning system. The meas time was set at 3 minutes for valid order of 0.1% for K and 1 ppm for eU and eTh concentration. Both map grids and statistical analysis was applied to the acquired data. The research revealed mean concentration of the radioelements-U, Th, and K as 17.527 ppm, 59.06 ppm, and 4.1092%, respectively, in the order of (Th > U > K), absorbed does rate values ranging from 33.45 to 676.49 nGyph^{-1} with average value of 48.3 nGyph^{-1} is lower than the world average value. Correlation of 0.9, 0.8, and 0.82 for (^{238}U and ^{232}Th), (^{40}K and ^{238}U), and (^{232}Th and ^{40}K), respectively, were obtained. The research identified rocks associated with these radioelements, thorium being major source of radioactivity and serve as awareness to the citizens.

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1. Introduction

Radioactivity, as the emission of ionizing radiation or particles caused by the spontaneous disintegration of atomic nuclei, has become of considerable economic importance. The most useful of these radiations in radiometric survey are gamma radiations. They are usually among the decay products of radioactive elements, such as Uranium, Thorium, and Potassium (K-40). However of all known radioactive elements, only those of Uranium, Thorium, and Isotopes of Potassium (K-40) are of importance in geologic mapping and mineral exploration (Orgun et al., 2007). The rest are either so rare or so weakly radioactive or both as to be of no significance in applied geology. Radiometric surveying came into lime light with the demand for uranium in nuclear technology and associate minerals in uranium core. 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 (El-Arabi et al., 2006). Two major natural radionuclides: uranium (U-238), thorium (Th-232), and the radioactive isotope of potassium (K-40), have been identified as the major sources of these radiations in

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the environment. These primordial radionuclides are the dominant sources of both indoor and outdoor radiations in the environment. Additionally, the environment do occasionally receive small doses of radiations from extra-terrestrial and artificial (e.g., application of phosphate fertilizer, atomic weapon etc.) sources also.

1.1. Study objective

The regional airborne spectrometric map produced by Hunting Geology and Geophysics LTD (1975), the aero spectrometric map of Gaya sheet 82 shows some radiometric anomalies as in; amplitude of Potassium anomaly is 14 m, amplitude of Uranium anomaly is 23 m, amplitude of Thorium anomaly is 31 m, and Total Count have an amplitude of 345 m in some part of Dutse LGA Jigawa State. Since there has been no ground radiometric survey to confirm the potentials of uranium, thorium, and potassium mineralization in the area under the study as observed on the airborne spectrometric map. The present work can, therefore, be considered as the first ground radiometric investigation to confirm the occurrence or otherwise of radioelements' mineralization and characterize such areas. Findings from this work therefore shed more light on the potentials of uranium mineralization in the study area and in general to the knowledge of uranium occurrences in Nigeria, areas of most promising uranium mineralization are delineated.

2. Materials and Methods

2.1. Geology of the study area

Dutse occupies a relatively high plains surface that occurs within the younger sediment of the Chad formation area of Kano Region. The rocks are Precambrian in origin with the granitic outcrops there are presence of isolated hills of plutonic rocks in the area (Olofin, 1987). In the study area, Turner (1983) also reports the occurrence of rocks of the Younger Granites series so termed because they are Jurassic in age, as well as volcanics, and occasional younger dykes and flows. The Basement Complex rocks in the study area (Fig. 1) include Mesozoic younger granite and pan African older granite. The Nigerian younger granite complexes are known to be mineralogically heterogenous with variations in their textures that are attributable to the proximity of the roofs of the batholiths (Turner, 1983). They are composed of a wide variety of rock types including, but not limited to hornblende porphyry, hornblende biotite granites, biotite granites, fayalite granites, riebeckites granites, and some basic to intermediate rocks (mostly named after the most abundant mafic mineral content). Individual younger granite suites are known to contain different rock types in the various sub provinces despite their age differences that decrease toward the south, suggesting that their emplacement was fundamentally controlled by thermal anomaly in the mantle or lower crust but not related to any orogenic activity and are thus referred to as unorogenic (Garba, 1992). This is also supported by their non-foliated and un-fractured surfaces (Wright, 1976), in contrast to the foliated calc-alkaline older granites (Turner, 1983).

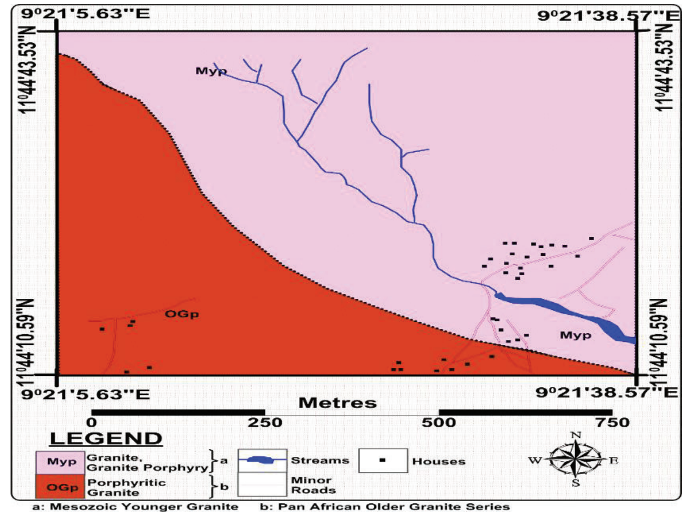

Figure 1. Geological map of the study area after NGSA (2006).

2.2. Instrumentation

The radiometric measuring principle is based on the attenuation of gamma radiation as it penetrates materials. Radiometric systems are used for point level detection, continuous level, density, and interface measurement. The areas of application of this non-invasive measuring method comprise liquids, solids, suspensions through to sludges as well as extreme process conditions, such as high pressures, high temperatures, corrosiveness, toxicity, and abrasion.

The compact spectrometer gamma surveyor instrument always measures the complete spectrum, from which it evaluates the cps values in Region of Interests (ROIs) and calculates the concentrations of elements K (%), eU (ppm), and eTh (ppm). The concentration of K is determined directly. The eU and eTh concentrations are based on detection of radioisotopes 214Bi and 208Tl that are parts of the related disintegration series (the balance of individual daughter products in the frame of measuring conditions is supposed).

The natural dose rate value (in nGy/h) is calculated from measured concentrations of K, eU, and eTh according to the IAEA recommendations using the following coefficients:

1 % K concentration contribution represents 13.078 nGy/hour

1 ppm eU concentration contribution represents 5.675 nGy/hour

1 ppm eTh concentration contribution represents 2.494 nGy/hour.

2.2.1. Basic features

- Measures and stores always the complete 512-channel spectrum
- Direct determination of concentrations of K (%), eU (ppm), and eTh (ppm)
- Dose rate measurement
- cps measurement in 10 ROIs—4 preset (K, U, Th, and TOT),
- Possibility of going through spectrum and matching of the measured peak with the isotope (built-in isotope library)
- Support of point, profile and borehole measurements
- Possibility of later continuation of the interrupted measuring file
- Very easy operation

The instrument transforms incident gamma radiation into visual readout of radioactive intensity as a function of the natural radioactive material present in geologic phenomena, the possible measurement type it does are: point, profile, borehole, or continuous. We used profile technique over 1 km × 1 km square at Gaya, North-Western Nigeria for four days from 30th of March to 2nd of April 2018. The entire study area was gridded into 21 profiles with both inter-profile and inter-station spacing of 50 m having total of 441 points, at each station coordinate were taken and recorded from external Global Positioning System (GPS). Figure 2 shows pattern of gridding and movement on field during data collection.

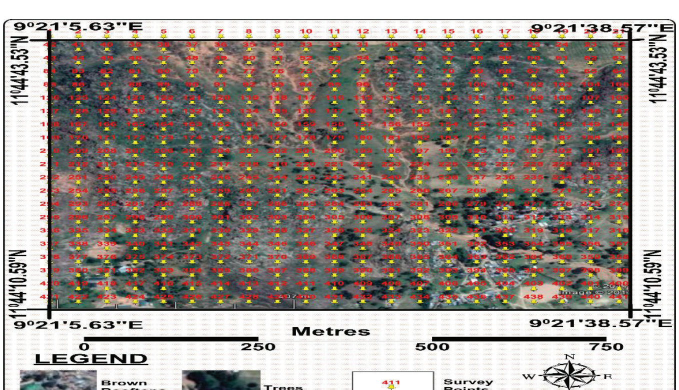

Figure 2. Survey stations and profiles orientation.

For a required accuracy of the results, meas time (time of the measurement on one point) was set at 3 minutes for valid order of 0.1% for K concentration and of 1 ppm for eU and eTh concentration, shorter measuring time causes decreased stability of reached results.

When the measurement is finished, window with the measured cps values in ROIs and calculated concentrations of K, eU, eTh is displayed. The natural dose rate values calculated from the related concentrations are displayed as well. All the measured and recorded data were run for background correction before further processing. Mean (x) as the ratio of the sum of the observed values to the number of observations, standard deviation (σ) which gives an idea of how close the entire set of data is to the average value and coefficient (r) that measures the degree of linear relationship between two variables were computed and tabulated using the following equations.

$$\text{Mean- } \bar{X}=\frac{\sum X}{N} \tag{1}$$

$$\text{Standard deviation- } \sigma=\sqrt{\frac{\sum(x-\bar{x})^2}{n-1}} \tag{2}$$

$$\text{Coefficient- } r=\frac{n\left(\sum xy\right)-\left(\sum x\right)\left(\sum y\right)}{\sqrt{\left[n\sum x^2-\left(\sum x\right)^2\right]\left[n\sum y^2-\left(\sum y\right)^2\right]}} \tag{3}$$

3. Results and Discussion

The results were presented in grid and statistical form; Figures 3–6 are, respectively, the total count in parts per million (TC in ppm), equivalent uranium (eU in ppm), equivalent thorium (eTh in ppm), and

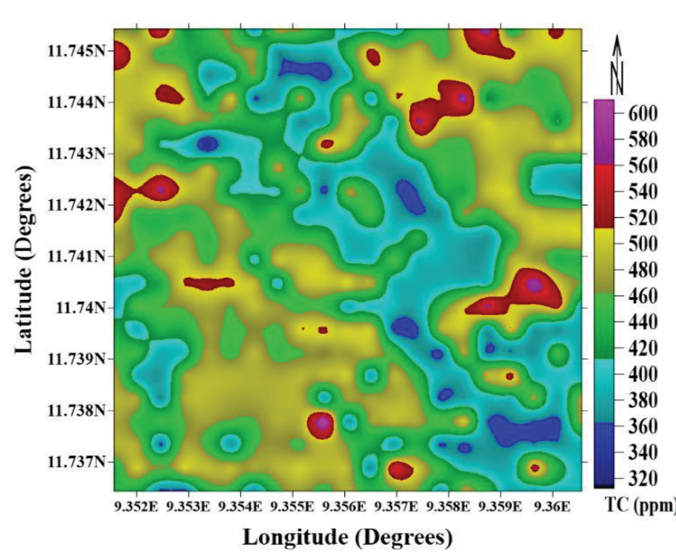

Figure 3. Total count map of the study area.

potassium (K in %) maps of the study area. Total count map of radioelements (Fig. 3) indicated high radiometric anomalies in few spots NE, NW, and Eastern region with the values ranging from 510 to 610 ppm average values of anomalies were observed in NE and SW, while low values ranging from 315 to 410 ppm were observed along NW-SE direction of the area. An average to high concentration of uranium between 20 to 40 ppm were observed around NE, NW and SW (Fig. 4) and trend of low to intermediate recorded in NW-SE direction ranging from 1 to 14 ppm. The thorium map (Fig. 5) shows few regions with high concentration in the north-eastern and north-western part ranging from 100 to 181 ppm with low concentration trending in NW-SE direction ranging from 10 to 40 ppm. Potassium concentration is high along West-Eastern direction, moderate in north-eastern, north-western, western region ranging from 3% to 5.7%, while lower concentration is observed along NW-SE direction with values ranging from 0.1% to 1.6% (Fig. 6). Radiometric ratios are more effective of lithology variation than the individual radiometric channels; however, a variety of radiometric ratio maps were produced. U/TH rations have particular value in exploration for uranium deposit because it has been found to increase locally within regions containing uranium ores (Shives et al., 1995). Figure 7 is the Uranium-to-Thorium (eU/eTH) ratio map that shows a low preferential increase in uranium to thorium. As thorium enrichment generally does not accompany potassium during hydrothermal alteration processes, Th/K ratio provides an excellent distinction between

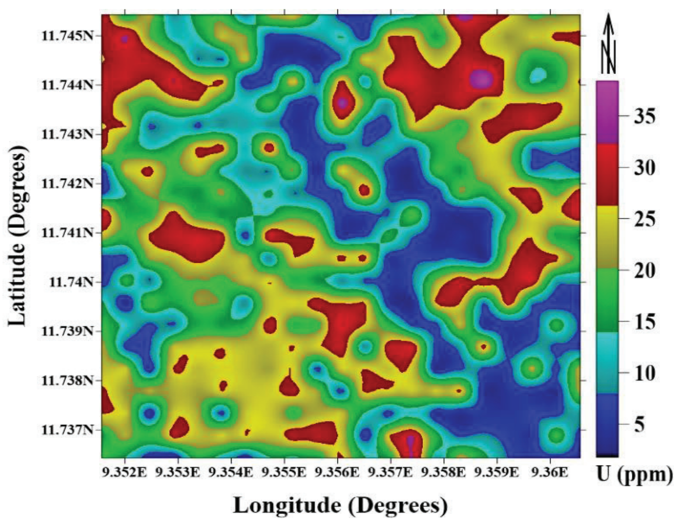

Figure 4. Uranium concentration (eU) map.

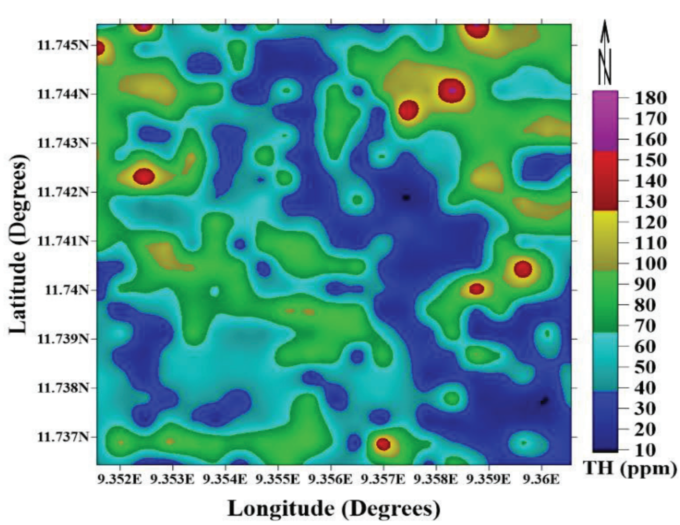

Figure 5. Thorium concentration (eTH) map.

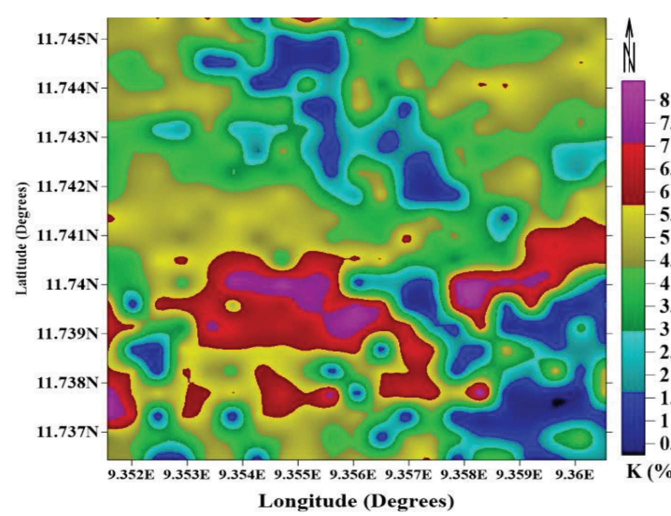

Figure 6. Potassium concentration (%K) map.

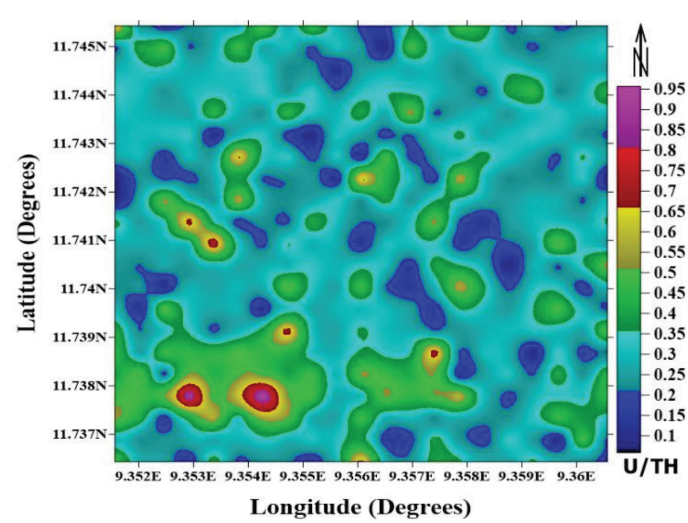

Figure 7. U/Th ratio map.

potassium associated with alteration and anomalies related to normal lithological variations. It has been established that in general, low Th/K ratios are excellent indicators of potassium alteration (Shives et al., 1995). Thorium-to-potassium (Th/K) ratio map (Fig. 8) shown high signatures in an isolated spots in south-eastern and north-western part of the area, central regions, and south-western part have low Th/K ratio which indicate preferential enrichment of potassium to thorium.

In the U/K ratio map (Fig. 9), there is preferential enrichment of potassium to uranium as most of the area has low U/K ratio values while uranium enrichment is observed in the south-eastern and north-western end of the study area. Ratios of the radioelements can provide further constraints for identifying potential uranium deposits. A ratio of U^2/Th proved effective in highlighting uranium mineralization. The U^2/Th is also effective in separating the primary uranium, associated with uranium-bearing rocks. High U^2/Th ratio values are associated with many uranium deposits and can be used to highlight new areas of potential mineralization. The U^2/Th ratio map is presented in (Fig. 10) which highlights the areas that are both high in U and U/Th. The areas of high U^2/Th are shown in south-western and south-south areas.

A standard ternary image (Fig. 11- is plotted in RGB (Red, Green and Blue) where R = Potassium, G = Thorium, and B = Uranium. Largely, ternary plots of the radioelements usually give a superior image

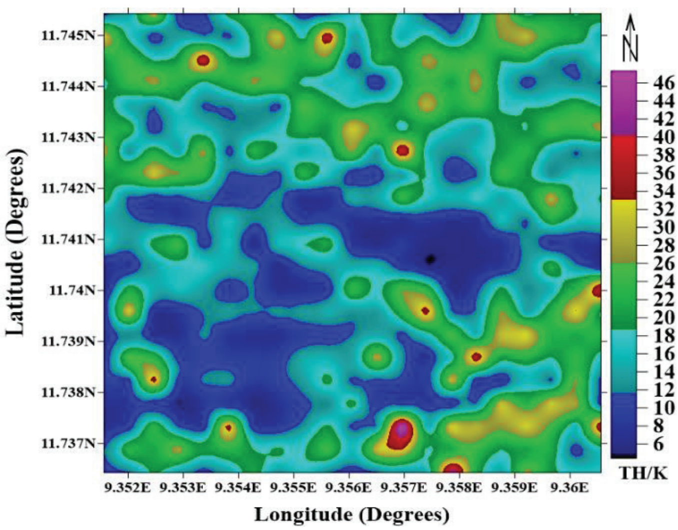

Figure 8. Th/K ratio map.

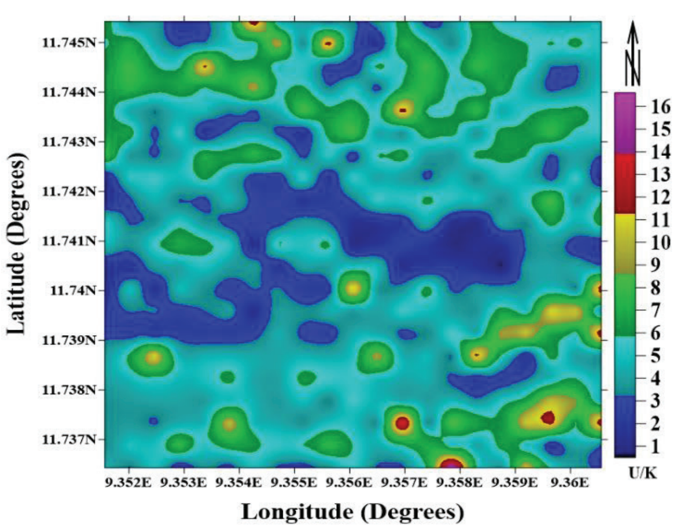

Figure 9. U/K ratio map.

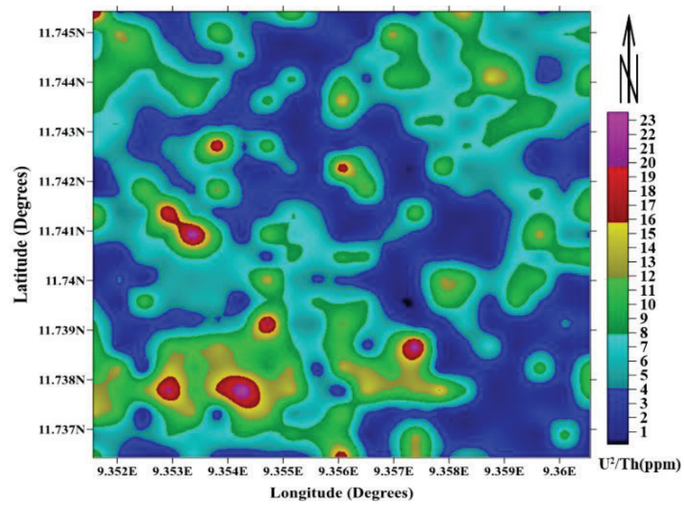

Figure 10. U^2/Th ratio map.

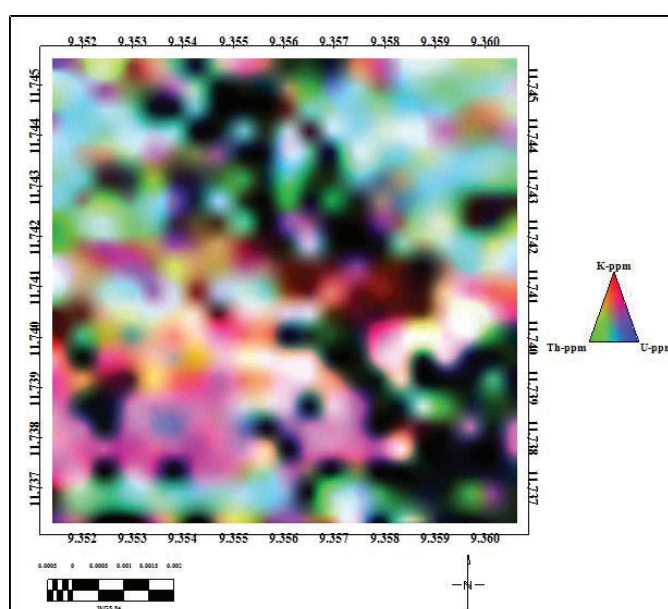

Figure 11. Standard ternary map of the study area.

of the geology (Salem et al., 2005). High concentration of the three radioelements tends to white, while low concentration of the three radioelements tend to black. Concentration of the radioelements is higher (i.e., the white portions) in the south-west and north-eastern part of the area, while low concentrations are observed along NW-SE direction. A consistence low concentration of the radioelements is observed along NW-SE direction due to stream running in the same direction that shields radiation of these radioelements significantly.

The statistical analysis was carried out to see if statistical correlations and mathematical relationship exist between the radiations of parameters investigated using Equations (1)–(3). Concentrations of the radionuclides and does rate for the data acquired are presented in the Table 1, while the activity ratios (U/Th, U/K, Th/U, Th/K, K/U, and K/Th) are displayed in Table 2. The correlation between the activity concentrations of (^{238}U and ^{232}Th), (^{238}U and ^{40}K), and (^{232}Th and ^{40}K) is presented in Table 3. The correlation is found to be linear and positive which may still be attributed to the property of the rock in retaining these radionuclides under varying weather conditions. However, strong correlation of 0.9, 0.80, and 0.82, respectively, is an indication of presence of significant amount of radioactive accessory minerals, such as zircon, monazite, thorite, and garnet, and ^{238}U and ^{232}Th came from natural decay series.

However, mean activity of each radioelement for each profile was computed and presented in bar chart (Figs. 12–14) in order to compare the gamma-ray activity of the radioelements. Statistical threshold

Table 1. Statistical analysis of the radionuclides.

Radionuclide	Minimum	Maximum	Mean	Standard Deviation
eU (ppm)	1.2	39.2	17.529	9.8907
eU (cpc)	0.7	6.9	2.988	1.6120
eTh (ppm)	7	187	59.06	33.522
eTh (cpc)	0.3	6.4	2.051	1.1218
K (%)	0.23	8.78	4.1092	1.9968
K (cpc)	0.7	13.5	6.478	3.0579
TC (cpc)	300.4	638.0	447.761	58.3806
Dose (nGyph-1)	33.45	676.49	300.512	149.7046

Table 2. Ratios of activity concentrations of the radionuclides.

Ratio	Minimum	Maximum	Mean
U/Th	0.048	1.0	0.3122
Th/K	4.265	51.154	16.647
U/K	0.374	17.391	4.765
Th/U	1	20.706	4.025
K/Th	0.020	180.234	0.077
K/U	0.058	2.677	0.284

Table 3. Correlation of K, U, and Th.

	^{40}K	^{238}U	^{232}Th
^{40}K	1.00		
^{238}U	0.802	1.00	
^{232}Th	0.822	0.888	1.00

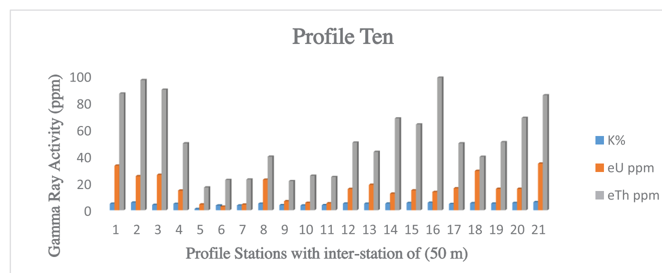

Figure 12. Mean gamma-ray activity of U, Th, and K along profile ten.

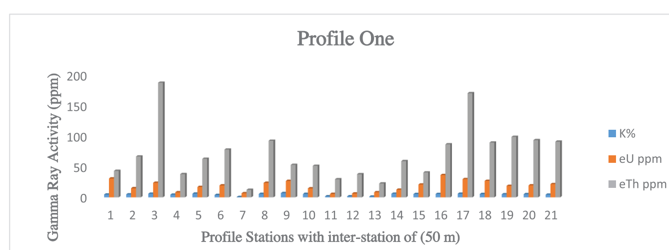

Figure 13. Mean gamma-ray activity of U, Th, and K along profile one.

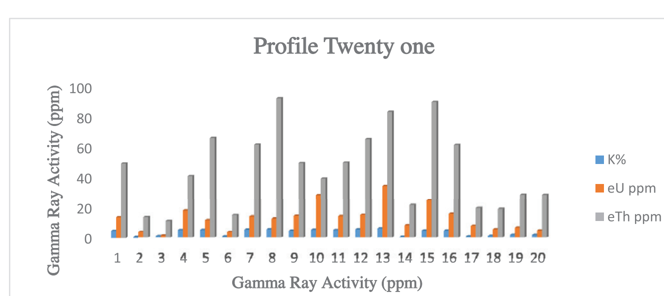

Figure 14. Mean gamma-ray activity of U, Th, and K along profile twenty one.

technique was computed using mean and standard deviation values in Table 1 thereby delineate areas of more prominent radiometric anomalies as presented in Figures 15–17 for uranium, thorium, and potassium, respectively.

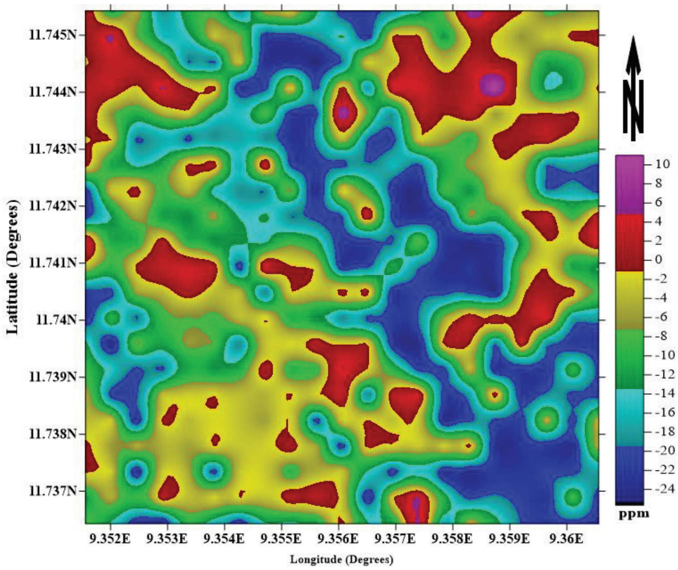

Figure 15. Concentration of uranium after separation of threshold value.

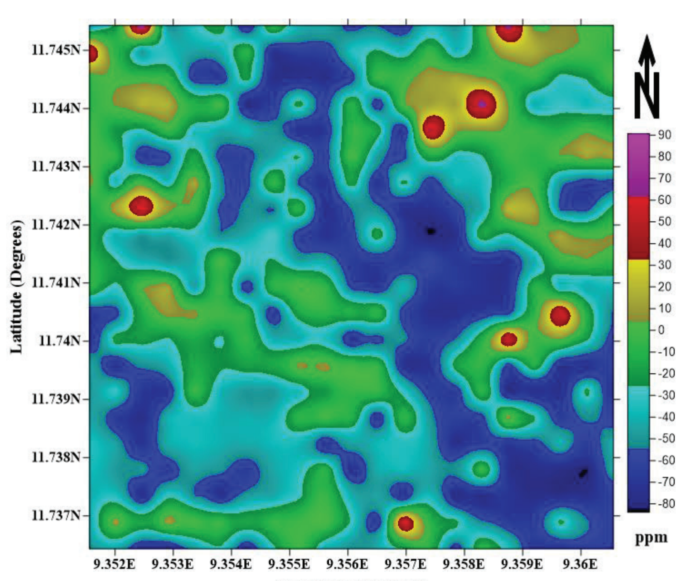

Figure 16. Concentration of thorium after separation of threshold value.

Concentration maps of radioelements ^{238}U, ^{232}Th, and ^{40}K were superimposed or draped over geologic map of the study area so as to see the variation of the concentrations of the radionuclides with geology as presented in (Fig. 18–20).

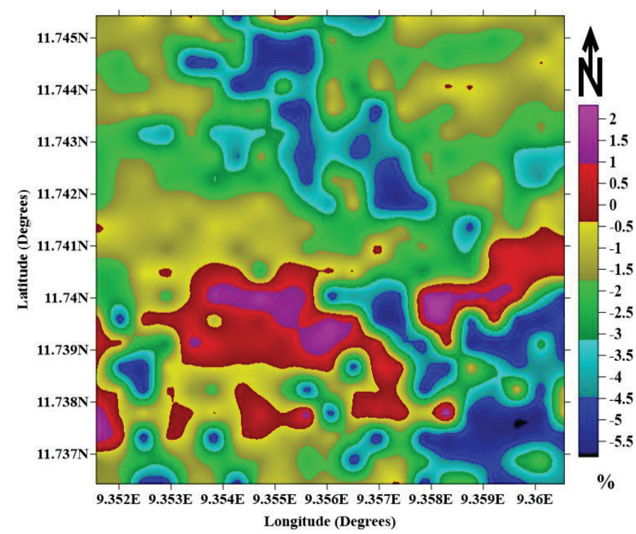

Figure 17. Concentration of potassium after separation of threshold value.

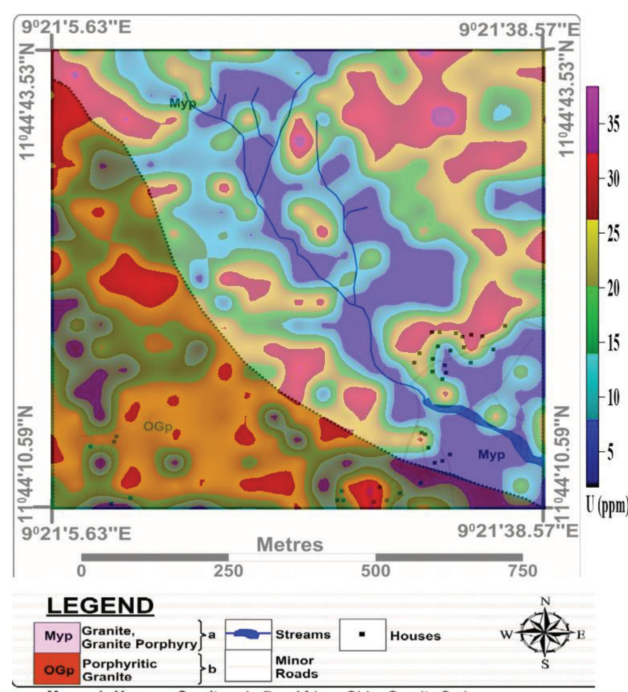

Figure 18. Uranium concentration map draped on geologic map.

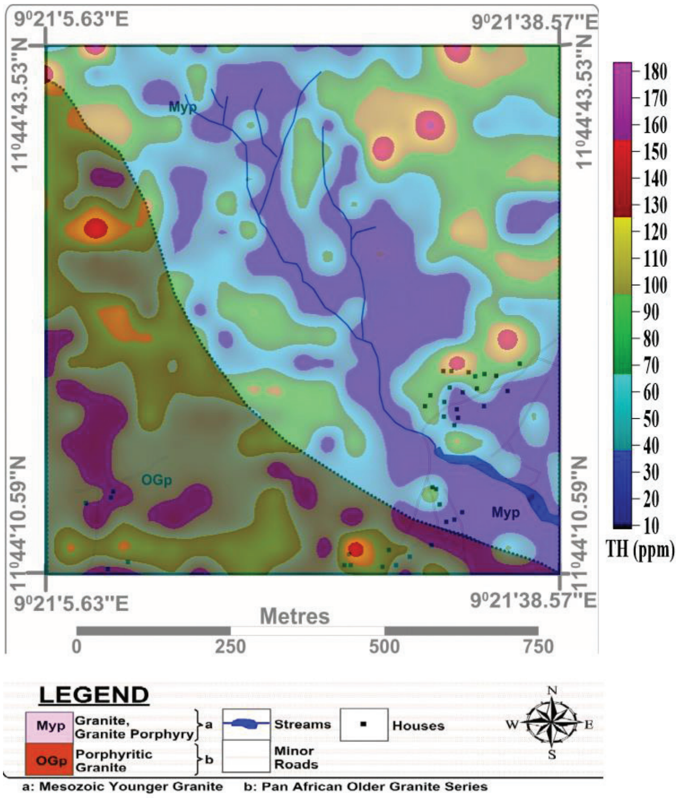

Figure 19. Thorium concentration map draped on geologic map.

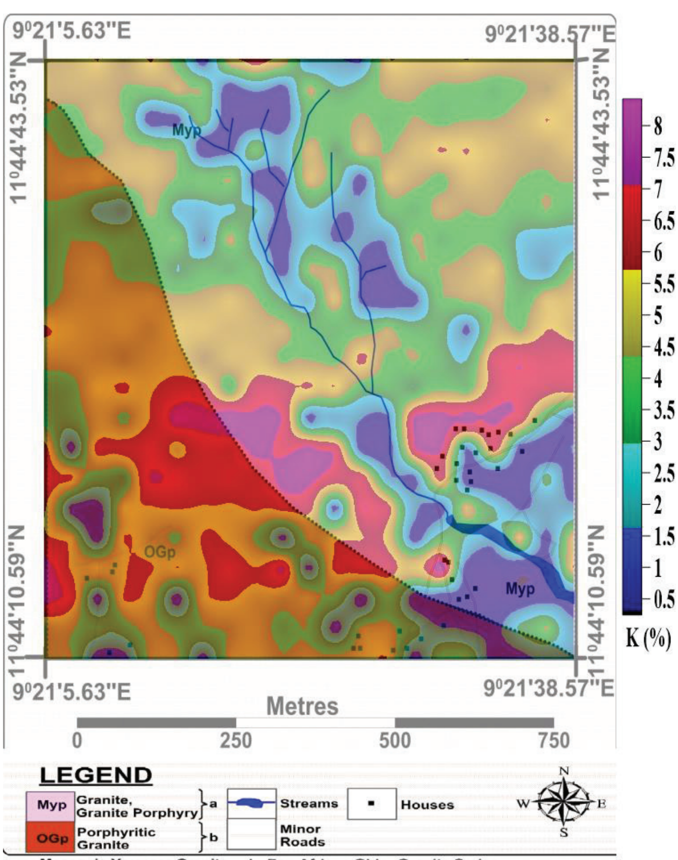

Figure 20. Potassium concentration map draped on geologic map.

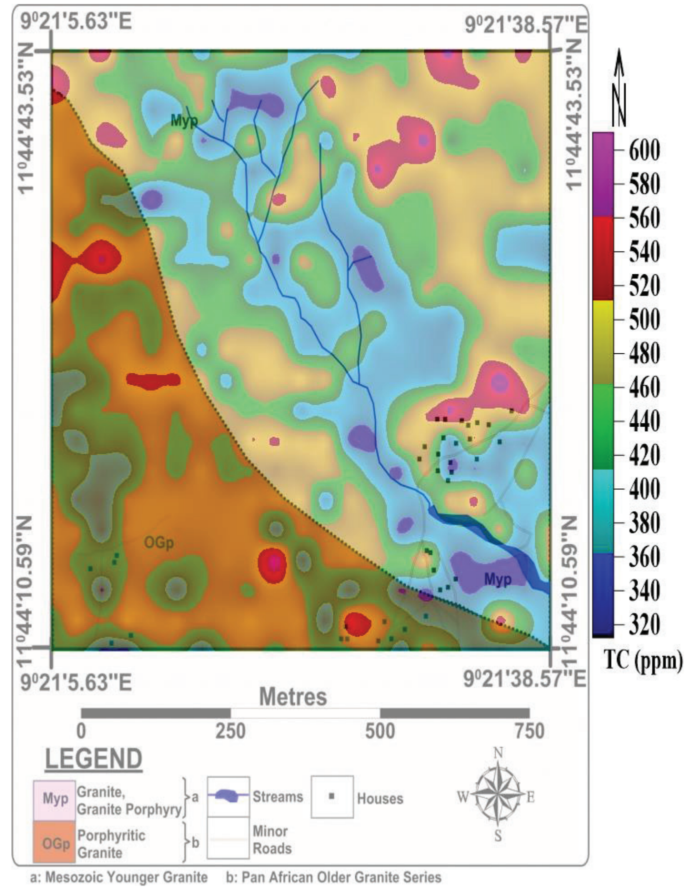

Figure 21. Total count map draped on geologic map.

4. Conclusion

The mean concentration of the radionuclides U, Th, and K in the study area are, respectively, 17.529, 59.06, and 4.1092 ppm, which are within the world average values. The area of promising uranium mineralization are in north-eastern, north-western edge consisting of Mesozoic Younger Granite and south-south part consisting of Pan African Older Granit Series and highly weathered ironstones.

The concentration of the radionuclides ^{238}U, ^{232}Th, and ^{40}K from both grid and statistical analysis confirmed an observed/studied anomalies from aero spectrometric map in the order of ($K < U < Th$) which indicates preferential enrichment of thorium to both uranium and potassium, as well being major source of radioactivity and that uranium mineral is not of large quantity.

The average absorbed dose rate obtained is below the world average value. On this basis, rocks of the study area are not harmful to humans and environment except if been exposed for many years. Figure 21 reveals that water is a good shedding agent of nuclear radiations.

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