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Characterisation for *Radioelements* over an Escarpment Feature(S): A Case Study of the Duku-Tarasa Gwandu Ridge Area of Birnin Kebbi NW Nigeria

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Abstract

The paper presents results of radiometric investigations of an area (Duku-Tarasa) near the capital city of the State of Birnin Kebbi, NW Nigeria. The area of study is about 440 m × 420 m and encloses an Escarpment Feature/Structure on a sedimentary rock generally referred to as the Gwandu Formation. The Gwandu Formation (though not described in the paper) consists of continental lacustrine sediments and is the youngest Palaeogene Formation present in the Sokoto sector of the larger Iullemmeden Basin. The study measured, along some selected profiles across this escarpment feature, radiometric signatures using a Sim-Max G411 portable field gamma-ray spectrometer (giving counts for U, Th and K relative to the background values over the area), the ground total-field magnetic data (using the proton precession magnetometer) along those profiles and collected some (5) rock samples for flame photometry and AAS analyses towards the target proposition. Activity concentration levels due to potassium (K), uranium (U) and thorium (Th) were measured in the area along the five established profiles spaced at 50 metres. The results from these measurements and analyses were displayed (in Tables/histograms and gray level maps/images of concentrations of Uranium, Thorium and Potassium prospects) and interpreted (dismissing the magnetic data as seemingly passive as no filter was applied to the mapped data).

Keywords

Gwandu Ridge, Iso-Radiometric Contour Map, Gamma Activity, Gamma-Ray Spectrometry and Radioelements

1. Introduction

In Nigeria Already, the initial stage in the large scale exploration for the radio-element was launched when high sensitivity aero-radiometric surveys were carried out in 1975. The survey covered the lower Benue area, the middle Niger and the Sokoto which was conducted by Fairly Surveys Ltd. Hunting Geology and Geophysics Ltd., respectively, on behalf of the Federal Ministry of Mines and Power. Although intensive ground follow-up surveys have been carried out in some area since 1977 (for example the Nigeria Uranium Mining Company (NUMCO), the Nigerian Mining Corporation, the Geological Survey of Nigeria and by the University of Ife), there is very little information on Uranium occurrences in Nigeria. The little available information on uranium occurrences in Nigeria is mainly from individuals who have analyzed a few rock samples and uranium ores from some locations around the Nigerian younger granite province. However, the work of [1] [2] [3] [4] [5] who carried out detailed Investigation of radiometric anomalies in the Sokoto Basin, Bisichi, Jingir and Kakuri areas of Sokoto, Plateau and the Kaduna States respectively, forms a very important step for a large scale exploration of uranium and allied minerals. Radiometric survey is of use in geological mapping as different rock types can be recognized from their distinctive radioactive signatures [6] [7]. There are in excess of 50 naturally occurring radioactive. The elements of principle interest in radiometric exploration are uranium ^{238}U, thorium ^{232}Th and ^{40}K potassium. In a reconnaissance exploration for radioelement in Nigeria, Hunting surveys LTD and Fugro Airborne surveys carried out aero-spectrometric survey for Nigerian Geological Survey Agency (NGSA). In the survey, whose final maps were produced in 1975, 2007 and 2010, most of the country was covered [8]. Anomalies recorded form the survey can be investigated to determine their worth regarding their uranium (u) and allied follower-up held part of Gwandu ridge escarpment features to one of such anomalies Birnin Kebbi sheet (49), in the Sokoto basin. The investigation involved using portable handheld gamma ray spectrometer (in which the total gamma activity due to U, Th and ^{40}K was determined). The investigation was carried out with the aim of ground follow-up of radiometric measurements and Assay of rocks analysis over an escarpment features Gwandu ridge to characterize the anomaly in terms of its Uranium (U) prospect. Because of the great number of these anomalies within the southeastern part of Iullumeden basin, a large reserve of Radioelements may exists; hence there is need for this investigation to study one such anomalous area. Hence, the results obtained from this study can be used to characterize the results from other anomalous areas (the Gwandu ridges) [9].

2. Study Area

The study area Duku-Tarasa is in Birnin Kebbi Local Government area of Kebbi State and is situated 5.6 km from Ambursa and 5.4 km from Kangiwa village (**Figure 1**). It is confined within the latitudes 12˚28'26.4''N - 12˚28'12''N and

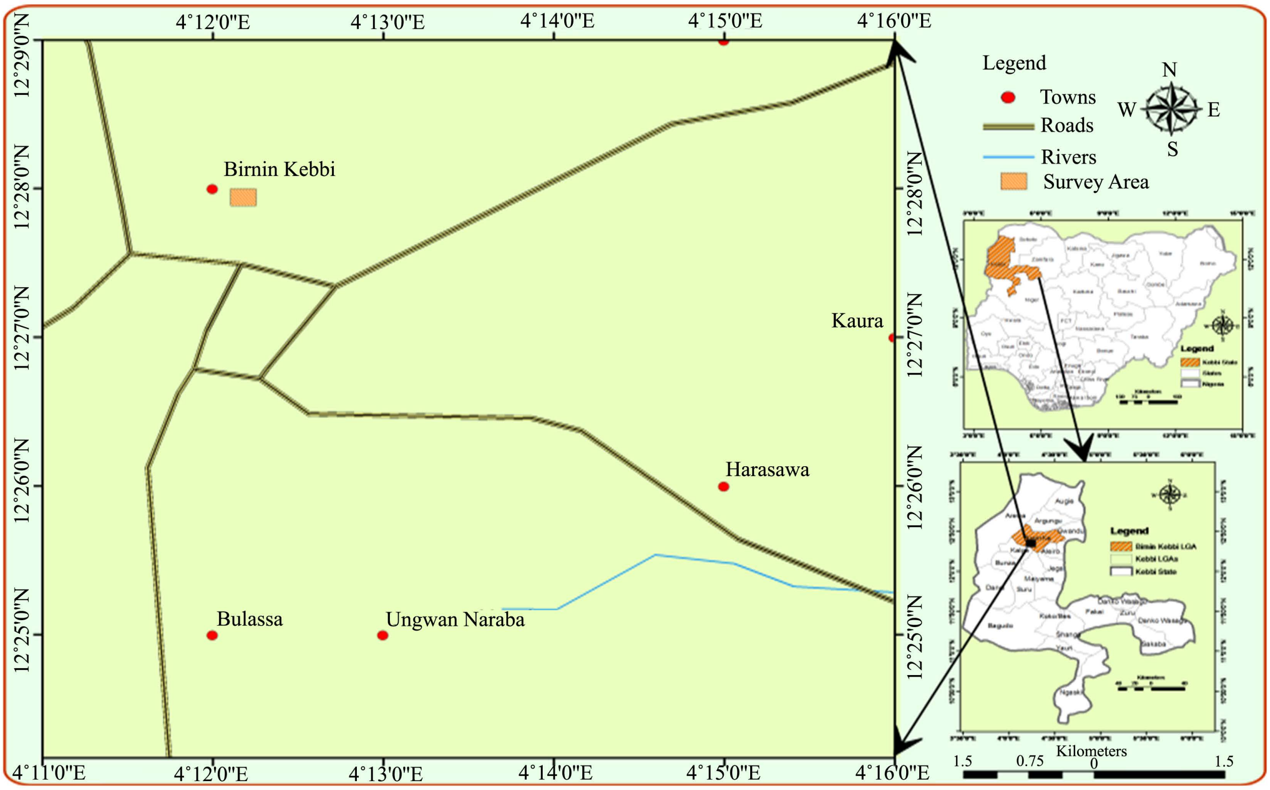


Figure 1. Location map of the study area (Adopted from Google earth map, 2018).

longitudes 4˚10'1.92"E - 4˚10'5.6"E. Accessibility to the study area is only by the Kebbi-Kangiwa which is a prominent federal road. A number of all season motorable roads, some of which are old tarred road also exist within the village.

General Geology of the Study Area

The geology of the area is predominantly a gentle undulating plain with an average elevation varying from 250 m to 400 m above sea level. The plain is occasionally interrupted by low mesas and other escarpment feature. Birnin Kebbi is part of the Sokoto Basin of the Nigeria sector of the larger Iullumeden Basin; the Iullumeden Basin itself is a broader sedimentary basin covering most part of Algeria, Niger Republic, Benin Republic, Mali, and Libya. The geology of Kebbi State is dominated by two formations Precambrian Basement complex in the South to southeast and young sedimentary rocks in the North. The basement complex region is composed of very old volcanic and metamorphic rocks such as granites, schist, gneisses, and quartzite consist of Gwandu, Illo and Rima group whose ages range from cretaceous to the Eocene (**Figure 2**). The Gwandu group consists of massive of clay interbeded with sandstone while Illo and Rima group consist of Pebbly grits, sandstones and clays, mudstones and siltstones respectively mineral that can be found in the state include quarts, Kaolin, photolytic bauxite, clay, potassium, silica sand, and salt [10] [11] [12]. The sediment dips gently and thickens gradually toward the northwest with maximum thicknesses attainable toward the border with Niger Republic [13]. The study area is affected

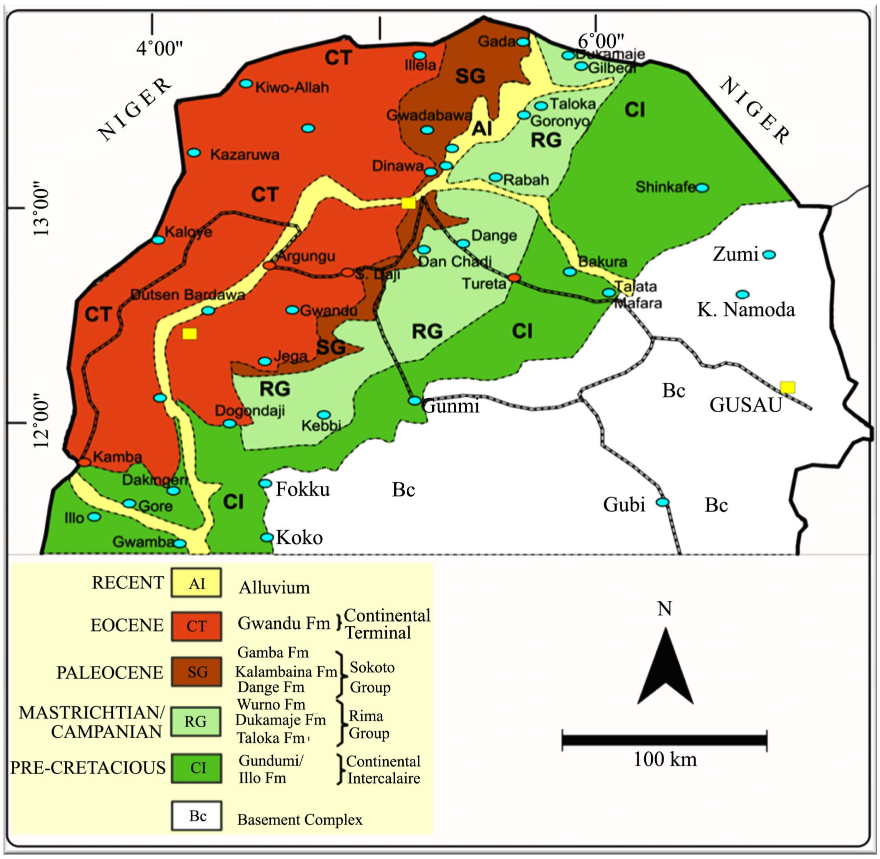


Figure 2. Generalized Geological map of Sokoto, Modified after Obaje [13].

by a series of faults and fractures generally characterized by more or less recent first phases of deposition within the Sokoto basin, which has caused alteration of several ridges (**Figure 2**).

3. Methods

A combined geophysical and geochemical method was used in this work. Below are the brief discussions on each of the method.

3.1. Gamma-Ray Spectrometry

The ground radiometric survey in this work was employed to investigate the radioactive mineral resources deposit over an escarpment feature(s) Duku-Tarasa area of Birnin Kebbi southeastern of part Iullumedden basin. These methods were used to measure the radioelement that may yield in the search for these radioactive deposits. A large number of the anomalies were also found within the Gwandu region (Birnin Kebbi, Sheet-49).

A detailed in-situ gamma-ray spectrometric survey of the area was carried out. This involves taking readings, on the surface on a square grid of 10 m interval. A total area of 440 m by 420 m was covered (**Figure 3**). The stations were established such that points outside the area delineated as anomalous from the escarpment feature(s) were considered. The readings include total gamma activity

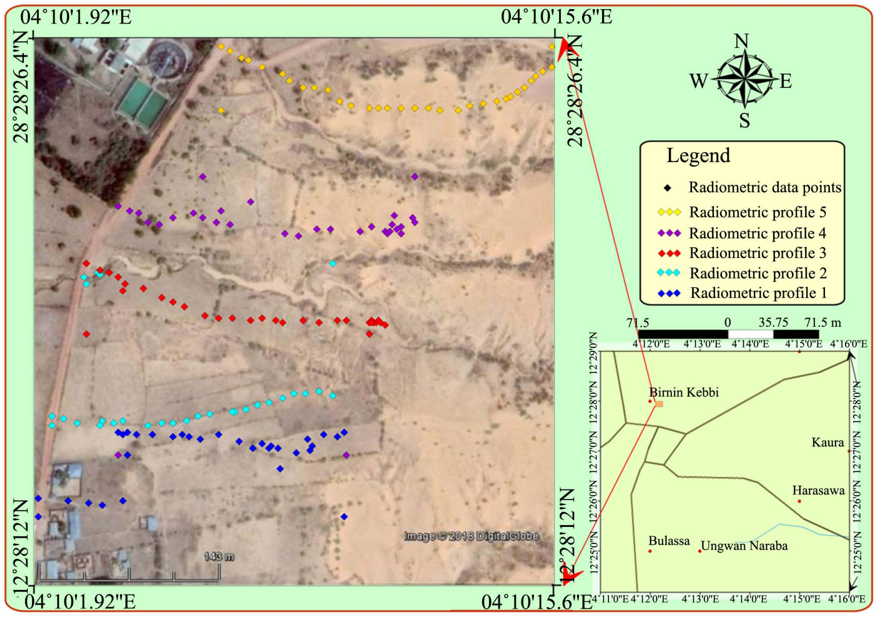


Figure 3. Profiles on Google earth map showing the survey area (Digital image, 2018).

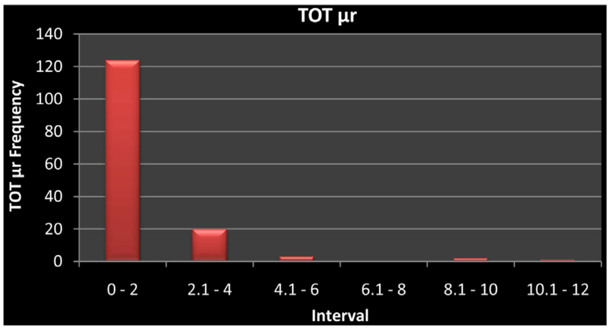
due to the equivalent radioelements eU, eTh, and ^{40}K as well as total count (TOT count) at each station. The gamma activity was recorded with a *Sim-Max-G*411 portable field gamma-ray spectrometer [14]. The procedure for taking readings involved placing the spectrometer on the ground at each station and readings taken for each window. The windows are for the total count TOTμr, eU, eTh and %K. Typically; it takes about 3 - 5 minutes to take readings from the four channels window at each station. Prior to analysis of the results obtained from the determinations described above, the readings were corrected for background due to gamma activity caused by cosmic radiation. The background readings (40, 20, 16 and 12 cpm for the total, %K, U and Th windows respectively) were obtained by taking spectrometer readings within (Gudi-Takalau dam and Irrigation farm at Duku River) Birnin Kebbi area. The data was thus reduced by subtracting the background in order to determine the true gamma activity due to the radioelements in the environment within the field of study. The reduced total gamma activity to each station was plotted and these were contoured to give (Figure 4), this map was used to delineate areas of anomalous gamma activity in the area as is explained below. The reduced gamma activities due to the individual radioelements, U, Th and %K measured (U_c, Th_c and K_c, respectively) was used to calculate their concentrations in ppm, for U and Th, and %K respectively [3]. The concentrations, referred to as equivalent element concentration (eU, eTh and %K, respectively), were calculated assuming secular equilibrium in the ^{238}U and ^{232}Th decay series using the following relationship.

$$\mathrm{eTh} = \mathrm{K_1 Th_c} \tag{1}$$

$$\mathrm{eU} = \mathrm{K_2}\left(\mathrm{U_c} - \mathrm{S_1 Th_c}\right) \tag{2}$$

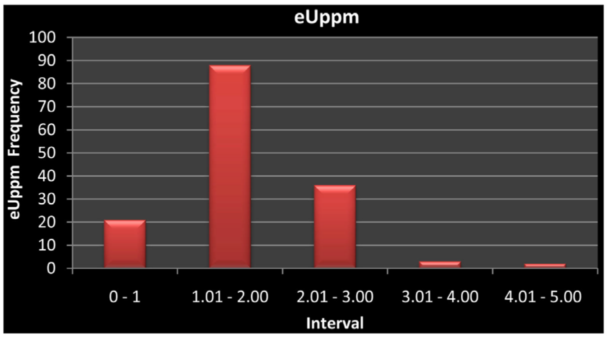
$$\mathrm{K} = \mathrm{K_3}\left(\mathrm{K_c} - \mathrm{S_2}\left(\mathrm{U_c} - \mathrm{S_2 Th_c}\right) - \mathrm{S_3 Th_c}\right) \tag{3}$$

where K_1, K_2, K_3 are instrument constants as determined in the calibration of the spectrometer [15]. S_1, S_2 and S_3 called stripping ratios, take care of the interference due to Th and U; and Th in the measurements of K and U, respectively [16]. Iso-radiometric plots of the eU and eTh are shown in (**Figures 5-7**).



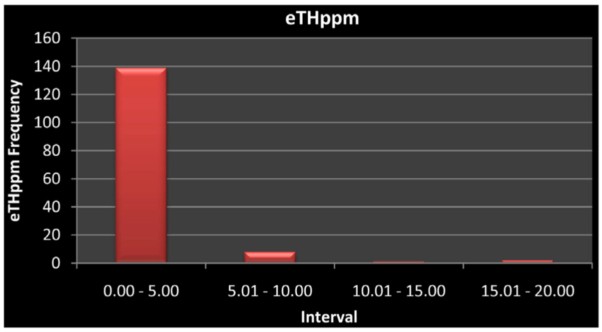
TOT µr	Freq.
0 - 2	124
2.1 - 4	20
4.1 - 6	3
6.1 - 8	0
8.1 - 10	2
10.1 - 12	1

Figure 4. Frequency distribution of total count (TOT) of gamma activity concentration contents.



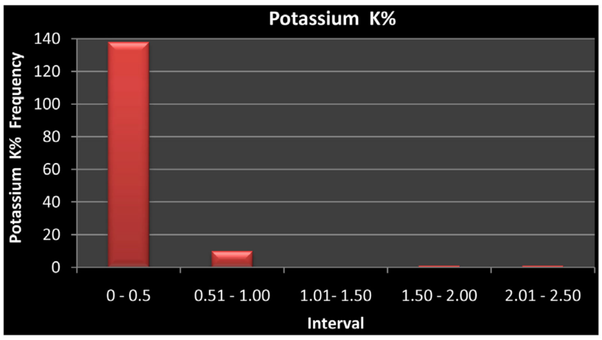
eUppm	Freq.
0.00 - 1.00	20
1.01 - 2.00	89
2.01 - 3.00	37
3.01 - 4.00	3
4.01 – 5.00	2

Figure 5. Frequency distribution for eU of gamma activity concentration contents in (ppm).



eTHppm	Freq.
0.00 - 5.00	139
5.01 - 10.00	8
10.01 - 15.00	1
15.01 - 20.00	2

Figure 6. Frequency distribution for eTh of gamma activity concentration contents in (ppm).



Potassium K%	Freq.
0 - 0.5	138
0.51 - 1.00	10
1.01- 1.50	0
1.50 - 2.00	1
2.01 - 2.50	1

Figure 7. Frequency distribution for %K of gamma activity concentration contents in (%).

3.2. Geomagnetic Survey

The geomagnetic survey was carried out with ACZ-8 Proton precession magnetometer at the locations where spectrometer readings were taken. The survey was carried out with the main objective of determining the parameters of any anomaly that the radiometric survey could provide, especially if some correlation between the two methods could be established. The readings obtained from the survey were corrected for diurnal variations. As there was no significant correlation between the results of the gamma ray survey and the magnetic survey, the results of the aforesaid was only qualitatively analyzed. The result was therefore not subjected to detailed analysis.

First Vertical Derivative

Spatial resolution can also be achieved using the vertical derivative filter. The first vertical derivative filter computes the vertical rate change in the magnetic field. A first derivative tends to sharpen the edges of anomalies and enhance shallow features. The vertical derivative map is much more responsive to local influence than to broad or regional effect and therefore tends to give sharper picture than the map of the total field [17].

3.3. Assay of Rock Sample

Rock samples were collected from exposures in the area. Five samples were collected and analyzed for their uranium (U), thorium (Th) content and other elements commonly associated with uranium (U) in Iron stone, laterite, potassium (K), lead (Pb), cobalt (Co), and copper (Cu) [18]. Uranium (U) content of the samples and other elements was determined by flame photometry at the Centre for Energy Research & Training (CERT) laboratory Ahmadu Bello University, Zaria. Both methods are discussed in exploration geochemistry text book [19] [20].

4. Results and Discussion

4.1. Radiometric Survey Analysis

In (1.1) above, the method of data collection was discussed. Treatments of data to obtain element concentrations from count were also detailed in the same section. Based on this, the results obtained are going to be analyzed to characterize uranium (U) and or thorium (Th) occurrence in the area of surveyed. The concentrations of equivalent uranium, eU, thorium, eTh and Potassium (%K) determined from the spectrometer readings were presented in **Table 1**, in order to actually characterize the anomaly considered interms of its radioelement's contents. The analysis for the radiometric data performed using the excel software for the histogram plots, results of the frequency distribution curve gamma activity measurements suggest the existence of gamma concentration contents of the

Table 1. Concentration of elements.

Sample		Elements-Concentration				
S/N	Station No.	Fe%	%K	Pb/ppm	Cu/ppm	U/ppm
1	01/10	4.5	6.1	2	203	1200
2	04/20	2.5	3.7	4	20	1200
3	04/40	3.2	3.1	-	5	-
4	05/50	5.6	2.3	-	8	1200
5	06/80	3.0	7.4	96	203	1200

total count (TOT) and the three radioelement's within the five establish profile (**Figures 4-7**) can be used to determine the frequency activity of the sources of radiations (radioactive source concentrations).

This can be achieved by determining a reference background count. The contour map of the total count (TOT) (**Figure 8**) reveals some anomalies. The sources of radioactivity in the area of surveyed were identified from this map. Some of these sources correspond with the areas of eU and %K anomalies. From this analysis and the computed values of the individual elements concentrations, uranium and thorium were identified as the main sources of the radioactivity in the area of surveyed. The contribution of uranium and potassium is also significant because at some stations, extremely high k values were recorded even though in most of the stations its concentration is negligible.

From the analysis of eU, eTh and K% of the contour or Iso-radiometric maps (**Figures 9-11**), the most probable areas of uranium/thorium mineralization constitute about 40% of the total area of surveyed. Results of potassium anomalies also show about 20% of the area is thorium anomalous. It must be stressed that these results were obtained assuming secular equilibrium in the uranium U and thorium, Th decay series.

A number of these anomalies were also found to correlate with the local topography, most anomalies coinciding with the local highs (ridges, and high rock exposures). These were however found to be associated more with gamma activity due to Uranium (U) [21].

4.2. Geomagnetic Survey Analysis

As reported above, the data obtained from this survey was not treated to any detailed interpretation/analysis. The reduced readings were plotted and a magnetic

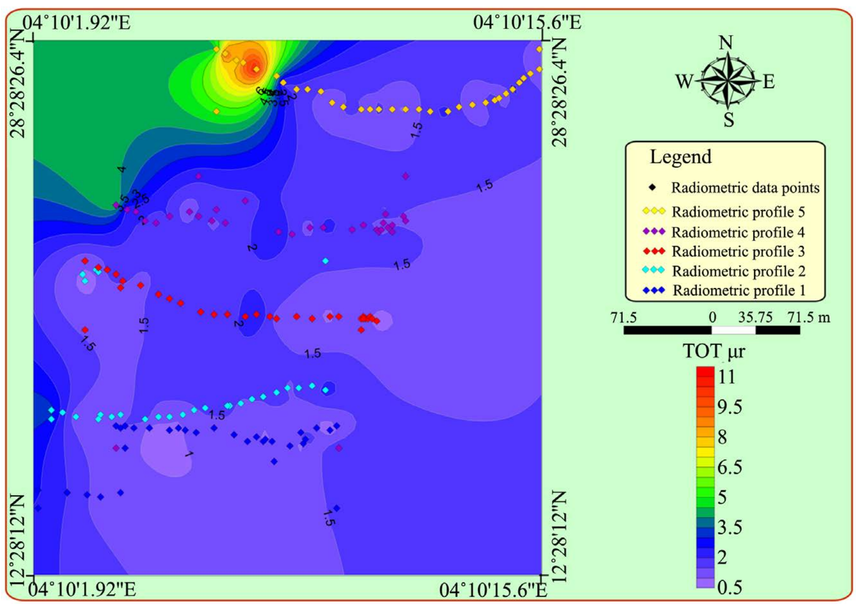


Figure 8. Iso-radiometric total count map showing the areas of sources of radiation (TOT μr).

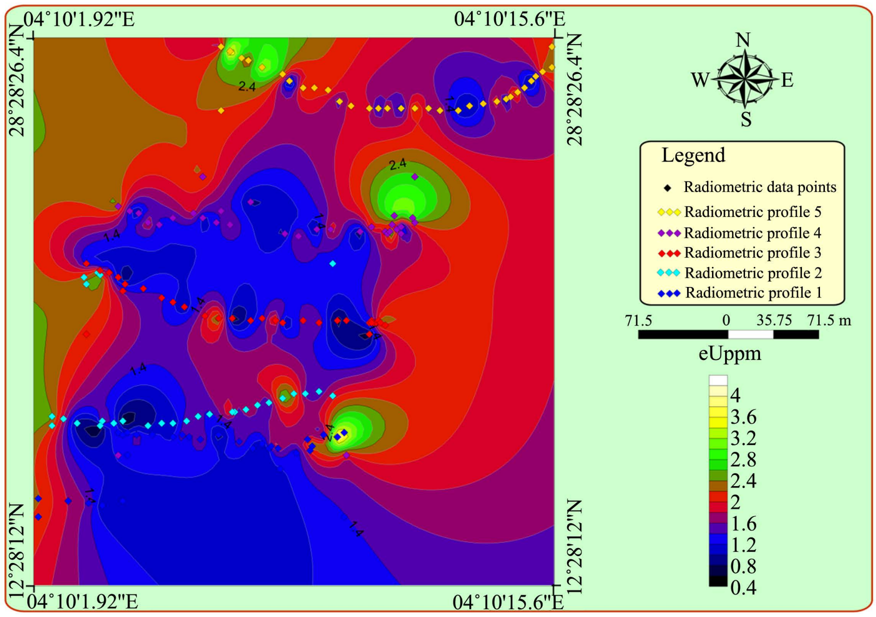


Figure 9. Iso-radiometric map of uranium surface concentration anomalies (ppm).

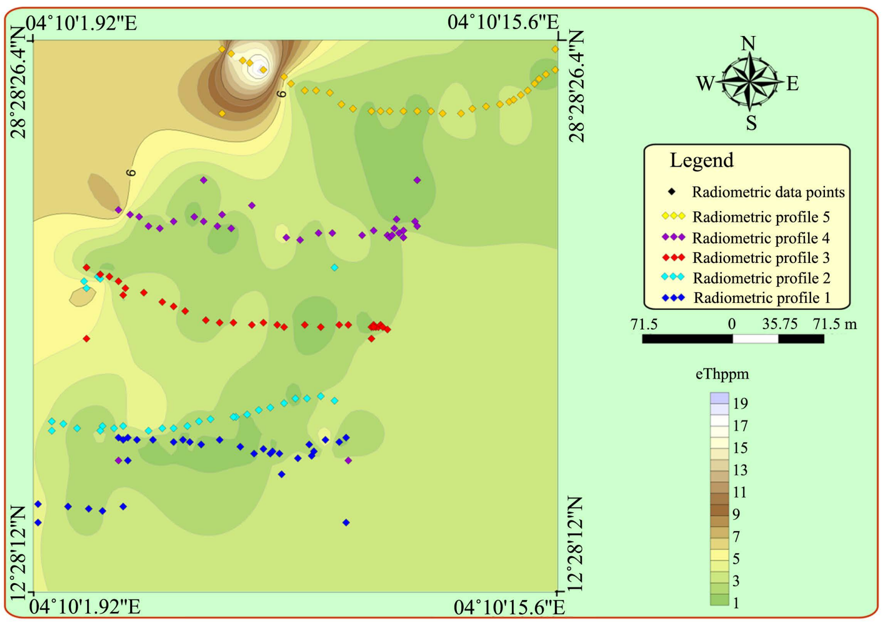


Figure 10. Iso-radiometric map of thorium surface concentration anomalies (ppm).

profile of the total field was produced. The results from the magnetic profile plots map [22], suggest that most of the magnetic profile anomalies obtained from the total field intensity, are caused by near surface effects (**Figure 12**). The results also suggest that the overburden in the area is relatively thin [23] (based on the areal size of the anomalies and gradients of the magnetic profile plots).

First Vertical Derivative Analysis

Result from the first vertical derivative, (**Figure 13**) reveals more of the surface structures with short wavelength and are of high frequency in occurrence. The

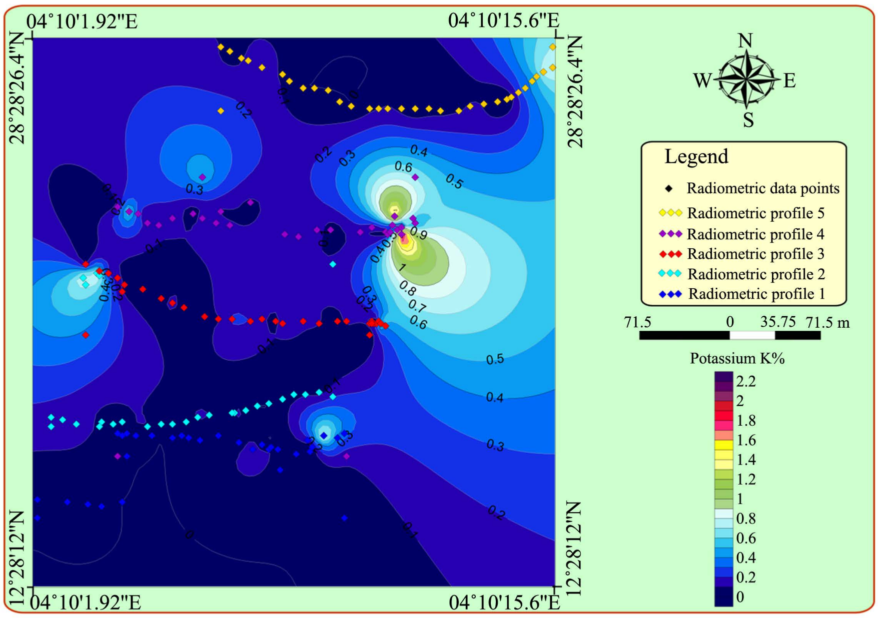


Figure 11. Iso-radiometric map of potassium surface concentration anomalies (ppm).

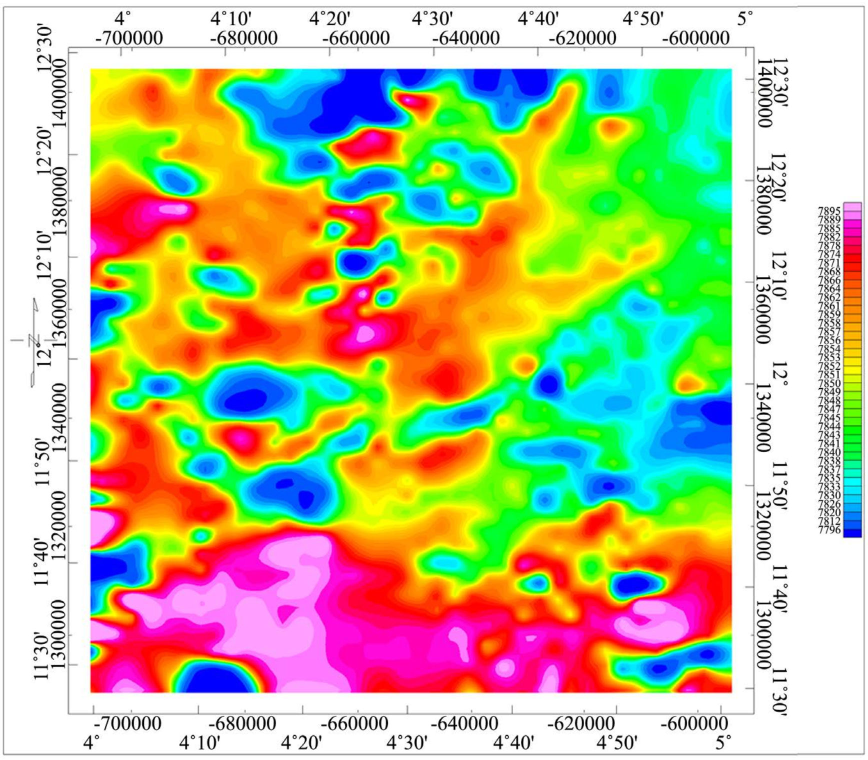


Figure 12. Total Magnetic field Intensity map (TMI) Adopted from NGSA, (2010).

southeast, northwest and northeastern edge of the study area shows mixtures of high and low magnetic susceptibility with features of lineation in value and trend (blue lines) that depicts fault line, fractures or lithology contact. Long wave signatures are predominant in the southwest region which reveals that there are deep magnetic source within the study area typical of a sedimentary basin.

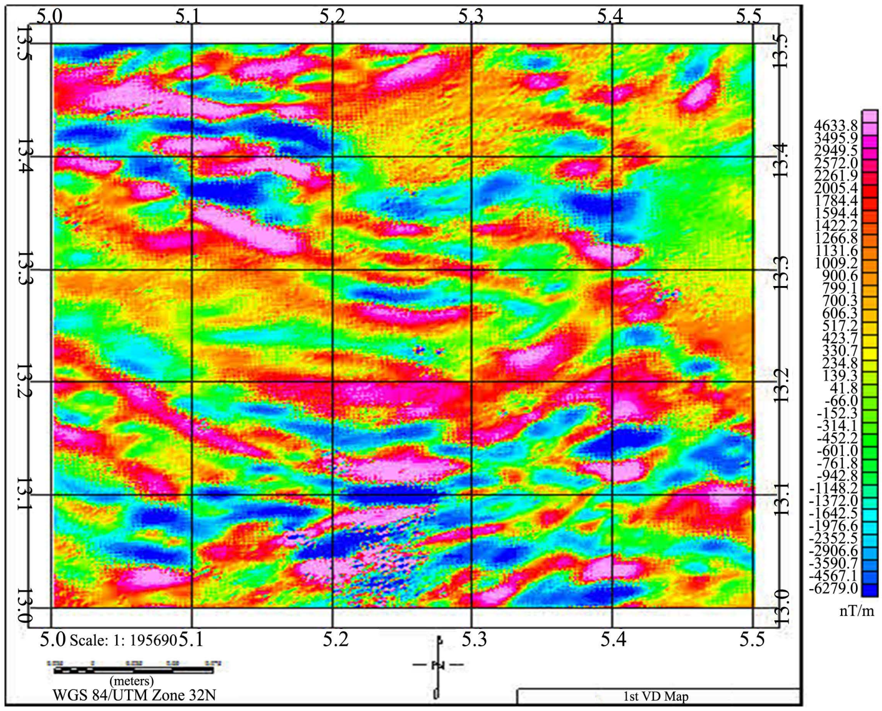


Figure 13. First vertical derivatives at 200 m.

4.3. Rocks Spectroscopy Analysis

The results from these determinations are shown below in **Table 1** below.

As reported above, rock samples obtained from the study area were analyzed for their radioelements concentration [24]. In addition, other elements in common association with U in minerals were also analyzed. The results as presented in **Table 1** above indicate normal concentration for the elements, Fe (%), K (%), Pb (ppm), Cu (ppm) and U (ppm). The trace element concentrations were however much higher than normal for avoidance of doubt, the analysis was repeated four times, each time recording the same results. However, in view of the high values, especially that apparent mineralization was observed on each sample, the results was therefore considered for further presentation, the accuracy of the results is due to the proper calibration of the equipment used for the analysis.

5. Conclusions

A Ground follow-up of an Aeroradiometric anomaly investigation with assay of rock analysis has been carried out over an escarpment/structure in Duku-Tarasa of Birnin Kebbi, NW Nigeria. The study measured, along some selected profiles across this escarpment feature, radiometric signatures using a Sim-Max G411 portable field gamma-ray spectrometer (giving counts for U, Th and K relative to the background values over the area), the ground total-field magnetic data (using the proton precession magnetometer) along those profiles and collected some (5) rock samples for flame photometry and AAS analyses towards the target proposition. The results from these measurements and analyses were displayed (in Tables/histograms and gray level maps/images of concentrations of Uranium, Thorium and Potassium prospects) and interpreted (dismissing the magnetic data as seemingly passive as no filter was applied to the mapped data).

This study illustrates how radiometric measurements can be used within the sedimentary unit of Gwandu formation area for mapping lithological units and outlining the characterization of anomalous zones altered by intercontinental processes. Our results show a radioelement distribution reflecting a geochemical coherence during the orogenic activity, which took place within Southeastern part of Iullummeden basin (**Figure 2**). The highest level of radioactivity is observed at the eastern part of the surveyed area, where the youngest intercontinental activity of the Gwandu formation developed (**Figure 2**).

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Authors' Contributions

AA carried out the data analysis and drafted the manuscript. OO, AL Ahmed and AY Sunusi joined the methodological discussion and helped to draft manuscript. Both authors read and approved the final manuscript.

Authors' Information

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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