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Analysis of high resolution aeroradiometric data over Sokoto basin and adjoining areas northwestern, Nigeria

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ABSTRACT
The analysis of high resolution aeroradiometric data over Sokoto basin was carried out to determine the radioactive heat production of the area, with a view of finding geothermal energy source to augment the epileptic power supply being experienced in the country. The findings of this research revealed that the total count map has range of values from 362.332cps to 2571.005cps, Potassium percent values range from 0.11 to 2.036, thorium values range from 3.920ppm to 17.470ppm and Uranium values range from 0.484ppm to 6.322ppm. The qualitative interpretation revealed that uranium, potassium and thorium are abundant in the basement rocks. Quantitative analysis of potassium, thorium and uranium to obtain heat production shows low radioactive heat production values with a range of 0.00036μWm-3 to 0.10490 μWm-3 and moderate radioactive values that range from 0.10490 μWm-3 to 0.16309μWm-3. The findings indicate that the area have low to moderate potentials of radioactive heat production and concentration of radioactive minerals.

KEYWORDS
aeroradiometric data; radioactive heat; potassium concentration; thorium concentration; uranium concentration

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(1) INTRODUCTION
The digital high resolution aeroradiometric data was analyzed to determine the radioactive heat flow of the study area. This was done with the aim to find out whether there are high concentration of radioactive minerals that may result to generation of radioactive heat which could serve as a geothermal energy source.

The essence of radiometric surveys is to determine the presence of uranium, thorium and potassium in the surface rocks and soils. Uranium, thorium and potassium, occur most in igneous rocks that are rich in silica and low in mafic rocks. Potassium is mostly found in granite and rhyolite but is low in basalt, uranium is common with pegmatite and black shales and thorium is associated with granite, pegmatite and gneiss. Potassium occur in association with minerals such as muscovite, biotite, sylvite, leucite, glauconite, orthoclase, microcline and sanidine and can be weathered, leached and absorbed in illite clays. While uranium and thorium are found association with resistant minerals like Zircon, Titanite, Apatite and Epidote. [1].

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. It is followed with emissions of radiations of particles such as alpha and beta particles, gamma ray, neutron and proton. The gamma rays are high energy radiations with particular energy for each decay reaction. Their spectrum can be used to understand the amount of different isotopes that decay [2].

Radiometric measurements can be used to delineate radiogenic heat production rate that is the amount of heat emitted with time in a given volume of rocks as resultant decay of radiogenic isotopes. This has been used to determine, sedimentary facies for oil and gas, radioactive contaminants and mineral exploration [3, 4, 5, 6, 7 & 8]

The findings of this research revealed that the Sokoto basin have low to moderate radioactive heat production and radioactive mineral concentration.

1.1 Geology of the Study area

Sokoto basin is part of the Illummeden basin of West Africa (Figure 1) bordered to the south by the northern basement complex, to the east by the Chad basin and to the north and west by the Illummeden basin of Niger. The study area lies between longitudes 4˚00'E and 6˚00'E and latitudes 11˚30'N and 13˚30'N (Figure 2). The area has an aerial extent of 48,400 km2. It has an elevation of 250m to 400m above sea level. The physiography of the area is generally typified by plain that is characterized by Mesas with the conspicuous Dange Scarp as the outstanding feature. The eastern part consists of undulating sandy plain, extending south-westwards to the basement complex. High drainage density produced various Mesas and outliers on the plains to the east. The outcrops of the Paleocene age strata are prominent along the face of the escarpment. [9]

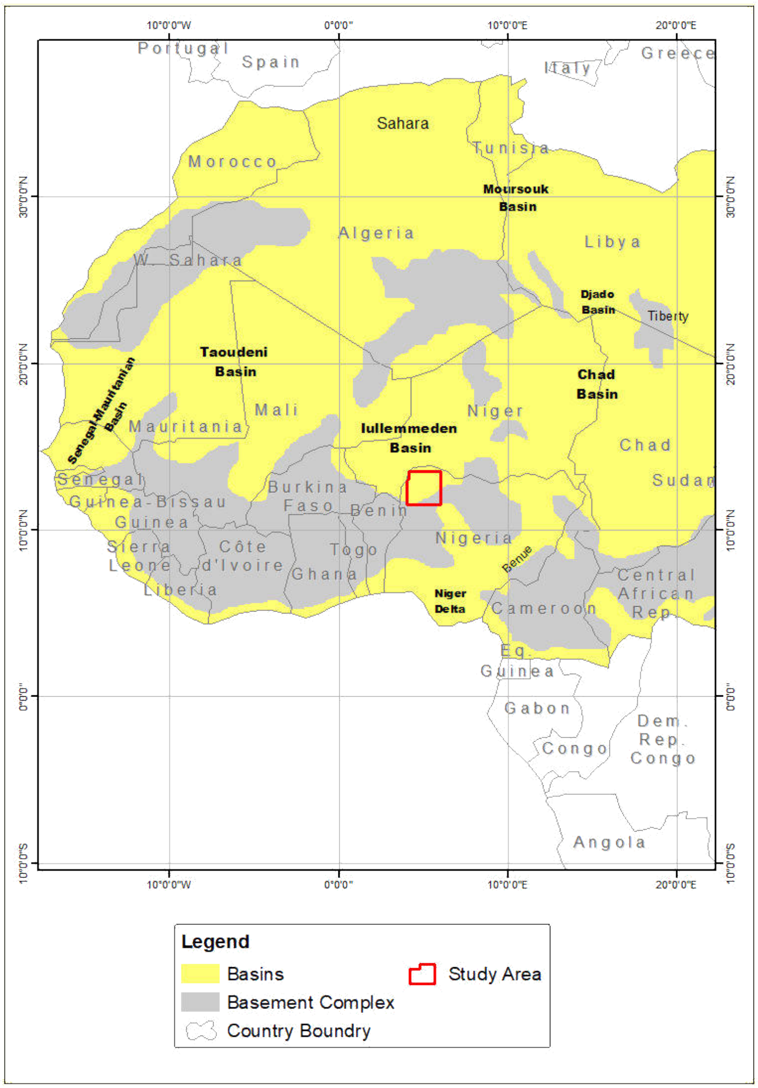

FIGURE 1: Major Sedimentary Basins of West Africa (Modified After, [10]).

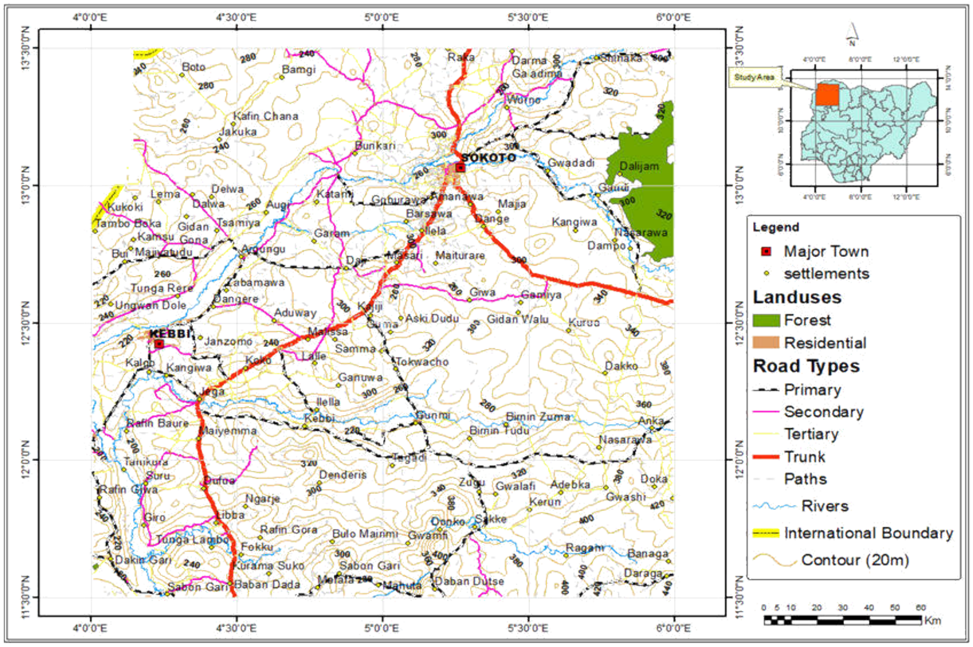

FIGURE 2: Topographic Map of the Study Area (Analyzed from [11]).

The basin is part of the Sahel region of Africa with temperatures of 16oC, in the months of January and December, while the months of April to June has maximum temperature of 38oC and minimum temperature of 24oC. Annual rainfall varies from 600mm - 1000mm throughout the basin. The months of May to September experienced much rainfall, October to April are dry months. The major river that drains the basin is river Sokoto. The river Sokoto and its tributaries of Ka, Zamfara and Rima originated from the rainy area of 600m - 900m highlands of Mashika and Dunia [12].

The geology of Sokoto Basin and adjoining areas (Figure 3 and 4) is unified into sediments of Gwandu Formation; Sokoto group consisting of Gamba Formation, Kalambaina Formation and Dange Formation; Rima group consisting of Wurno Formation, Dukamaje Formation and Taloka Formation; Illo Formation and Gundumi Formation. The Gwandu formation lies uncomformably on the Gamba formation. The formation is Eocene in age with sediments of continental origin, which are interbedded slightly consolidated sands and clays. The beds of the clay are thick, massive, white, red grey, black and brown, with fine to very coarse sands and Lignite beds. The thickness of the formation ranges from almost 0 in the eastern margin, to about 300 m to the northwest towards the middle of the basin down dip.

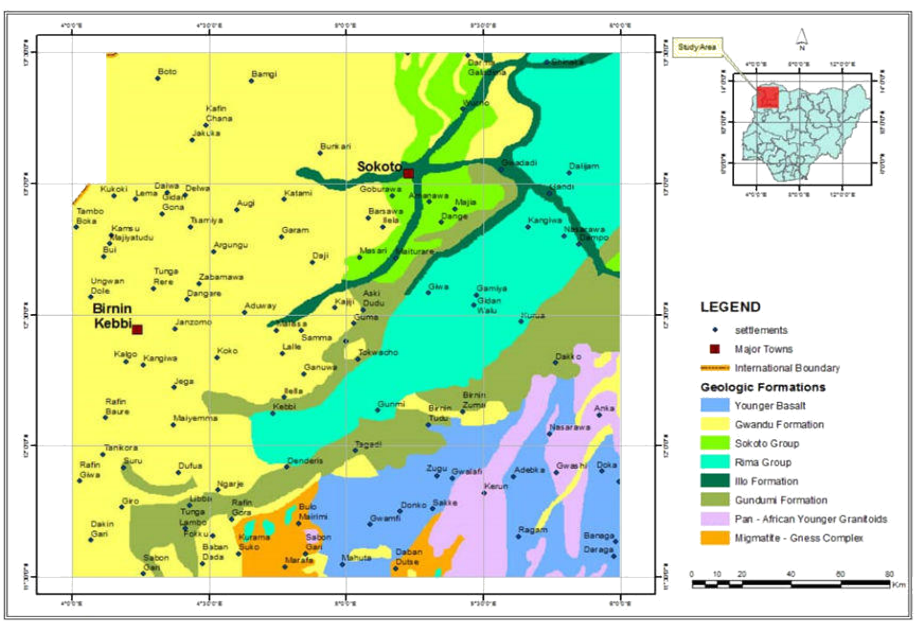

FIGURE 3: Geologic Map of the Study Area (After, [13]).

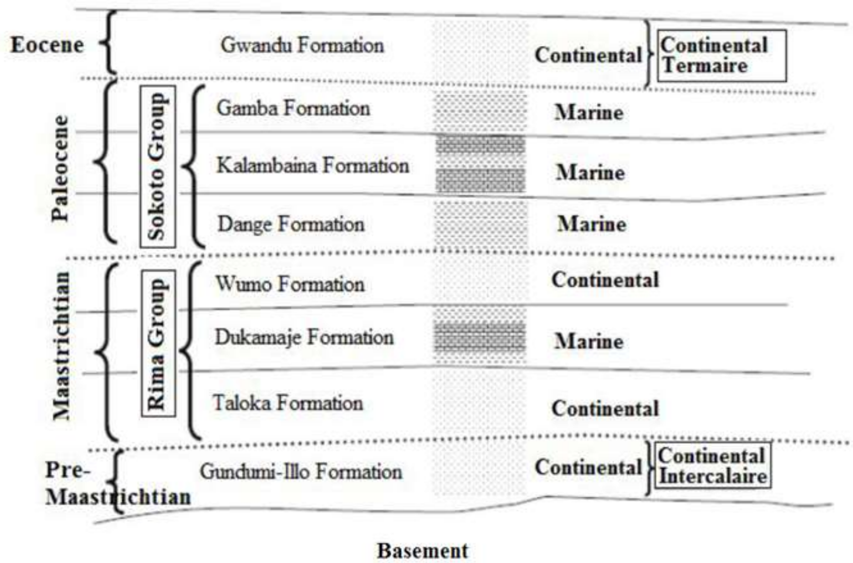

FIGURE 4: Stratigraphic Succession in the Nigerian Sector of the Illummeden Basin of West Africa (After, [14]).

The marine sediments of the Gamba formation were deposited in the late or upper Paleocene. This formation overlies the Kalambaina formation and consists of clay and shale and it is the topmost formation of the Sokoto group. The marine Kalambaina formation is the middle formation of the Sokoto group and overlies the Dange formation, consisting of light grey and white clayey limestone, nodular and crystalline. The limestone series and the calcareous clay beds especially the lower calcareous clay beds are constant in lithology and thickness in the formation. Limestones are chalky, soft, and friable and can dissolve easily, forming slumping features and solution cavities. The formation is of middle Paleocene age [15].

The marine Dange formation is the lower unit of the Sokoto Group. The formation is of early or lower Paleocene in age. The formation unconformably overlies the Wurno formation and consists of yellowish to greenish grey marine clay shale with the upper part distinguished by phosphate nodules and gypsum, with the lower part consisting of calcareous limestone bands. Green clay bed marks the base of the formation. A thick exposure of the formation occur at the base of the Dange Scarp [9].

The continental Wurno formation is the top unit of the Rima Group and is of late or upper Maastrichtian in age. It consists of pale fine sand and silt. At places it consists of well sorted fine, white sand, with dark grey lignite clay containing pyrites. Towards the southern part of Wurno the lithology changes from fine grained sands and clays to medium and coarse sands with less abundant clays. The formation is white to grey, fine to medium grained and silty carbonaceous clays around Sokoto. At the Sokoto Tannery the formation is fine to medium grained sands underlain and overlain by black lignite clays and grey silts and carbonaceous clays respectively. Towards Balle, the sediments became arenaceous and coarse sands predominate [15].

The marine Dukamaje formation is of middle Maastrichtian in age and is the middle formation of Rima group, consisting of shale, limestone and mudstones. At the base it consists of shally bone beds, fragments of fossil vertebrae, limbs and skulls. The formation overlies the Taloka formation [12].

The continental Taloka formation is the oldest or lowest of the Rima group and overlies the Gundumi and Illo formations unconformably. The formation is of early or lower Maastrichtian in age. It is made up of sandstones and mudstones. Exposures of the formation occur at Guronyo, Taloka and Shinaka with white fine-grained friable sandstones and siltstones with intercalated mudstone and shales. However, coarse fractions occur in Dogondaji and Jega areas [12&15].

The continental Illo formation is similar in lithological characteristics to Gundumi formation. It is the southern lateral equivalent of Gundumi formation. Both formations overlie the Basement complex unconformably and are Pre-Maastrichtian in age. The Gundumi formation consists of clays, sandstones and pebble beds. The base of the formation is characterized by conglomeritic beds that contain rounded quarts cobbles and pebbles that are well exposed by the road side at Tureta and Ruwan Kalgo. The formation is the oldest sedimentary rock in the area. Occurrence of the exposures of the formation are also found by rivers Zamfara and Dutsin Dambo, near Bakura [9&12].

The basement rocks of the area are classified into Younger Basalts; Granitoids and Migmatite-Gneiss Complex. The Basement Complex was affected by the Pan-African deformational episode which was accompanied by regional metamorphism, migmatization and extensive granitization and gneissification which produced syntectonic granites and homogeneous gneisses. Late tectonic emplacement of granites and granodiorites and associated contact metamorphism accompanied the end stages of the Pan African deformation. The end of the orogeny was marked by faulting and fracturing [16, 17&18].

(2) MATERIALS AND METHODS

2.1 Materials

Sixteen (16) digital half degree sheets that were procured from the Nigerian geological Survey Agency (NGSA), on a scale of 1:100000 were used in this research. The Nigerian geological survey agency carried out a nationwide airborne aeroradiometric survey in 2009 with aim of diversifying the country's economy from mono product economy to another sector. Regional high resolution aeroradiometric data, were acquired in Nigeria by Fugro airborne survey limited for the NGSA between 2004 and 2009. The acquisition, processing, compilation of the new data was jointly financed by the federal government of Nigeria and the World Bank as part of the sustainable management for mineral resource project. The aeroradiometric data was acquired using the airborne gamma ray spectrometry surveys, using Scintillation detector as counters with data recording interval of 0.1 seconds, were carried out by means of fixed-wing aircrafts flown at mean terrain clearance at 80m with 500m line spacing and nominal tie line spacing of 2km. The flight line and tie-line trends were 135 and 45 degrees respectively. Unlike the preceding surveys that were carried out in 1970's, the data in an analogue paper map format from a flight height of 152m with line spacing of 2km and nominal tie-line spacing of 20km. The stressful work of digitizing a map and the likely human error that could be introduced during the processing and correction of errors are problems associated with earlier analog data. These problems have all been eliminated because the high resolution digital aeroradiometric data is in a digital format.

2.2 Methods

The total count map of the area was analyzed to obtain potassium content map, thorium content map, uranium content map and Ternary Image using oasis montaj software. The radioactive heat flow values were calculated from the potassium (%) map, Thorium (ppm) map and Uranium (ppm) map and density of tocks from the geologic map, using an empirical equation by (Rybach et al., 1988) expressed as:

$$A(\mu W m^{-3}) = \rho(9.67C_U + 2.56C_{Th} + 2.89C_K) \times 10^{-5} \quad (1)$$

Where, A = radioactive heat, ρ = density of rock adapted from (Telford et al., 1990) Table 1, C_u, C_{Th} and C_k are the concentrations of uranium (ppm), thorium (ppm) and potassium (%), respectively. To obtained the values of ρ, C_u, C_{Th} and C_k the geologic map was divided into 64 blocks, the density of the dominant rock in each block was used also the uranium (ppm), thorium (ppm) and potassium (%) maps were divided into 64 blocks, in each block the high values of concentration of uranium, thorium and potassium were obtained and substituted into the empirical formula to calculated the heat flow.

The empirical method was adopted because of its simplicity and easy understanding of the parameters to be used in the calculation of the radioactive heat production. These parameters can be obtained with ease once the data is available.

TABLE 1: Average Density for each Rock Unit

Rock Density	(g/cm^3)
Basalt	2.99
Gwandu Formation (Sands and Clays)	2.10
Sokoto Group (Shale)	2.10
Rima Group (Sandstone)	2.24
Illo Formation (Sandstone)	2.24
Gundumi Formation (Sandstone)	2.24
Pan-African Granitoids	2.64
Migmatite-gneiss Complex	2.80

(3) RESULTS

3.1 Total Count Map

The total count map (Figure 5) of the study area shows combine effects of ^{40}K, ^{232}Th and ^{238}U for the area and has total count values ranging from 362.332cps to 2571.005cps. The three radioactive elements are abundant in the southeastern part of the study area of east of Sakke, Dabban Dutse, east of Ragam, south and west of Baraga, east and south of Birnin Zuma, west and north of Nassarawa and south Dakko; northeastern part of the study area north and east of Sokoto, north and south of Dange, Dampo, south of Darma Galadima and south of Shinaka; and pockets in the southwestern part of the study area east Bulo Mairimi. Sabon Gari.

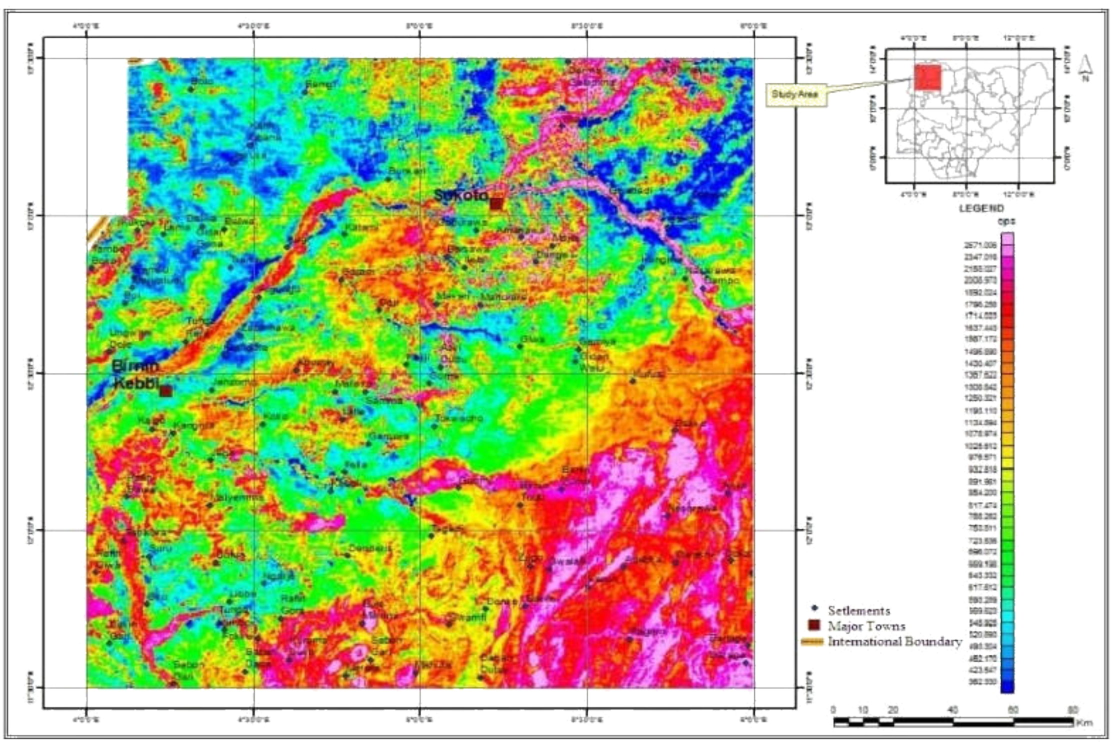

FIGURE 5: Total count Map of the Study Area.

3.2 Potassium Map

Potassium abundance values (Figure 6), range from 0.11 to 2.036%. potassium concentration occur around Nassarawa, Anka, east of Sakke, Gwalafi, east of Birnin Zuma, southof Dakko, Babban Dutse, east of Donko, west of Sabon Gari, east of Bulo Mairimi, Dampo, west of Gandi, and north of Gummi. These areas correspond with area shown on the geological map (Figure 2) have basement which is associated with potassium mineralization from basement granitic rocks.

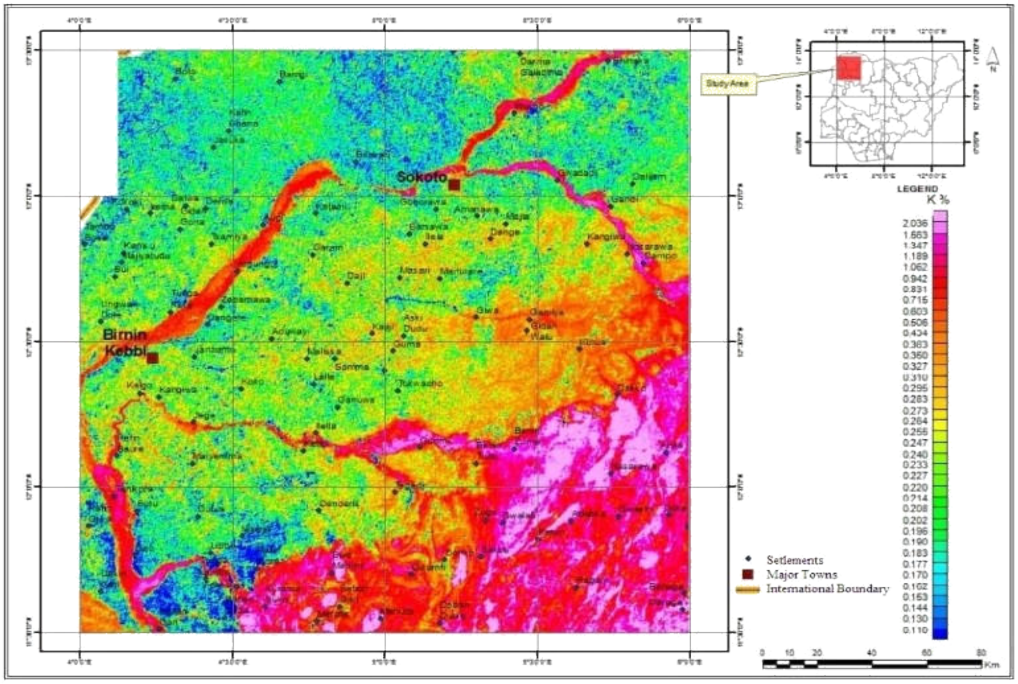

FIGURE 6: Potassium concentration Map of the Study Area.

3.3 Thorium Map

The thorium content map (Figure 7) have range of values from 3.920 to 17.470ppm. Thorium concentration occur west and south of Anka, east of Birnin Zuma, east of Ragam, east of Sakke, east of Gwalafi, west of Sabon Gari and east of Bulo Mairimi. These areas also correspond with the basement area of the geological map (Figure 2) have granitic rocks that are associated with thorium mineralization.

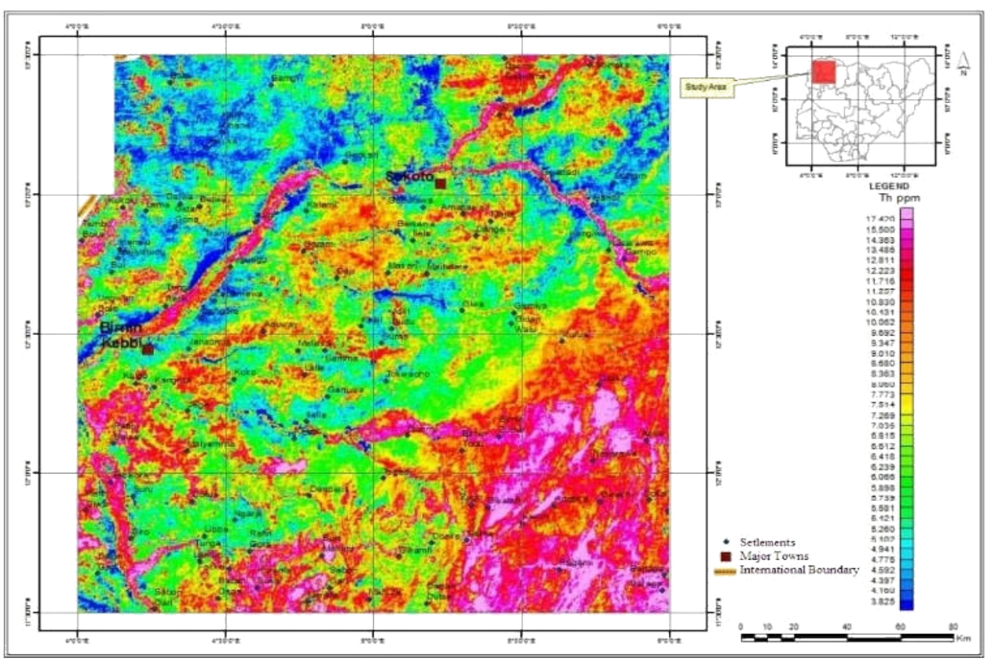

FIGURE 7: Thourium Concentration Map of the Study Area.

3.4 Uranium Map

Uranium content map (Figure 8) have values which range from 0.484ppm to 6.322ppm. Uranium concentration are found in the east of Darma Galadima, south of Shinaka,around Dange, east of Amanawa, north of Majia, west of Barsawa, east of Garam, east of Daji, east of Jega, east of Maiyema, west of Denderis, Northwest of Dakin Gari, east of Rafin Giwa, north of Rafin Baure, southeast and northeast of Sakke, southeast and northeast of Ragam, northeast of Nassarawa and south of Daraga. These correspond to geologic map (Figure 2) have shales in the Gwandu Formation and Sokoto group and the basement basalt, granitic and migmatite gneiss which are associated with uranium mineralization.

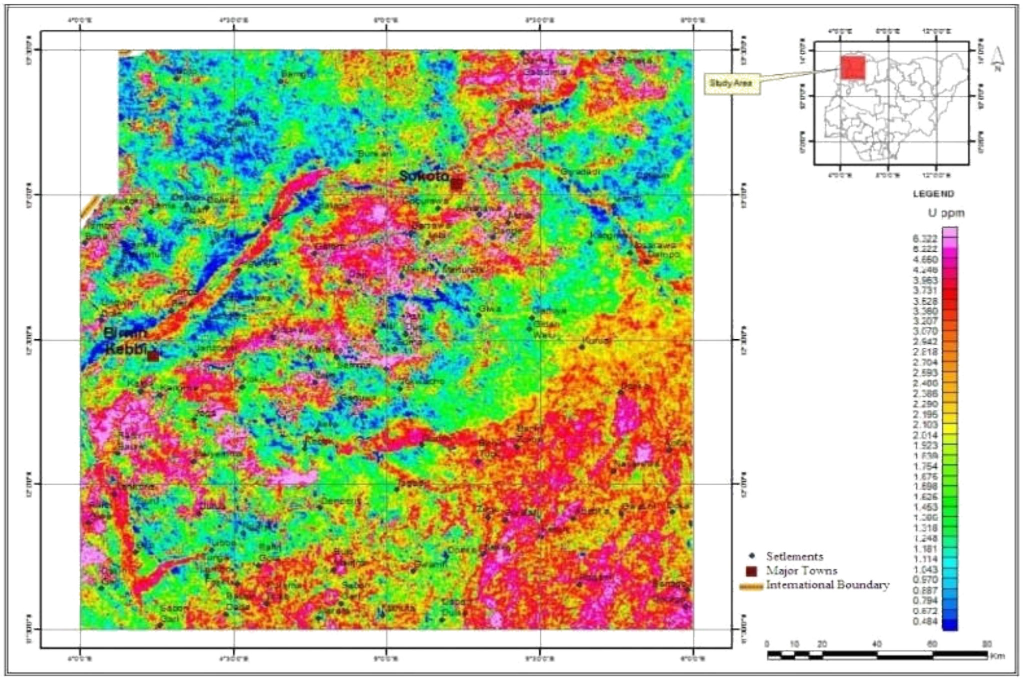

FIGURE 8: Uranium concentration Map of the Study Area.

3.5 Ternary Image

The qualitative interpretation of the Ternary Image (Figure 9) revealed that the three radioactive elements are dominant in the southeastern part of the map, which corresponds with basement rocks that consists of basalt, granitoids and migmatite-gneiss complex (Figure 3). Table 2 shows how the ternary image was interpreted.

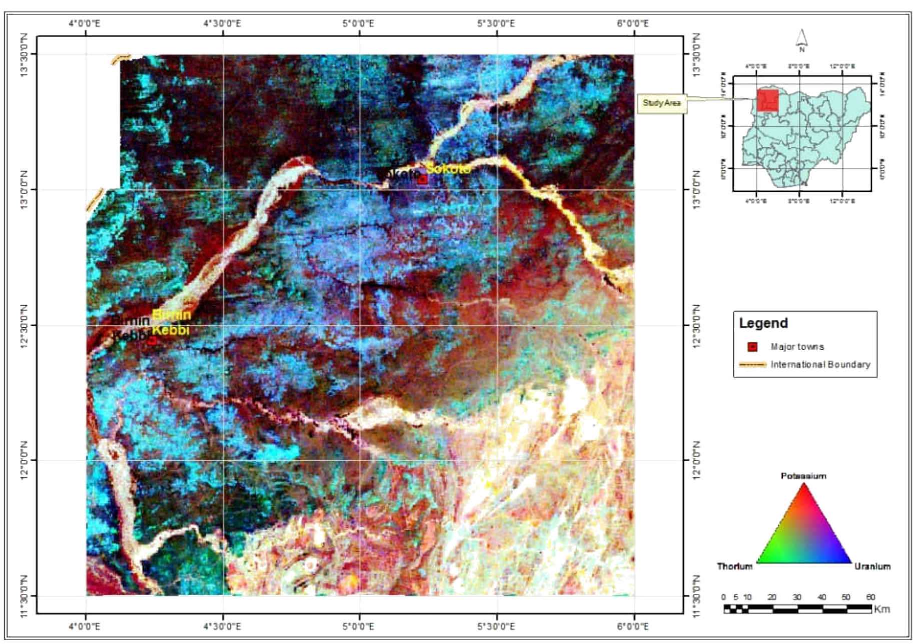

FIGURE 9: Ternary Image of the Study Area.

TABLE 2: Interpretation of Colours in the Ternary Image

Radio-element	Potassium (K)	Thorium (Th)	Uranium (U)
Colour	Red	Green	Blue
Red	High	Low	Low
Green	Low	High	Low
Blue	Low	Low	High
Cyan	Low	High	High
Magenta	High	Low	High
Yellow	High	High	Low
Black	Low	Low	Low
White	High	High	High

3.6 Radioactive Heat Flow Map

The result presented in Table 3 was contoured to obtain the radioactive heat flow map (Figure 10). The result varies from 0.00036μWm^{-3} to 0.16309μWm^{-3}. Low radioactive heat production values range from 0.00036μWm^{-3} to 0.10490μWm^{-3} and moderate radioactive heat production values range from 0.10490μWm^{-3} to 0.16309μWm^{-3}. The area of moderate heat production occurs northwest of Rafin Baure in the sedimentary area, east of Donko and west of Sakke corresponding to the basement basalt.

TABLE 3: Summary of Radioactive Heat Production Analysis
[Potassium (K) %, Thorium (Th) ppm, Uranium (U) ppm and Heat flow (q) μWm^{-3}].

Block	Potassium (%)	Thorium (ppm)	Uranium (ppm)	Heat Production (μWm^{-3})
1	0.26	13.49	6.820	0.00102
2	0.27	13.49	6.320	0.00097
3	0.27	6.810	3.730	0.00051
4	0.26	10.06	4.240	0.00068
5	0.25	11.26	3.960	0.00069
6	1.35	14.36	6.320	0.00106
7	1.35	17.42	49.41	0.00531
8	1.35	11.26	49.41	0.00515
9	0.27	13.49	6.320	0.00097
10	0.26	13.49	4.640	0.00081
11	0.26	13.49	4.640	0.00081
12	0.94	13.49	6.320	0.00101
13	0.94	13.49	4.240	4.00081
14	1.56	13.49	6.320	0.00105
15	1.56	13.49	4.640	0.00089
16	1.56	10.83	49.41	0.00515
17	0.26	13.49	6.320	0.00097
18	0.27	12.81	3.520	0.00069
19	0.60	13.49	6.320	0.00099
20	0,60	12,81	49.41	0.00514
21	0.60	0.81	49.41	0.00514
22	0.31	13.49	49.41	0.00524
23	0.32	15.50	6.320	0.00103

Block	Potassium (%)	Thorium (ppm)	Uranium (ppm)	Heat Production (μWm^{-3})
24	2.03	15.50	3.350	0.00085
25	2.03	2.03	15.50	0.00113
26	0.51	15.50	4.240	0.00083
27	0.51	10.06	49.41	0.00506
28	0.32	10.06	49.41	0.00506
29	0.35	10.06	49.41	0.00506
30	0.38	10.06	6.320	0.00036
31	0.43	10.06	3.060	0.00124
32	0.51	15.50	4.240	0.00993
33	1.56	17.42	49.41	0.01106
34	0.51	15.50	49.41	0.01090
35	0.32	17.42	49.41	0.01311
36	0.32	17.42	49.41	0.01099
37	0.32	56.86	49.41	0.01373
38	0.35	56.86	4.640	0.00421
39	0.38	56.86	3.200	0.00391
40	1.19	56.86	6.320	0.00462
41	5.44	15.50	49.41	0.10150
42	1.56	12.82	49.41	0.01082
43	0.51	56.86	49.41	0.01312
44	1.01	56.86	49.41	0.01378
45	2.02	56.86	5.220	0.00444
46	2.04	56.86	4.640	0.00432
47	5.44	56.86	49.41	0.01662
48	5.44	5.870	49.41	0.01068
49	5.44	5.870	49.41	0.01068
50	1.56	13.49	4.640	0.00169
51	0.34	13.49	4.640	0.00169
52	0.34	56.86	4.640	0.00574
53	5.44	17.42	4.640	0.00316
54	1.35	56.86	6.320	0.00508
55	5.44	56.86	6.320	0.00254
56	5.44	56.89	6.320	0.00667
57	2.04	56.86	49.47	0.01323
58	2.04	56.86	4.640	0.00432
59	5.44	56.86	5.220	0.00593
60	5.44	56.86	6.320	0.00513
61	5.44	10.43	4.640	0.00119
62	5.44	56.86	6.320	0.16309
63	5.44	56.86	6.320	0.00667
64	5.44	56.86	6.320	0.00667

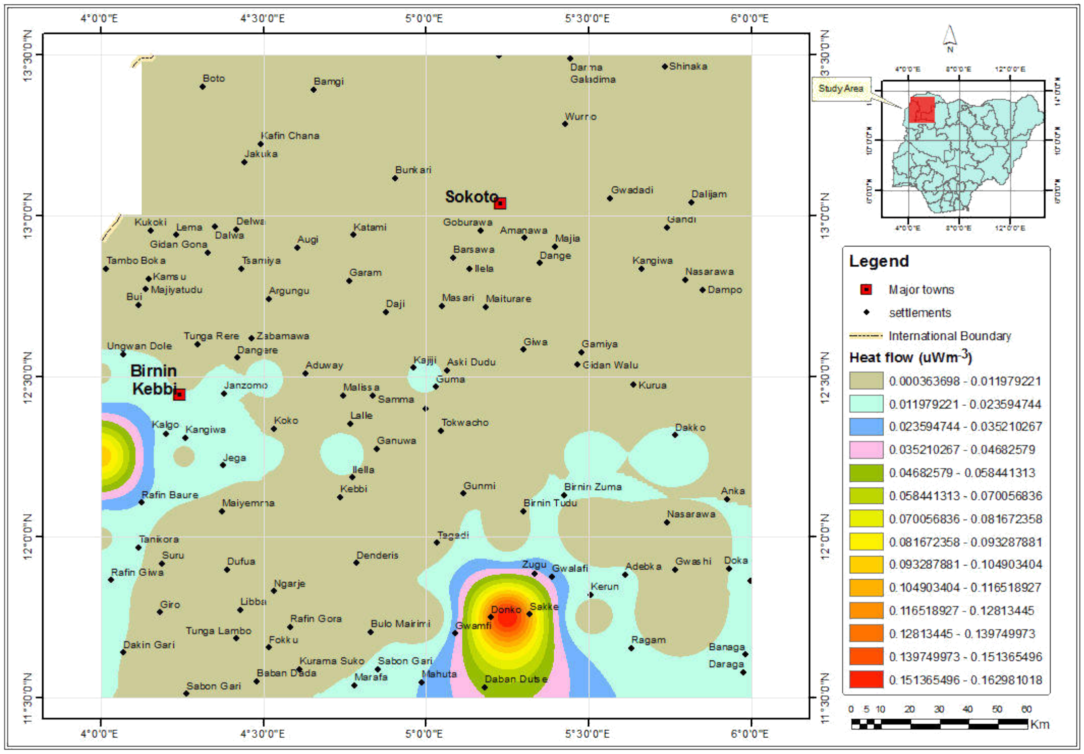

FIGURE 10: Radioactive Heat Production Map of the Study Area.

(4) DISCUSSION

The result of the analysis of radioactive heat production revealed low radioactive heat production in almost the entire area (Figure 8) with exception of an area northwest of Rafin Baure in the sedimentary area measuring approximately 10km in length and 5km in diameter, east of Donko and west of Sakke corresponding to the basement having moderate heat production, measuring about 15km in diameter and 20km in length. According to [6], the average heat production value for an area to be considered as a geothermal energy source is from 2.25μWm^{-3} and above. Which also means that for an area to have the average mentioned value, there must be high concentration of radioactive minerals in the area. This therefore revealed that the area have low to moderate radioactive heat production as a result of low to moderate concentration of radioactive minerals. Correlation of the radioactive heat flow with the geology of the area shows that the moderate heat production occur in an area in the younger basalts and Gwandu formation, which signify concentration of the three radioactive minerals in the area.

(5) CONCLUSION

The following conclusion can be drawn from this research work:

1. The analysis of the total count map into Potassium (%) concentration map, Thorium (ppm) concentration map and Uranium (ppm) concentration map revealed prevalence of the three radioactive minerals in the basement rocks.
2. Potassium and thorium abundance in the sedimentary area decrease from southeast to northwest.
3. Uranium abundance cut across the sedimentary area from northeast to southwest.
4. The Ternary Image revealed the high presence of the three radioactive elements in the southeastern part of the area dominated by the basement complex especially on the basaltic rock and some parts of the river channels, which could be weathered products of the parent rock from the basement area.
5. Quantitative analysis revealed low to moderate heat production. Indicating that the area has low to moderate potentials for geothermal energy and therefore low to moderate concentration of radioactive minerals.

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Conflicts of Interest

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

Statements & Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [Kamureyina Ezekiel] and [Ahmed Nur]. The first draft of the manuscript was written by [Kamureyina Ezekiel] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

REFERENCES

[1] Ramadas, G., Subhash, B.A., Laxmi, U.G. (2015). Structural Analysis of Airborne Radiometric Data for Identification of Kimberlites in Parts of Eastern Dharwar Craton. *International Journal of Science and Research, 4(4), 2375-2380.*

[2] Glimore, G. (2008). *Practical Gamma Ray Spectroscopy, (2nd ed.) UK. Wiley.*

[3] Bristow, C., Williamson, B. (1989). Spectral Gamma Ray Logs: Core to Log Calibration, Facies Analysis and Correlation Problems in the Southern North Sea. *Geol. Soc. Lond. Spec. Publ. 41:81 - 88.*

[4] Davies, S., McLean, D. (1996). Spectral Gamma-Ray and Palynological Characterization of Kinderscoutian Marine Bands in the Namurian of the Pennine Basin. *Proc. Yorks. Geol. Polytech. Soc., 51, 103-114*.

[5] Myers, K., Bristow, C. (1989). Detailed Sedimentology and Gamma-Ray Log Characteristics of a Namurian Deltaic Succession II: Gamma-Ray Logging. *Geol. Soc. Lond. Spec. Publ. 136, 1-7.*

[6] Rybach, L., Hokrick, R., Eugester, W. (1988). Vertical Earth Heat Probe Measurement and Prospects in Switzerland. Communication and Proceedings, 1, 167-372.

[7] Sanderson, D, East, B, Scott, E. (1989). Aerial Radiometric Survey of Parts of North Wales in July 1989. Scottish Universities Research and Reactor Centre. Glasgow, UK.

[8] Mero, J.L., (1960). Uses of the Gamma-Ray Spectrometer in Mineral Exploration. *Geophysics, 25, 1054-1076.*

[9] Kogbe, C.A. (1976). Outline of the Geology of Illummeden Basin, Geology of Nigeria. *Elizabethan Publishing Co. Pp. 331 – 338.*

[10] Ali, M., Wagani, I., Handa, M. (2019). Geochemistry and Mineralogy of the Upper Cretaceous-Paleocene Marine Series Iullummeden Basin, Niger Republic. *Journal of Geosciences and Environment Protection*. Vol. 7, Pp. 1 – 19.

[11] Nigeria Geological Survey Agency, NGSA (2006). Topographic Map of Latitude $11^0.30'$ – $13^0.30'$ and Longitude $4^0.00'$- $6^0.00'$.

[12] Offodile, M.E. (2002). Ground water study and development in Nigeria (2nd ed.). *Mecon Geology and Eng., Services Ltd., Jos Nigeria.*

[13] Nigerian Geological Survey Agency, NGSA (2006). Geological Map of Latitude $11^0 30'$ - $13^0 30'$and Longitude $4^0 00'$ and $6^0 00'$.

[14] Obaje, G. N., Aduku, M., Yusuf, L. (2013). The Sokoto Basin of Northwestern Nigeria: A Preliminary Assessment of the Hydrocarbon Prospectivity. *Petroleum Technology Development Journal, 3(2), 66-80.*

[15] Oteze, G. E. (1976). The Hydrogeology of Northwestern Nigeria Basin, in Geology of Nigeria "Edited by Kogbe C. A." Elizabethan Press. Pub.

[16] Abaa, S. I. (1983). The structure and petrography of alkaline rocks of the Mada Younger Granite Complex, Nigeria. *Journal of African Earth Sciences*. Vol. 3, Pp. 107-113

[17] Burke, K.C., Dewey, J. F. (1972). Orogeny in Africa. In: Dessauvagie, T. F. J., Whiteman, A. J. (eds), Africa Geology. University of Ibadan Press, Ibadan, 583-608 Complex, Nigeria. *Journal of African Earth Sciences, 3:107-113*

[18] Gandu, A. H., Ojo, S. B., Ajakaiye, D. E. (1986). A gravity study of the Precambrian rocks in the Malumfashi Area of Kaduna State, Nigeria. *Tectonophysics*, 126, Pp. 181-194