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Evaluation of Geothermal Energy Potential of Parts of Upper Benue Trough Nigeria Using High Resolution Aeromagnetic Data

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Abstract

Objective: To conduct geophysical evaluation in Yuli, Futuk, Kaltungo, Guyok, Shellen, Bashar, Muri, Lau, Dong and Numan area Upper Benue Trough, Nigeria to ascertain the region's geothermal energy potential for electricity generation. **Methods:** Radial average power spectrum method was employed in this research work. The residual upward continued data was divided into twenty-seven (27) overlapping spectral block using the filtering feature of the Oasis montaj program. Fast Fourier Transform (FFT) MAGMAP technique of oasis montaj program transformed the data into radial average power spectrum for each block. **Findings:** The estimated Curie point depth ranges from 10.131 to 16.461 km, the geothermal gradient ranges from 35.235 to 57.250 $^{\circ}\mathrm{C/km}$ having a mean value of 45.214 °C/km while the heat flow ranges from 88.087 to 143.125 mWm^{-2}. These results shows that the research area has good potential for geothermal energy generation especially the Dong area with the highest geothermal gradient value of 57.250 $^{\circ}\mathrm{C/km}$. **Novelty:** This research has successfully employed radial average power spectrum method to depict viable zones of geothermal energy potential in Upper Benue Trough, Nigeria for electricity generation.

Keywords: Upper Benue; Curie Point Depth; Geothermal; Heat flow; Electricity generation

1 Introduction

The quest for sustainable power supply to meet the rapidly increasing population in Nigeria has been an immense challenge for both the public and private sectors. The hydroelectric power and fossil fuels are among the main sources of electricity generation in Nigeria; however, they are insufficient for the vast and rapidly growing population. Consequently, finding supplementary and potential alternative energy sources such as geothermal energy, is very important in order to meet the need of the growing population. Comparatively, geothermal energy which is a renewable energy offers sufficient energy which does not release carbon compounds that are harmful to human health. Therefore, it is imperative to step up efforts to explore geothermal energy-rich locations in Nigeria.

Some researchers have deployed aeromagnetic method in search for potential area of geothermal energy at different Basins in Nigeria [1–8]. Few recent geothermal research has been reported in Upper Benue Trough [9,10] but not in all parts of the Upper Benue Trough. However, no specific geothermal research has been reported on integrated aeromagnetic sheets of Yuli, Futuk, Kaltungo, Guyok, Shellen, Bashar, Muri, Lau, Dong and Numan areas, Upper Benue Trough Nigeria using radial average power spectrum method. Therefore, the aim of this research is to evaluate the hotspot zones for geothermal energy exploration using integrated high resolution aeromagnetic sheets of Yuli, Futuk, Kaltungo, Guyok, Shellen, Bashar, Muri, Lau, Dong and Numan parts of Upper Benue Trough, which all are yet to be ascertain by researchers. Also, we wish to compare our results with that of scholars within the Upper Benue Trough.

The aeromagnetic method maps the subsurface volcanic rocks relevant to geothermal exploration, however, its primary purpose is to determine the depth to the Curie temperature [1]. The rate at which the Earth's temperature rises per unit depth as a result of heat outflow from the Earth's core is known as the geothermal gradient. At a crucial temperature known as the Curie temperature, ferromagnetic materials exhibit a remarkable loss of practically all magnetic susceptibility and take on paramagnetic properties [1,5]. The study of Curie isotherm fluctuations may offer valuable insight regarding the depth to the spatial distribution of thermal energy of a region. Therefore, evaluation of the CPD, geothermal gradient and heat flow of aeromagnetic data of our study area will help to ascertain the region's potential for geothermal energy which can be of interest in identifying suitable area for siting of geothermal plants for the generation of electricity.

1.1 Geology and Location of the research area

The research area is bounded by coordinate 9.0° to 10.0° North and 10.0° to 12.5° East. It has an area of approximately 30,250 km^2. The Trough belongs to the sedimentary Basins in Nigeria which stretches in a NE-SW direction, laying unevenly upon the basement of the Precambrian Period [9,10]. It is made up of the earliest sediment (Bima formation). Overlying the Bima formation, which is exposed in the majority of the Basin, is the Yolde formation. The transition from continental to marine sedimentation is marked by the Bima sandstone and the Yolde formation, which are varied sequences of sandstones and shale [9,10].

2 Methodology

There are few reports of geothermal research in Upper Benue Trough [9–12]. These researchers employed different approach and techniques such as spectral analysis method with software program such as oasis montaj and MATLAB program. In this research work, radial average power spectrum with software program which are Oasis montaj 8.4, ORIGIN and SURFER software were utilized. Different technique such as first order polynomial fitting and upward continuation were employed to enhance the longer wavelength of the TMI anomaly for CPD estimates.

2.1 Data source

Ten aeromagnetic data sheets of Yuli, Futuk, Kaltungo, Guyok, Shellen, Bashar, Muri, Lau, Dong and Numan area, Upper Benue Trough with sheet number 171, 172, 173, 174, 175, 192, 193, 194, 195 and 196 respectively, utilized for this research were gotten from Nigerian Geological Survey Agency (NGSA).

2.2 Method

The aeromagnetic data sheets were merged and gridded in Oasis Montaj program. The gridding of the data produced the total magnetic intensity anomaly map (TMI). Radially averaged power spectrum ($P(k)$) was employed for the quantitative interpretation. Applying filters to the TM1 anomaly to accentuate interesting anomalies was the first step in the quantitative data interpretation process. Polynomial fitting was employed to obtain the residual anomaly. The upward continuation enhancement was applied to the residual data to suppress the short-wavelength components of the residual magnetic anomalies and enhance the longer wavelength of the residual sources for CPD estimates. The residual upward continued data was divided into twenty-seven (27) overlapping spectral block using the filtering feature of the Oasis montaj program. Each block is 55 by 55 kilometers square in size. Fast Fourier Transform (FFT) MAGMAP technique of oasis montaj program transformed the data into radial average power spectrum for each block. The spectrum graph of each block was plotted in ORIGIN software as a logarithm scale against the radial wave number in cycle/km to obtain the centroid and the top bound depth. The centroid depth (Z_O) is estimated from the slope of the longest wavelength part of the spectrum and is expressed by equation 1 [8,9];

$$ln(P(k)^{1/2}/k) = A - |k_O \quad (1)$$

The top boundary depth (Z_t) is obtained from the slope of the second longest wavelength part of the spectrum and is expressed by equation 2 [8,9];

$$ln(P(k)^{1/2}) = B - |k_t \tag{2}$$

where, k is the wavenumber, A and B are constant. The CPD (Z_b) was obtained from equation 3 [8,9];

$$Z_b = 2Z_0 - Z_t \tag{3}$$

The geothermal gradient $\left[\frac{\partial T}{\partial Z}\right]$ and heat flow (q) values were calculated from equation 4 and 5 respectively;

$$\left[\frac{\partial T}{\partial Z}\right] = \frac{\theta}{Z_b} \tag{4}$$

$$q = \lambda \left[\frac{\theta}{z_b}\right] \tag{5}$$

where, θ is the CPD temperature of 580 ^{0}C and λ is the coefficient of thermal conductivity with a constant value of 2.5 Wm^{-10}C^{-1} [8,9].

3 Results and Discussion

The TMI ranges from -46.2 to 140.4 nT (Figure 1). According to the TMI map, the region is magnetically diverse with visibility of wide range of anomalies. Areas with significant positive anomalies probably signify igneous intrusion with a higher concentration of magnetic susceptibilities. Similar to broad magnetic lows, these regions are probably low in magnetic concentration and so less susceptible. The residual map (Figure 2) has positive and negative residual anomalies ranging from -121.8 to 64.9 nT that may be caused by the combined action of zones of fundamental intrusive bodies that are present in the sedimentary basin or basement complex. The upward continuation residual map (Figure 3) ranges from −110.4 to 60.0 nT.

In computing the CPD, twenty-seven (27) identical overlapping spectral blocks were created from the upward continuation residual map (Figure 4). Fast Fourier Transform (FFT) MAGMAP technique of oasis montaj program transformed the data into radial average power spectrum for each block. The spectrum graph of each block was plotted in Origin software as a logarithm scale against the radial wave number in cycle/km to obtain the centroid and the top bound depth. The graphs are shown in Figure 5. The CPD, geothermal gradient and the heat flow values were calculated (Table 1) using equations 3, 4 and 5 respectively. The SURFER software was used to construct the 2D CPD map and likewise the geothermal gradient and heat flow maps (Figures 6, 7 and 8, respectively).

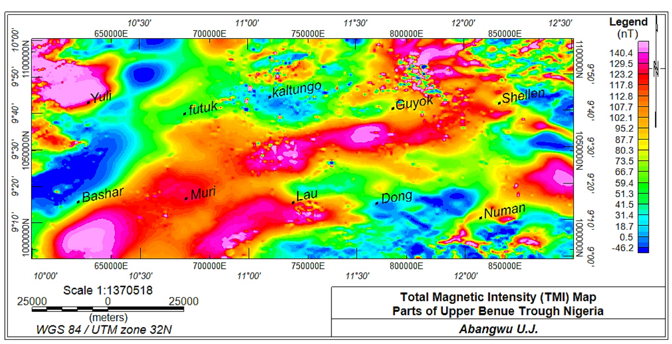

Fig 1. Total magnetic intensity map of the study area

From Table 1, the depth to centroid varies from 5.642 to 9.187 km while the depth to the top magnetic sources ranges from 0.757 to 2.659 km. These shallow depths to top boundary may be attributed to magma and volcanic intrusive rocks deposit in the area. The CPD ranges from 10.131 to 16.461 km. These values were contoured to obtain the CPD map (Figure 6). The Futuk and Yuli area has the deepest CPD from examination of the map whereas the shallowest is noted to be noticeable in the Dong and Lau area. The geothermal gradient ranges from 35.235 to 57.250 °C/km with mean value of 45.214 °C/km (Table 1). The lowest geothermal gradient values are observed mainly around Futuk and Yuli areas while the highest geothermal gradient is

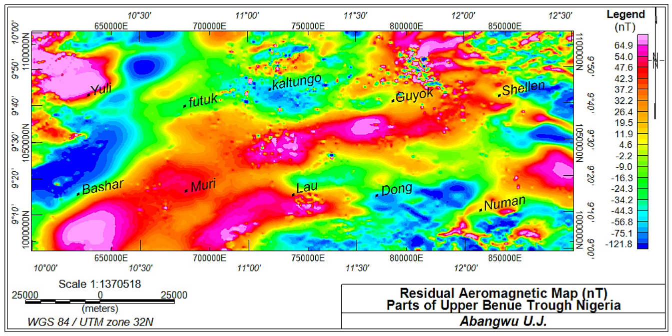

Fig 2. Residual map of the study area

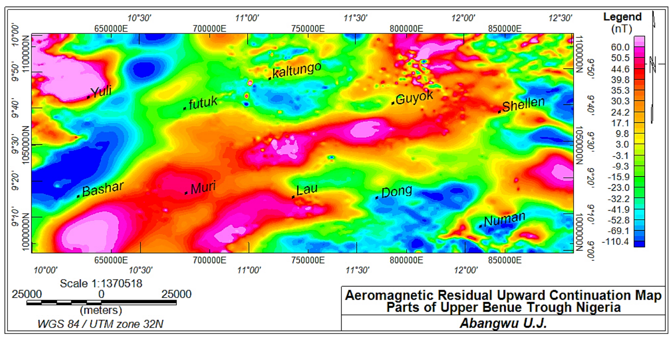

Fig 3. Residual upward continuation map of the study area

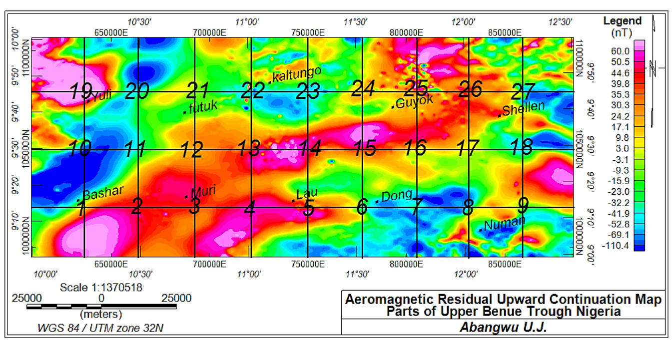

Fig 4. Spectral blocks map

observed around Dong and Lau area (Figure 7). It was evident that places with a high CPD had a low geothermal gradient, whereas areas with a low CPD have a high geothermal gradient. The heat flow values range from 88.087 to 143.125 mWm^{-2} (Table 1). Figure 8 depicts that the Dong and Lau area has the highest heat flow values, the intermediate heat flow values are distributed nearly all part of the research area, while the lowest heat flow values are observed in Futuk and Yuli area. The Dong and Lau area with maximum geothermal and corresponding heat flow values are possibly due to igneous intrusions into the sedimentary formation.

The results of the CPD, geothermal gradient and heat flow values obtained in this study compared favourably with the results of earlier scholars within the Upper Benue Trough [9–12]. According to the CPD values of 10.131 to 16.461 km obtained, the research area most probably belongs to the volcanic and geothermal field zone [6,10]. The locations with geothermal gradient greater than 50 °C/km could be potential hotspot zones for geothermal energy exploration for the production of electricity [6,8,10].

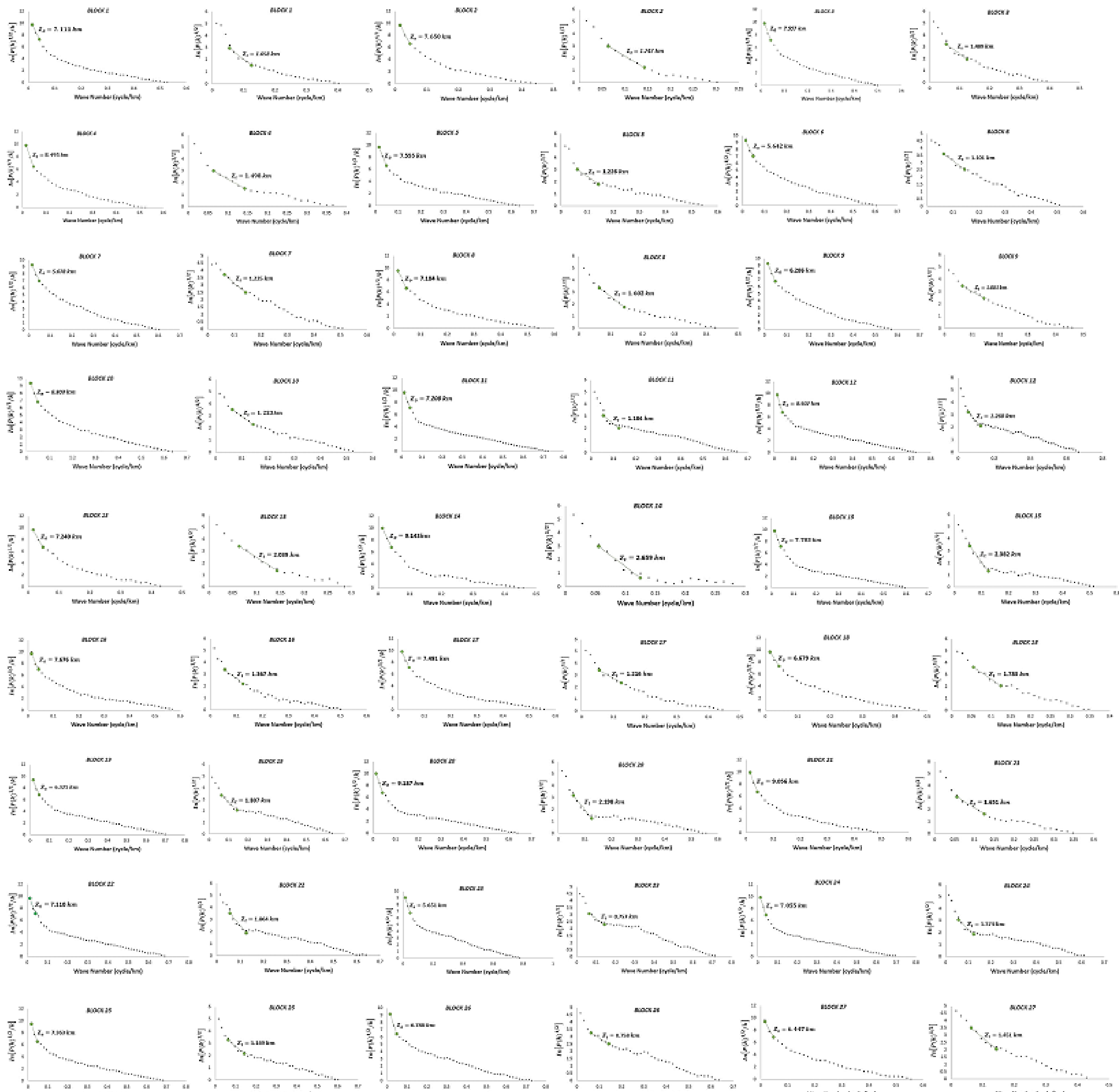

Fig 5. Spectral graphs

Table 1. Results of CPD, Geothermal gradient and Heatflow

Blocks	Depth to centroid (Z_o) in km	Depth to top boundary (Z_t) in km	Curie point depth (Z_b) in km	Geothermal gradient $\left(\frac{dT}{dZ}\right)$ in °C/km	Heat flow (q) in
1	7.111	1.658	12.564	46.164	115.409
2	7.650	1.747	13.553	42.795	106.987
3	7.557	1.489	13.625	42.569	106.422
4	8.495	1.498	15.492	37.439	93.597
5	7.555	1.226	13.884	41.775	104.437
6	5.642	1.101	10.183	56.958	142.395
7	5.678	1.225	10.131	57.250	143.125
8	7.184	1.602	12.766	45.433	113.583
9	6.286	1.003	11.569	50.134	125.335
10	6.503	1.223	11.783	49.223	123.059
11	7.208	1.184	13.232	43.833	109.583
12	8.502	1.260	15.744	36.839	92.099
13	7.240	2.039	12.441	46.620	116.550
14	9.143	2.659	15.627	37.115	92.788
15	7.703	2.382	13.024	44.533	111.333
16	7.676	1.367	13.985	41.473	103.683
17	7.491	1.216	13.766	42.133	105.332
18	6.679	1.783	11.575	50.108	125.270
19	6.321	1.307	11.335	51.169	127.922
20	9.187	2.198	16.176	35.856	89.639
21	9.056	1.651	16.461	35.235	88.087
22	7.110	1.864	12.356	46.941	117.352
23	5.651	0.757	10.545	55.002	137.506
24	7.055	1.374	12.736	45.540	113.851
25	7.363	1.149	13.577	42.719	106.798
26	6.788	0.758	12.818	45.249	113.122
27	6.447	1.451	11.443	50.686	126.715
Average			13.052	45.214	113.036

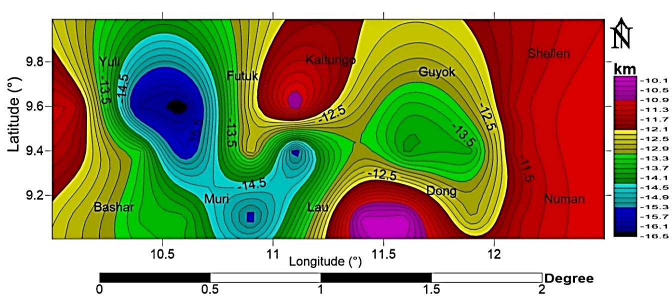

Fig 6. CPD map of the study area (contour interval of 1 km)

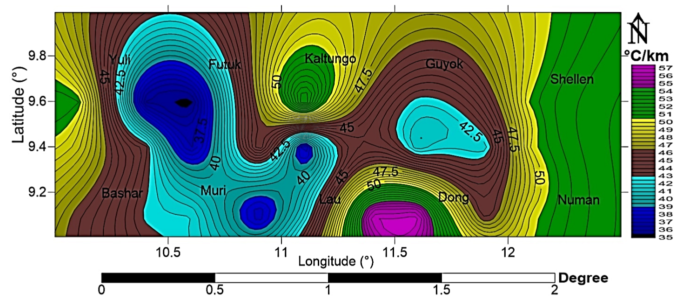

Fig 7. Geothermal gradient map of the study area (Contour interval of 0.5 °C/km)

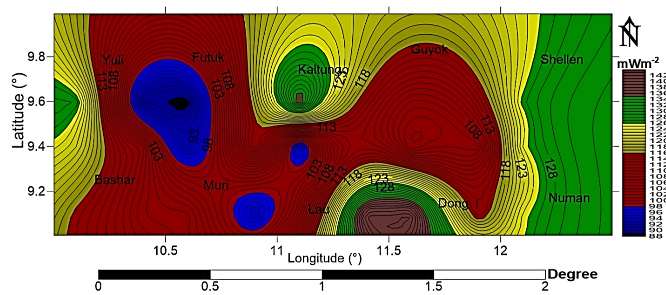

Fig 8. Heat flow map of the study area (Contour interval of 1 mWm^{-2})

4 Conclusion

The aeromagnetic data of Yuli, Futuk, Kaltungo, Guyok, Shellen, Bashar, Muri, Lau, Dong and Numan have been analyzed to ascertain the geothermal potential of the area. The CPD values range from 10.131 to 16.461 km, while that of the geothermal gradient is from 35.235 to 57.250 °C/km and heat flow values vary between 88.087 to 143.125 mWm^{-2}. These results shows that the research area has good potential for geothermal energy generation especially the Dong area with the highest geothermal gradient value of 57.250 °C/km and highest heat flow of 143.125 mWm^{-2}. Therefore, this research has successfully employed radial average power spectrum method to depict viable zones of geothermal energy potential in Upper Benue Trough, Nigeria for electricity generation. Geothermal exploration in Nigeria would help overcome the epileptic power distribution which is affecting the economic growth.

References

1) Abangwu JU, Obiora DN, Ibuot JC, Ekwueme OU. Estimation of Curie point depth and geothermal gradient in parts of the Bida Basin, Nigeria. *Journal of Environmental Engineering and Science*. 2022;17(1):41–50. Available from: https://doi.org/10.1680/jenes.20.00054.
2) Alasi TK, Nwobodo AN, Ikeri HI, Onyishi GE, Chibuowgu IU. Investigation of Curie Point Depth, Geothermal Gradient and Heat Flow over parts of the Lower Benue Trough using Aeromagnetic Data. *International Journal of Recent Research in Physics and Chemical Sciences (IJRRPCS)*. 2022;2022(2):11–21. Available from: https://doi.org/10.5281/zenodo.7365096.
3) Alfaifi HJ, Ekwok SE, Ulem CA, Eldosouky AM, Qaysi S, Abdelrahman K, et al. Exploratory assessment of geothermal resources in some parts of the Middle Benue Trough of Nigeria using airborne potential field data. *Journal of King Saud University - Science*. 2023;35(2):102521. Available from: https://doi.org/10.1016/j.jksus.2022.102521.
4) Ijeh BI, Anyadiegwu FC, Onwubuariri CN, Eze MO. Evaluation of geothermal resource potential of the Lower Benue Trough using aeromagnetic and radiometric data. *Modeling Earth Systems and Environment*. 2023. Available from: https://doi.org/10.1007/s40808-023-01796-1.
5) Ngene T, Mukhopadhyay M, Ampana S. Reconnaissance investigation of geothermal resources in parts of the Middle Benue Trough, Nigeria using remote sensing and geophysical methods. *Energy Geoscience*. 2022;3(4):360–371. Available from: https://doi.org/10.1016/j.engeos.2022.06.002.
6) Suleiman TI, Okeke FN, Obiora ND. Spectral Analysis of High-Resolution Aeromagnetic Data for Geothermal Energy Reconnaissance across Sokoto Basin. *Journal of the Earth and Space Physics*. 2021;46(4):147–158. Available from: https://doi.org/10.22059/jesphys.2020.299866.1007205.
7) Yakubu JA, Amuche ID, Igwe AE, Shuaibu A, Okwesili AN. Investigation of Curie Point Depth Using High Resolution Aeromagnetic of Igumale and Ejekwe Area, Lower Benue Trough Nigeria. *Indian Journal Of Science And Technology*. 2023;16(8):540–546. Available from: https://doi.org/10.17485/IJST/v16i8.27.
8) Yakubu MB, Lawal KM, Dewu BBM, Ikpokonte AE. Investigation of geothermal energy resource potential using aero-magnetic and aero-radiometric data of Kano, Nigeria. *Fudma Journal of sciences*. 2022;6(1):296–307. Available from: https://doi.org/10.33003/fjs-2022-0601-900.
9) Dopamu KO, Akoshile CO, Nwankwo LI. Regional estimation of geothermal resources of the entire Benue Trough, Nigeria using high-resolution aeromagnetic data. 2021. Available from: https://doi.org/10.1007/s40948-021-00276-z.

10) Yusuf A, Lim HS, Abir IA. Curie-Point Depths, Geothermal Gradients and Sub-Surface Heat Flow Estimation from Spectral Analysis of High-Resolution Aeromagnetic Data over Gongola Basin and Its Environs, Northeastern Nigeria. *Sains Malaysiana*. 2022;51(3):657–677. Available from: http://doi.org/10.17576/jsm-2022-5103-03.

11) Kasidi S. Determination of Curie Point Depth, Heat Flow and Geothermal Gradient from High Resolution Aeromagnetic Data around Lamurde Area, Adamawa State, North-Eastern Nigeria. *Open Journal of Geology*. 2019;09(11):829–838. Available from: https://doi.org/10.4236/ojg.2019.911093.

12) Mohammed A, Adewumi T, Kazeem SA, Abdulwaheed R, Adetona AA, Usman A. Assessment of Geothermal Potentials In Some Parts of Upper Benue Trough Northeast Nigeria Using Aeromagnetic Data. *Journal of Geoscience, Engineering, Environment, and Technology*. 2019;4(1):7. Available from: https://doi.org/10.25299/jgeet.2019.4.1.2090.