ISSN Online: 2756-3898, ISSN Print: 2714-500X https://doi.org/10.47514/phyaccess.2022.2.1.011

Estimating Geothermal Energy Resource Potential within Jema'a Local Government Area of Kaduna State, Nigeria

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Received 18-05-2022
Accepted for publication 17-06-2022
Published 22-06-2022

Abstract

This study used aeromagnetic data of Jema'a, sheet No.188 to estimate the geothermal energy resource potential in Jema'a Local Government Area of Kaduna State, Nigeria. The study area lies between latitude $9^0 11'$ and $9^0 27'$ N and longitude $8^0 00'$ and $8^0 17'$ E. Total magnetic intensity (TMI) map of the area was produced from the gridded data. Residual map was obtained by removing regional field from the TMI which was divided into 36 blocks for spectral analysis. The centroid depth (Z_0) was obtained by dividing the gradient of the lengthiest wavelength part of the spectrum by the wave number. The depth to top (Z_t) of the magnetic source was obtained from the gradient of high wave number portion of the power spectrum. The values of Z_0 and Z_t were used to obtain the values for depth to bottom of the magnetic source (Z_B). The geothermal gradient ($\frac{dT}{dZ}$) values were obtained by dividing 580°C by Z_B while the heat flow(q) values were obtained by multiplying $\frac{dT}{dZ}$ by the constant k (2.51).The $\frac{dT}{dZ}$ values obtained range from 13.560 to 4000.000°C/km with an average value of 46.393°C/k and having the least (13.560 °C/km) around Kafanchan axis and the highest (4000.000 °C/km) around Sanga. The q values range from 34.036 to 1004.00 $mW\text{m}^{-2}$ with an average value of 118.089 $mW\text{m}^{-2}$. The $\frac{dT}{dz}$ values were observed to be greater than 100 $mW\text{m}^{-2}$ around Sanga and Andaha axes. The Curie depth (28 km) was deepest at the South-South, South-East and South-West regions. Since magnetic properties of minerals disappear at this temperature and thermal conductivity of rocks increases with depth, these areas are potential geothermal energy source.

Keywords: Curie point Depth; Geothermal; Heat flow; Spectral Analysis; Aeromagnetic Data.

I. INTRODUCTION

Aeromagnetic data of an area can be quantitatively and qualitatively analysed and interpreted with the aim of estimating the Curie point depth and heat flow within an area based on reconnaissance for geothermal energy. The Curie point which is the bottom of magnetic source is that point beneath the earth crust at which the magnetic properties of rocks disappear and the materials begin to exhibit paramagnetic properties. This temperature is taken to be about 580°C for magnetite under atmospheric pressure [1]. The earth is not flat and the rocks are buried at different depths within the sub-surface. The temperature of these rocks is not the same as it varies from location to location. The magnetic contents in rocks is temperature dependent and the depth at which temperature reaches the Curie point is assumed to be the bottom of the magnetized bodies in the earth crust. It largely depends on the geology and magnetic contents of rocks and so, the Curie point temperature varies from place to place. The study of variation of temperature across various depths is essential as it will help provide appreciated information about the area temperature distribution and depths with potential geothermal energy within the sub-surface [2]. Some scholars such as [3] stated that regions within the subsurface with potential geothermal energy are likely to have minimum Curie point depth (CPD). At these regions, there could be a young volcanism and a thin crust. A geophysical method known as spectral analysis can be applied to study geothermal energy at any location. The significant of spectral analysis in physics and science in general, cannot be overemphasized as it is applied in the interpretation of potential field data to determine the basement depths as well as to study crustal temperatures [4]. Several researchers applied this method at different locations to study different things within the sub-surface. For instance, [5] applied 1D spectral analysis to aeromagnetic anomalies in the Anambra basin, to interpret aeromagnetic anomalies over Maiduguri-Dikwa depression of Chad basin. Reference [6] also applied spectral analysis to evaluate aeromagnetic anomalies over parts of upper Benue through Southern Chad basin, Nigeria. Spectral analysis method has a lot of advantages over other geophysical methods because it has the ability to filter all the noise away from the data, keeping the desired information intact and easy to use especially when transformation from space to frequency domain is performed [7]. The application of spectral analysis to the interpretation of potential field data is a method that can be used to determine the basement depth [8]. The procedures involved in this study include digitization of the aeromagnetic maps, separation of magnetic data and production of magnetic anomaly map, production of the first vertical derivative of the total field and analysis of magnetic anomaly data amongst others. To perform this analysis, the average radial energy spectrum will be calculated and graphs of the natural logarithm of energy against frequency will be plotted and the gradient of the linear segments will be computed in order to obtain the depths to the basement [9] and [8].

Within Nigeria, there are places such as Ikogosi spring which is a warm spring, an evidence for a potential geothermal energy being generated within the sub-surface; this geothermal energy is a renewable energy source that can be used for generating electricity. Considering the unstable power supply bedeviling Nigeria today, generating electricity from this source of energy will go a long way in curtailing this challenge. Thus the study of the Curie-Temperature Depth and heat flow deduced from spectral analysis of aeromagnetic data within Jema'a Local Government Area of Kaduna State, Nigeria was conducted in order to estimate geothermal energy resource potential of the area.

II. Geology of the Study area

Jema'a Local Government area is one of the 23 local governments of Kaduna state in north-western Nigeria. The area has an average elevation of about 650 m above sea level; it is of low relief with slightly undulating topography and low-lying outcrops and a few prominent ridges of weathered granite scattered over the landscape. Jema'a local Government lies between latitude $9^0 11'$ and $9^0 27'$ N and longitude $8^0 00'$ and $8^0 17'$ E. The Local Government shares border with Kagoro to the East in Kaura Local Government, with Ungwan Rimi of Zangon Kataf Local Government to the North, with Jaba Local Government to the west and with Nasarawa state to the south. The population of the area has grown tremendously in the last 30 years to around 278, 202 according to 2006 Census [10]. The local government has several villages among them are Kafanchan, Zikpak, Gidan Waya, Godo-godo, Ambe, Kagoma, Ungwan Baki, Ungwan Fari, Takau, etc. The geological map of Jema'a Local Government area is depicted in Fig. 1.

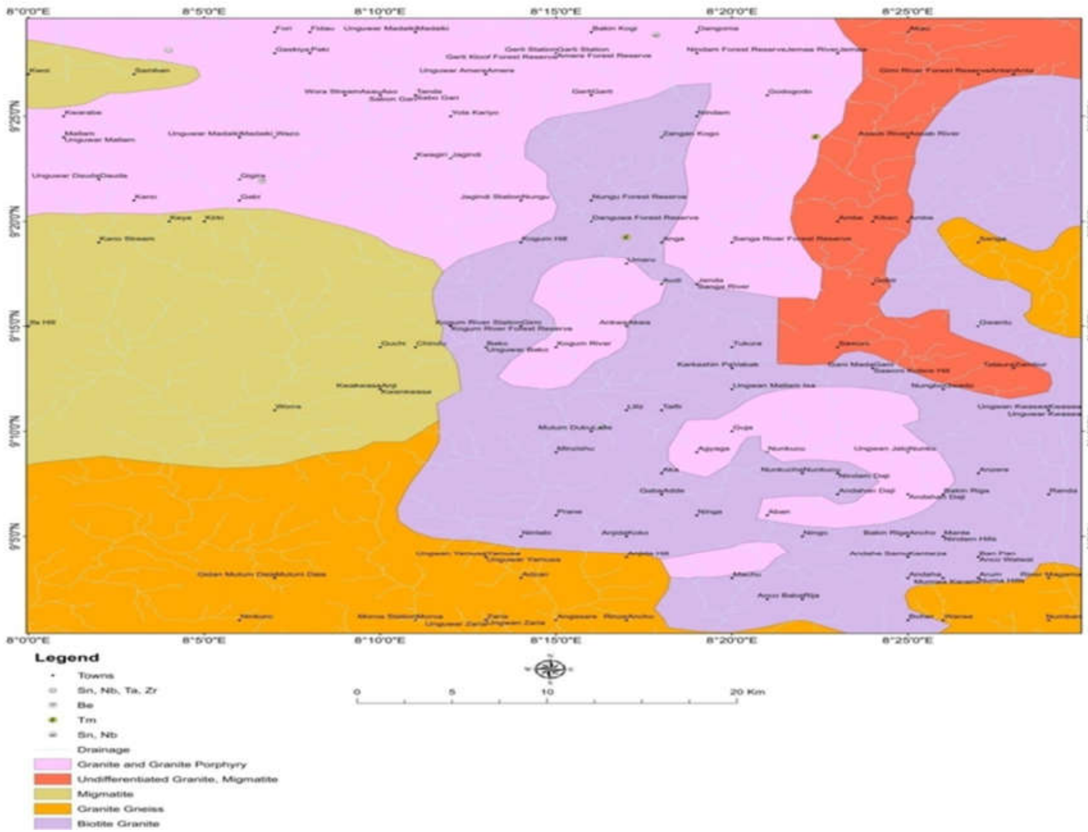

Fig. 1 Geological map of the study Area [11]

III. Materials and Method

A. Materials

The materials used for this research include Aeromagnetic data (Sheet No. 188) procured from Nigerian Geological Survey Agency (NGSA), Geological map of Jema'a Local Government; suffer 13 software, Oasis Montaj 8.4® software and Micro Excel®. The data used was acquired on a scale of 1:100,000 in half degree sheets collected at a flight altitude of 80m along North-East to South-West flight lines spacing of 500 m and a tie line spacing 2 km.

B. Method

The data was gridded and yielded the total magnetic intensity (TMI) map of the study area (Fig. 2). The first-order polynomial regression fit was applied on the total magnetic intensity (TMI) data of the study area to remove the regional field within (Fig. 3) which shows a North-East to South-West trend with the decrease in the magnetic intensity in the North-West direction. After removing the regional field within, what was left is the residual map of the study area (see Fig. 4). In an attempt to understand the subsurface architecture of the study area, spectral analysis was applied to the magnetic data procured from Nigeria Geological Survey Agency (NGSA). This spectral analysis uses Fast Fourier Transform (FFT) as a mathematical tool which is usually applied to a regular spaced data and it provides relationship between the spectrum of the magnetic anomalies and the depth to magnetic sources by transforming the spatial data into frequency domain. This study adopted spectral analysis used by [6] to determine depths to the top, centroid and bottom of the magnetic source of the study area. This work adopted the method and formulae used by researchers in estimating the Curie point depth. Equation (1) is used in estimating CPD [1].

$$P_{(K)} = A_1 e^{-2|K|Z_t}(1 - e^{-|k|(Z_B - Z_t)})^2 \qquad (1)$$

Where A_1 is a constant, Z_t and Z_B denotes the depth to the top and bottom of the magnetic contacts respectively and K is the wave number of the field.

According to [12], the centroid depth (Z_B) of the inmost magnetic contact can be evaluated from the gradient of the lengthiest wavelength part of the spectrum divided by the wave number using (2).

$$\text{In}\left(\frac{P(K)^{\frac{1}{2}}}{K}\right) = A|K|Z_0 \qquad (2)$$

Where $P_{(K)}$ is the power density spectrum.

The uppermost depth to the magnetic contact was equally evaluated by using the gradient of high number given by (3).

$$In(P(K)^{\frac{1}{2}}) = B - |K|Z_t \quad (3)$$

Where B is a constant and the depth to magnetic contact (Z_B) is given by

$$Z_B = 2Z_0 - Z_t \quad (4)$$

Equation (5) can be used to calculate the heat flow (q) [1].

$$q = k\frac{dT}{dZ} \quad (5)$$

Where k is the thermal conductivity constant ($2.51Wm^{-1}C^{-1}$)and $\frac{dT}{dZ}$ is the thermal gradient which is given by (6).

$$\frac{dT}{dZ} = \frac{\theta_C}{Z_B} \quad (6)$$

Where θ_C is the Curie temperature taking to be 580℃ since it is related to Curie depth [13].

IV. Data Processing and Analysis

The data was gridded to yield the Total Magnetic Intensity (TMI) map of the area. The TMI has magnetic intensity within the range 32976.5 – 33093.3nT (Fig. 2). The TMI underwent filtration in order to remove the regional field (Fig. 3) so as to obtain a residual map (Fig. 4) which reveals a better picture of subsurface architecture.

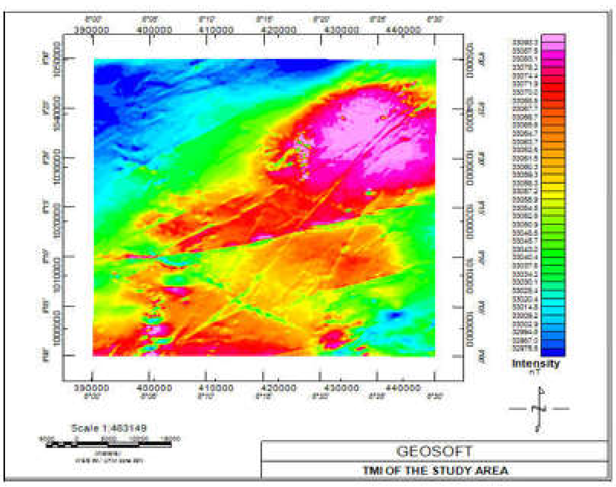

Fig. 2 TMI Map of the Study Area

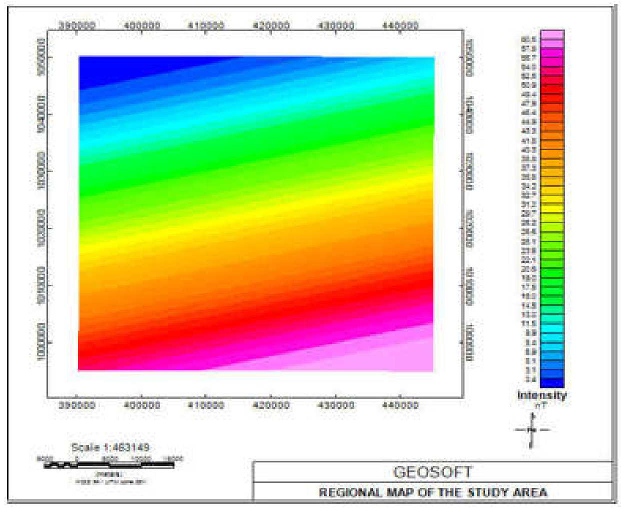

Fig. 3 Regional Map of the Study Area

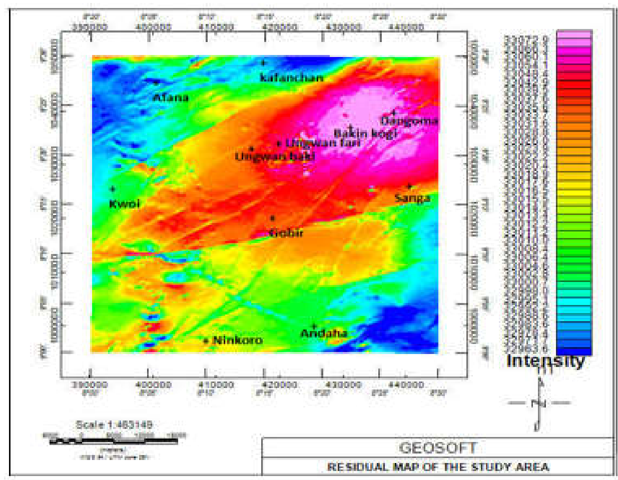

Fig. 4 Residual Map of the Study Area

V. Results and Discussion

The residual data was divided into 36 overlapping blocks of equally spaced area. Each of the blocks was subjected to zero padding and tapering to correct for edge effects. It was then subjected to fast Fourier transform to convert the data from a space domain to a frequency domain. The Fourier transformed data was then subjected to spectral analysis to yield its power spectrum and wave number, thus the depths to the top, and the centroid were determined based on the procedure of [14]. Two out of the 36 spectral plots were shown in Fig. 5. The depth to a centroid (Z_0)for each of the 36 blocks was obtained by the ratio of the gradient of the lengthiest wavelength part of the spectrum to the wave number. The depth to top (Z_t) of the magnetic source was obtained from the gradient of high wave number portion of the power spectrum.

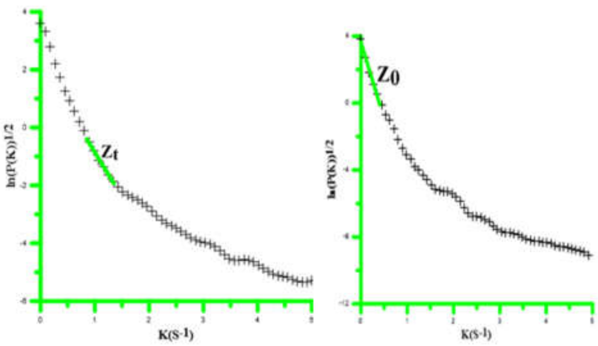

Fig. 5 spectral plots

The depth values obtained from Z_0 and Z_t were used to obtain the values for depth to bottom of the magnetic source (Z_B) which yielded the Table I.

The geothermal gradient and the heat flow of every location within the study area were given in the table above. These values were obtained by dividing 580 by the value of Z_B of every block while the values of the geothermal gradient were multiplied by the constant k (2.51) to obtain the values of the heat flow. The values of the geothermal gradient range from 13.560 to $4000.000℃/km$ with the average value of $46.393℃/km$. The least value was at block five (5) around Kafanchan axis while the highest value $(400.000℃/km)$ was at block seventeen (17) south of Sanga. The values of the heat flow across the study area as shown in table 1, range from 34.036 to 1004.00 m$Wm^{-2}$with the average value of 118.089 mWm^{-2}. The Curie point depth varies according to the terrain and geological architecture as reported by [1].

Table I Depth value for the blocks in the study area

Blocks	Latitude (°)	Longitude (°)	Depth to Top Z_t (Km)	Depth to Centroid Z_0 (km)	Depth to Bottom (Z_B)	Geothermal gradient °C/ km	Heat flow mWm^{-2}
1	9.452	8.044	3.054	12.810	22.566	025.703	0064.515
2	9.407	8.089	4.148	08.407	12.666	045.792	0114.930
3	9.362	8.135	3.047	10.194	17.341	033.447	0083.952
4	9.317	8.181	1.651	11.856	22.061	026.291	0065.990
5	9.272	8.226	3.109	11.879	20.649	013.560	0034.036
6	9.227	8.249	1.015	12.574	24.133	024.033	0600.323
7	9.407	8.089	3.657	08.580	13.503	042.953	0107.812
8	9.407	8.089	3.430	10.475	17.520	033.105	0083.094
9	9.317	8.181	3.570	12.520	21.470	027.014	0067.805
10	9.272	8.612	2.080	10.252	18.424	031.481	0079.017
11	9.227	8.272	1.689	01.993	02.297	252.503	0633.782
12	9.182	8.295	1.738	12.810	23.882	024.286	0060.958
13	9.362	8.135	1.913	10.463	19.013	030.505	0076.568
14	9.317	8.181	3.711	09.121	14.531	039.915	0100.187
15	9.272	8.226	0.742	09.997	19.252	030.127	0075.619
16	9.227	8.272	3.091	10.549	18.007	032.210	0080.847
17	9.182	8.317	2.680	02.065	01.450	400.000	1004.000
18	9.136	8.336	1.400	11.695	21.990	026.376	0066.204
19	9.317	8.181	0.641	10.423	20.205	028.706	0072.052
20	9.272	8.226	1.934	10.881	19.828	029.252	0073.423
21	9.227	8.272	1.903	09.849	17.795	032.593	0081.808
22	9.182	8.317	3.589	09.577	15.565	037.231	0093.450
23	9.137	8.363	2.855	10.804	18.753	030.928	0077.629
24	9.091	8.386	3.751	10.342	16.933	034.253	0085.975
25	9.272	8.226	2.294	09.068	15.842	015.842	0039.763
26	9.227	8.272	2.766	10.536	18.306	031.683	0079.524
27	9.182	8.317	0.644	10.351	20.058	028.916	0072.579
28	9.137	8.363	1.714	15.876	30.038	019.309	0048.466
29	9.091	8.409	2.325	10.714	19.103	030.362	0076.209
30	9.046	8.431	1.856	13.237	24.618	023.560	0059.136
31	9.245	8.272	4.525	08.802	13.079	044.346	0111.308
32	9.204	8.317	3.616	09.220	14.824	039.126	0098.206
33	9.159	8.363	1.284	07.482	13.680	042.398	0106.419
34	9.114	8.409	2.485	12.594	22.703	025.547	0064.123
35	9.069	8.454	3.485	11.061	18.637	031.121	0078.113
36	9.024	8.477	1.571	10.706	19.841	029.232	0073.372

Reference [15] revealed that heat flow up to the magnitude 80– 100 mWm^{-2} is a good pointer of geothermal anomalous conditions. Result of the findings of [16], revealed that heat loss anomalies usually occur at locations with thermal manifestation.

The maps of the depth to centroid (with depth range from 3 – 14.5 km), depth to top with depth range from 0.8 – 4.4 km and depth to bottom (with depth range from 3 – 28 km) of the magnetic source are depicted in Fig. 6, 7 and 8 respectively.

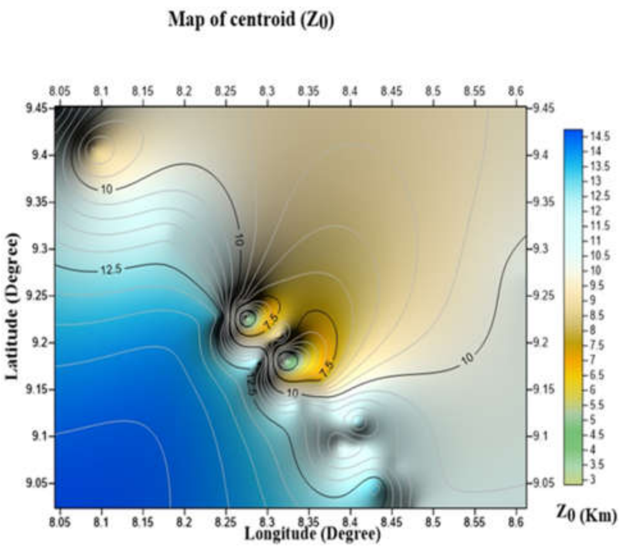

Fig. 6 Map of depth to Centroid of the magnetic source of the study area

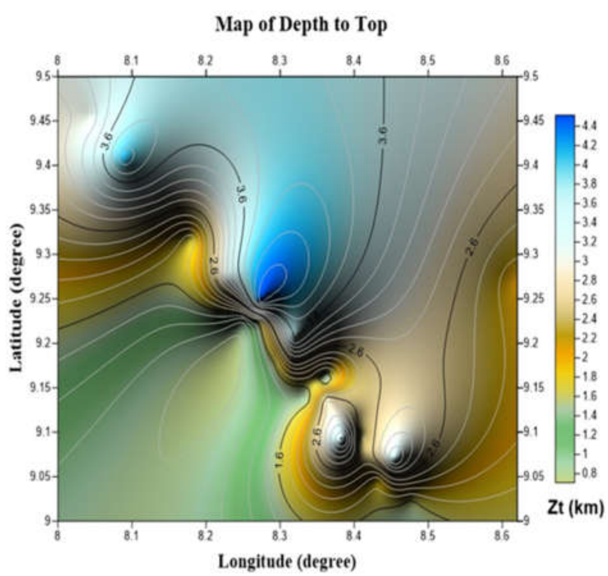

Fig. 7 Map of depth to Top of the magnetic source of the study area

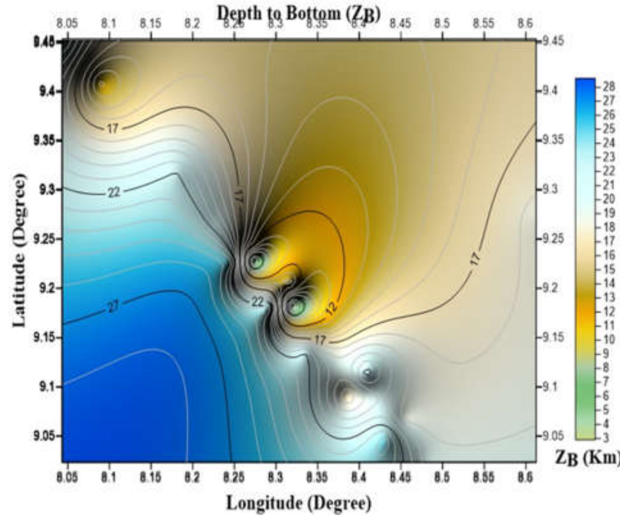

Fig. 8 Map of depth to Top of the magnetic source of the study area

Similarly, the heat flow map (Fig. 9) which has values ranging from 50– 850 mWm^{-2} depicts areas with potential geothermal energy sources, with the highest values toward South-South region depicted by blue color in the color legend

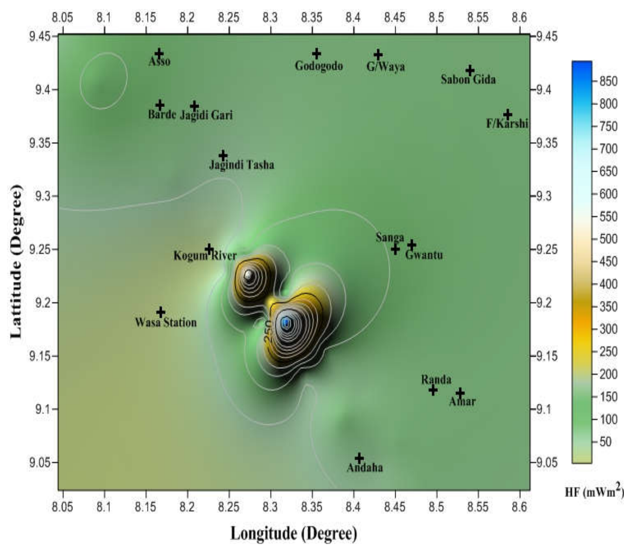

Fig. 9 Heat flow Map of the Study Area

VI. Conclusion

An estimation of the geothermal energy resource potential of areas within Jema'a Local Government Area of Kaduna State, Nigeria was carried out. From this study, it was found that areas around Afana (block 2), north of Kwoi (block 7), south- south and south -west of Sanga (block 17) and region east of Andaha (block 31 and 33) all have geothermal heat gradient above 100 mWm^{-2}. The Curie depth is deepest at the South-South, South-East and South-West regions (28 km)

and the highest heat flow is around South-South (1004.000 $mW\ m^{-1}$). Since magnetic properties of minerals disappear at this temperature and thermal conductivity of rocks increases with depth, those areas where these properties are exhibited are regions with potential geothermal energy source and there's a need to exploit this as it will serve as alternative source of energy to energy from fossil fuel and also curtail the energy challenges currently facing Nigeria.

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