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Radiogenic Heat Production and Its Effects On the Geothermal Potentials of Ikogosi Warm Spring, South-West, Nigeria

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Abstract: *The existence of geothermal potentials at Ikogosi warm spring has been previously established by the authors with integrated geophysical prospecting workflows using aeromagnetic data and given the favourable geologic conditions obtainable in the study area, the contribution to subsurface heat production derived from radioactivity cannot be neglected. Hence this work considers the estimation of radiogenic heat production that may have significantly contributed to the geothermal potentials of Ikogosi warm spring leveraging on the approach of Salem and Fairhead (2011). The aero-radiometric data utilized in the study covers sheets 243 and 244 in the nationwide high resolution systematic airborne geophysical survey conducted by Fugro Airborne surveys over Nigeria on behalf of Nigerian Geological Survey Agency (NGSA). The Geosoft Oasis Montaj 8.4 version software was used for the analysis.*

The analysis of aero-radiometric data indicates the study area holds high content of Potassium, Uranium and Thorium. The concentration of these radioelements at Ikogosi warm spring shows that Potassium is around 0.8%, Thorium eTh is around 6ppm and Uranium eU 2.5ppm while in the vicinity of the study location, the concentration of Potassium ranges between 0.3 and 3.5%, Uranium eU ranges from 0.5 to 7.5ppm, and Thorium eTh ranges between 5 and 40ppm. The total count of radioelements and their concentrations are mapped leading to the estimation of radiogenic heat production in the study area. The result of the estimated radiogenic heat production ranges from 0.8 to 5.44 $\mu W/m^3$ with an average RHP of 3.01 $\mu W/m^3$ within the crystalline rocks and 1.26 $\mu W/m^3$ in the metasediment quarzitic rocks in the study area which suggests that sizeable quantity of heat contributing to the thermal activities within the subsurface in the study area is generated through the radioactive decay in the crystalline rocks assemblage predominantly located in the east and north-east of Ikogosi warm spring.

I. Introduction

Given current global unattractive disposition toward energy generation from conventional fossil fuel due to the devastating greenhouse effects on the environment, the search and development of alternative energy sources in Nigeria has become very critical. In consideration of the above, the exploration of geothermal potentials in Nigeria particularly at Ikogosi warm spring is inevitable now as Nigeria is currently in dire need of stable energy supply that is required to kickstart the economy. Geothermal energy is a constant non-polluting source renewable natural heat that is emitted from within the earth's crust (McGee, 2007). It is used in various applications ranging from small domestic application to massive generation of electricity, which requires steam turbines (Rashid *et al.,* 2012). The type of conversion technologies includes dry steam, flash, and binary type processes, which depend on the state of the fluid and its temperature. Other uses include agricultural processes that require heat, and even residential conveniences such as home heating in the winter, heated pools, bathing,

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and spas (Hepbasli, 2003; Alsuhaibani and Hepbasli, 2013; Reyes, 2010). Low enthalpy geothermal energy resources are also used for recreational and cultural tourism (Pohatu *et al.,* 2010; Carey, 2010; Neilson *et al*., 2010). Ikogosi warm spring is the first known warm spring in Nigeria and it is within the Precambrian basement and schist belt. The spring is a low enthalpy system and its temperature is around 37^oC (Oladipo *et al*., 2005). There are other known and unknown thermal springs in Nigeria such as Wikki Warm Spring, Rafin Rewa Warm Spring, Lamurde Hot Spring, Keana-Awe Thermal Springs, and Akiri Warm Spring; few were reported within the crystalline province and some within the Middle Benue Through (Bako, 2010; Kurowska and Schoeneich, 2010; Garba et al., 2012; Abraham et al. (2017). Several geophysical analyses carried out on aeromagnetic data including the recent work of the authors suggested possible existence of geothermal potentials at Ikogosi warm spring and considering the geology of the area, it has become absolutely essential to compute from the available high resolution aero-radiometric data the radiogenic heat production which might have contributed to the thermal system. Some research work on radiogenic heat production had been previously carried out in Nigeria notable amongst them are Sedara (2022); radiometric survey in Ikogosi lake, Sokari *et al.* (2022); radiogenic heat production due to three natural radionuclides from the Coastal communities of Okrika Local Government Area of Rivers state, Braja (2018); radiogenic heat production and geothermal potential around Rafin Rewa, Bubu and Ononugbo (2018); determining the concentrations, distribution and the pattern of radiogenic heat production of radioactive elements in sediment samples from Bonny River, Olorunsola and Aigbogun (2017); investigation of Southern Anambra basin for the prospect of producing radiogenic heat, Joshua *et al*. (2008); radiogenic heat production of fifty-three rock samples from five states in South-eastern Nigeria, and Omanga (1998); preliminary geophysical investigation of the source of heat of the Wikki warm spring.

Sedara (2022) performed radiometric survey in Ikogosi lake and showed the distribution of radio-nuclides and heat production in rocks. His study revealed that the heat production value varied between 1.8 and 3.5µW/m^3. Since most of these rock samples were collected from surface outcrops, there is an uncertainty about the concentration of the radioactive elements with depth.

Sokari *et al.* (2022) analysed samples of soil and sediments for radiogenic heat production from the coastal communities of Okrika Local Government Area of Rivers state, Nigeria. The used NaI(Ti) Gamma-Ray Spectrometer and the result indicated low radiogenic heat production rate. The radiogenic heat production rate of soil ranged from 0.0058µW/m^3 to 0.0245µW/m^3 with a mean of 0.01255$\pm$0.02µW/m^3, while for the sediment it varied from 0.0030 to 0.0131 with a mean value of 0.01255$\pm$0.02µW/m^3.

Braja (2018) attempted to determine the radiogenic heat production and geothermal potential around Rafin Rewa, Dan Alhaji area. The results of the study showed a range of radioactive heat production varying from 0.155µWm^{-3} to 154.54µW/m^3 with mean value of 31.993µW/m^3. They concluded that Uranium and Thorium are the major contributing elements to the radioactive heat of the study area.

Bubu and Ononugbo (2018) analysed sediment samples from Bonny River, Rivers State. The results showed that the contribution and rate of heat production of ^{40}K, ^{238}U and ^{232}Th in the samples vary significantly with geological locations, which ranged 0.0286µW/m^3 to 2.5094µW/m^3 with an average value of 0.6002±0.64 µW/m^3.

Olorunsola and Aigbogun (2017) used high-resolution aero-radiometric data to investigate the Southern Anambra basin for the radiogenic heat production. The results of the analysis of the radiogenic heat production of the area ranges between 0.01 – 5.43µW/m^3. The highest value of the radiogenic heat production in this basin has a value of 5.43µW/m^3 around Aimeke and Ogobia.

Joshua *et al*. (2008) employed the NaI (T1) Gamma-Ray Spectrometer to determine elemental concentration and radiogenic heat production in soil and rock samples. The average total heat production in the area reflects the geological rock types. Cross River State with granite/metamorphic basement has the highest heat production and Akwa Ibom State, which is predominantly sedimentary, has the lowest. The ratio of ^{233}Th contribution to radiogenic heat production with respect to ^{238}U and ^{40}K is 1.0:0.73:0.09.

Omanga (1998) used the electrical resistivity and radiometric methods, employing VES and gamma ray spectrometry around the Wikki warm spring area. His resistivity results showed that low resistivity values exist around the WWS area while the radiometric survey measurements revealed high gamma activity in this region.

This higher radioactivity in the area is indicative of the importance of radiogenic heat activities within the WWS area and a pointer to the heat source probably due to radioactivity.

This current work utilized high resolution aero-radiometric data to compute the concentration of the radioelements at Ikogosi warm spring and environ. The result revealed that Potassium is around 0.8%, Thorium eTh is around 6ppm and Uranium eU 2.5ppm at IKWS while in the vicinity of the study location, the concentration of Potassium ranges between 0.3 and 3.5%, Uranium eU ranges from 0.5 to 7.5ppm, and Thorium eTh ranges between 5 and 40ppm. The total count of radioelements and their concentrations are mapped leading to the computation of radiogenic heat production which ranges from 0.8 to 5.44 µW/m^3 with an average RHP of 3.01 µW/m^3 within the crystalline rocks and 1.26 µW/m^3 in the metasediment quarzitic rocks in the study area. The average RHP of 3.01 µW/m obtained in the crystalline rock assemblage in this work is higher than the global mean value of Radioactive Heat Production of 2.8µW/m^3.

II. Location and Geology of the Study Area

The Ikogosi warm spring is in the south-western part of Ekiti State of Nigeria. Ikogosi warm spring lies on the geographic latitude of 7°35'N and longitude 5°00'E (Figure 1) within the central region of the area covered by this study. It is situated between lofty steep-sided and heavily forested, north-south trending hills about 27.0 km east of Ilesha, and about 10.5 km southeast of Efon Alaye (Rogers et al., 1969). The warm spring is in a quiet town called Ikogosi that has a rich culture, in the Western part of Ekiti State where warm and cold flow parallel, and meet somewhere to form a confluence, with each maintaining its thermal quality (Adeyemi, 2016). The warm spring has a temperature of around 70^{o}C at the source and 37^{o}C after meeting the cold spring as the meeting point of the two spring serves as unique attraction to tourists.

A well-landscaped 116-hectare resort is located around the warm spring at Ikogosi-Ekiti with a view to give tourists and visitors a long-lasting experience. Located within the Precambrian basement complex of South Western Nigeria, it is at an altitude of 450 to 500m (Adegbuyi and Abimbola, 1997) above the mean sea level. The dominant geology of Nigeria is constituted mainly of crystalline Precambrian basement complex and sedimentary rocks of Cretaceous recent sediments.

Figure 1, Geological Map of Nigeria showing major structural units and warm springs. (after Kurowska and Schoeneich, 2010)

The warm spring temperature is 37°C near the foot of the eastern slope of the north-south trending ridge from a thin quartzite unit within a belt of quartzite which includes quartz-mica schist and granulitic migmatite east of Ilesha (Figure 2). The Okemesi quartzite member is characterized by a North-South trending ridge called the Efon ridge (Elueze, 1998; Oyinloye, 2011). The quartzitic rocks are composed of dominant quartz with muscovite, chlorite and sericite occurring in minor proportions (Adegbuyi and Abimbola, 1997). It was suggested that the source of springs in the Efon Psammite formation is associated with a faulted and fractured quartzite band sandwiched between schists (Rogers *et al*., 1969). Geochemical data of Ikogosi shows that quartzite is largely metamorphosed sandstones containing minor arkosic intercalations (Elueze, 1998).

Based on petrology, a medium pressure Barrovian and low medium pressure types of metamorphism had been suggested for the Precambrian basement rocks in South Western Nigeria (Oyinloye, 2011). It is believed that the intersections of the NNE-SSW epeirogenic belts with the NW-SE fracture trends in Nigeria coincide with the centres of Ikogosi warm spring. The issue of the spring is controlled by permeability developed within the quartzite because of intergranular pore spaces coupled with fracturing of the relatively competent quartzite (Rogers, 1969).

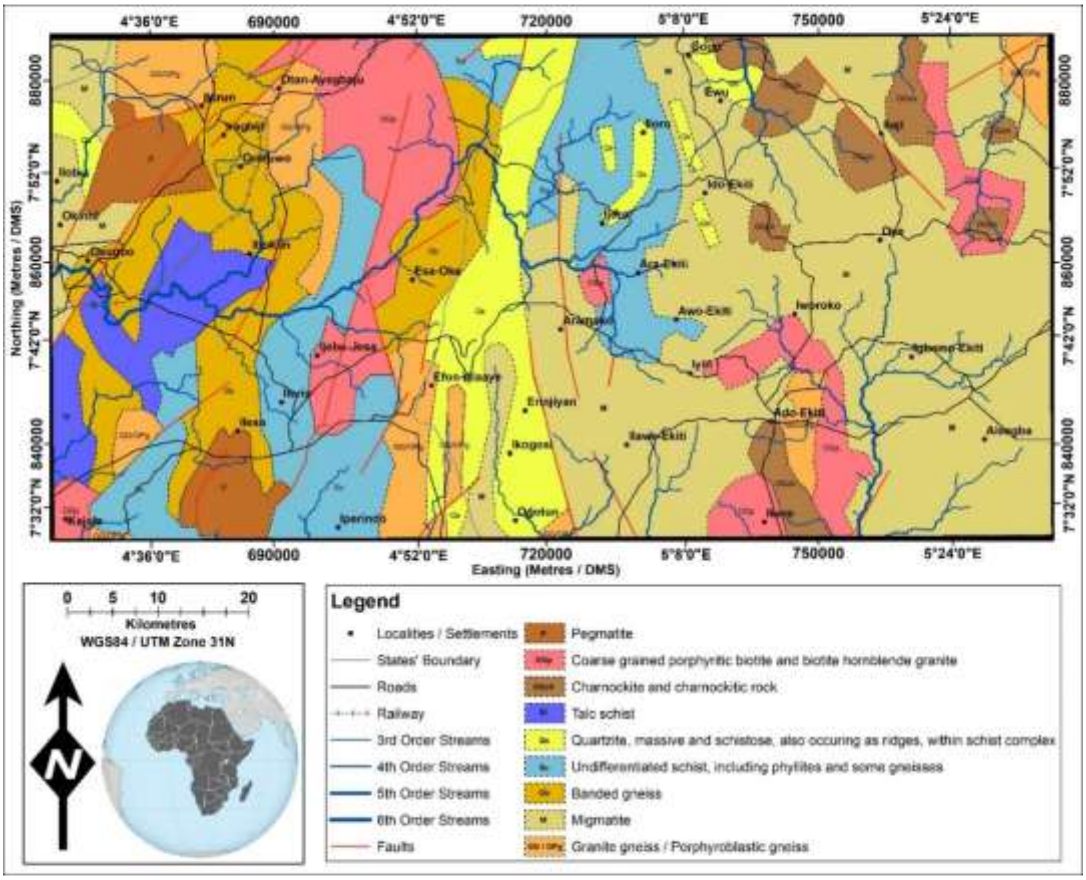

Figure 2, Geological map of the study area (modified from NGSA, 2006).

III. Materials and Methods

The study area covers sheets 243 and 244 included in the nationwide high resolution systematic airborne geophysical survey conducted by Fugro Airborne Surveys over Nigeria on behalf of the Nigerian Geological Survey Agency (NGSA). A high-sensitivity airborne gamma ray spectrometer flown at 500 m line spacing and 80 m mean terrain clearance was used to acquire the gamma ray spectrometric survey. The data were corrected for background radiation resulting from cosmic rays and aircraft contamination, variations caused by changes in aircraft altitude relative to ground and Compton scattered gamma rays in potassium and uranium energy windows. The uranium and thorium concentrations are, therefore, expressed as equivalent concentrations, eU and eTh, in ppm. Potassium (40K) is processed to produce equivalent ground concentrations in %K. Total counts are here converted into (μR hr–1) called unit of radiation (Ur). The corrected radiometric data provides an estimate of the apparent surface concentrations of potassium, uranium and thorium (K, eU and eTh), as well as the Total Count (TC) values. The projection method used in processing the data was the Universal Transverse

Mercator (UTM) and the WGS 84 as Datum. The software utilized in this work is Geosoft Oasis Montaj 8.4 version software.

3.1 Total Count of Radioactive Elements

The surface distribution of the total count of radioactive elements in the study area was gridded to produce a map of the total count of radioactive elements. The geological map of the study area was superimposed on the total count map to deduce the correlation between the lithology and total count distribution of radioelements in the study area.

3.2 Concentration Maps of Radioactive Elements

The surface distributions of the Potassium's concentration, Thorium's concentration, and Uranium's concentration were gridded to produce maps of the concentration of the radioelements.

3.3 Ternary Map of Radioactive Elements

The ternary map of the radioelements (K, eTh, and eU) is a colour composite image produced by modulating the red, green, and blue in proportion to the radioelement concentration values of the K, eTh, and eU. Since rock types often have characteristic of the three radioactive elements, the ternary map is a useful geological and mineral exploration tool for discriminating the zones of consistent lithology and contacts between contrasting lithologies. The resulting ternary grid of K, eTh, and eU in the study area is presented under the study result.

3.4 Ratio Maps of Radioactive Elements

Ratio maps of radioactive elements are produced by meaningful arithmetical combinations of their grids. These ratio maps have the tendency of reducing the effects of environmental factors (such as vegetation, soil moisture, topography, and weather condition) on the recorded radiometric data. Ratio maps are another way of visually comparing the surface distribution of radioactive elements in the study area and can enhance geological features in radiometric data sets.

For this study, two ratios $\frac{eU}{K}$ and $\frac{eU}{eTh}$ maps of radioactive elements were produced. The former is the ratio of concentration of Uranium to potassium while the latter is the ratio of concentration of Uranium to Thorium.

3.5 Estimation of Radiogenic Heat Production

The estimation of the radiogenic heat production from the subsurface of the study area was obtained from the radiometric data following Salem and Fairhead (2011) as,

$$A = 10^{-5} * p\,(9.52C_U + 2.56C_{Th} + 3.48C_K) \quad (1)$$

where, A is the radiogenic heat production in µW/m^3, p is the density of rock in kg/m^3 (from Telford et al., 1990), C_U, C_{Th}, and C_K are the concentrations of Uranium (in ppm), Thorium (in ppm), and Potassium (%), respectively. The rocks' density grid obtained from the lithology (Figure 3) was used for the computation of the radiogenic heat production of the study area. The geological map of the study area was superimposed on the radiogenic heat production map to deduce the relationship between the lithology and radiogenic heat produced in the study area.

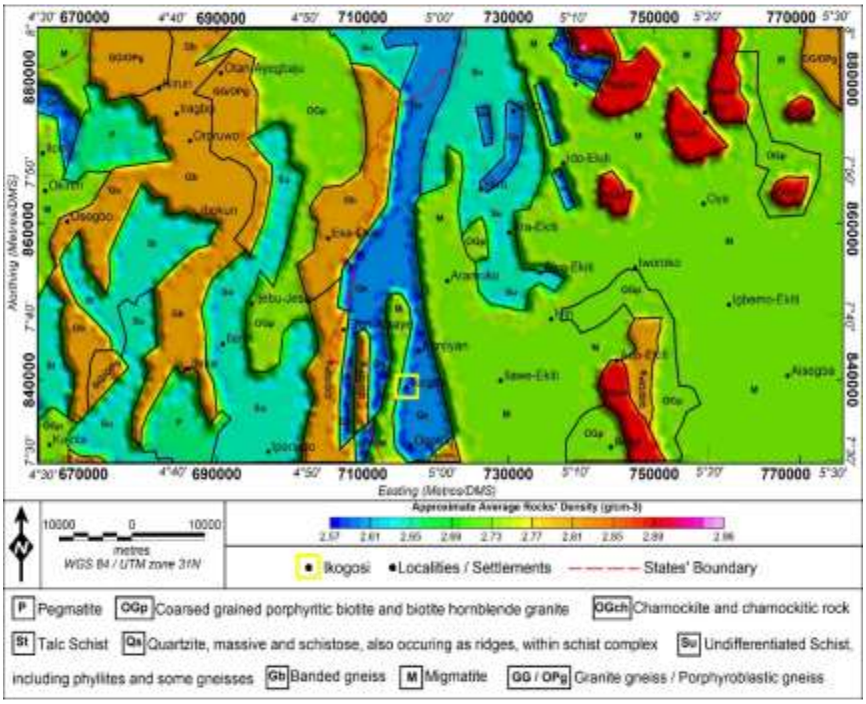

Figure 3, Map of the density distribution of lithology (from Telford et al., 1990) in the study area.

IV. Result and Discussion

The map of the surface distribution of the total count of radioactive elements in the study area is presented in figure 4. The distribution of the radioelements shows varying concentration which is higher in the north-east and east of Ikogosi warm spring that is predominantly covered by crystalline rocks than metasediment quartzitic rocks deposit to west and north of the study area. The map of the surface distribution of the total count is suggestive of minerals rich in radioactive elements are present all around the study area especially in the north-west, north-east and east of Ikogosi warm spring.

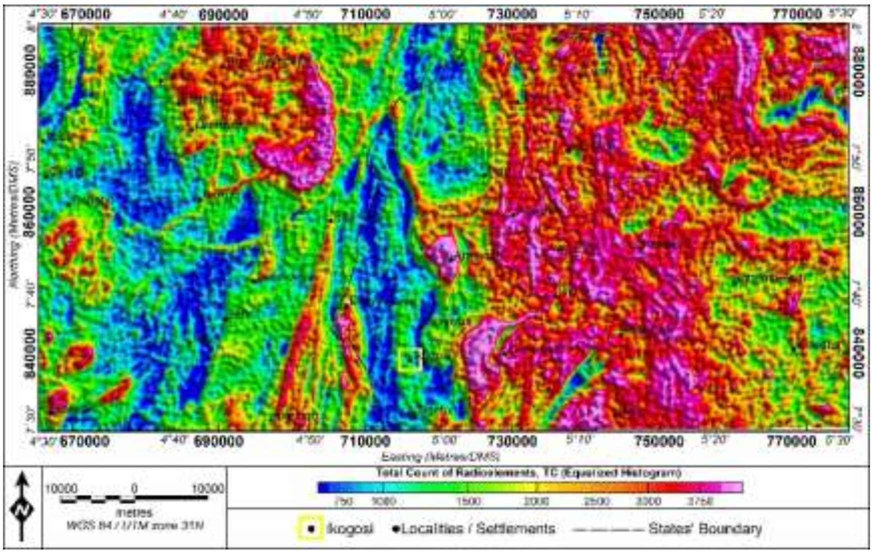

Figure 4, Map of the Total Count of Radioelements in the Study Area

At Ikogosi warm spring on the quarzitic ridge, the concentration of these radioelements reveals that Potassium is around 0.8%, Thorium eTh is around 6ppm and Uranium eU 2.5ppm while in the vicinity of the study location, the concentration of Potassium ranges between 0.3 and 3.5%, Uranium eU ranges from 0.5 to 7.5ppm, and

Thorium eTh ranges between 5 and 40ppm. The maps of the concentration of the radioelements is presented in figure 5, 6 and 7 respectively.

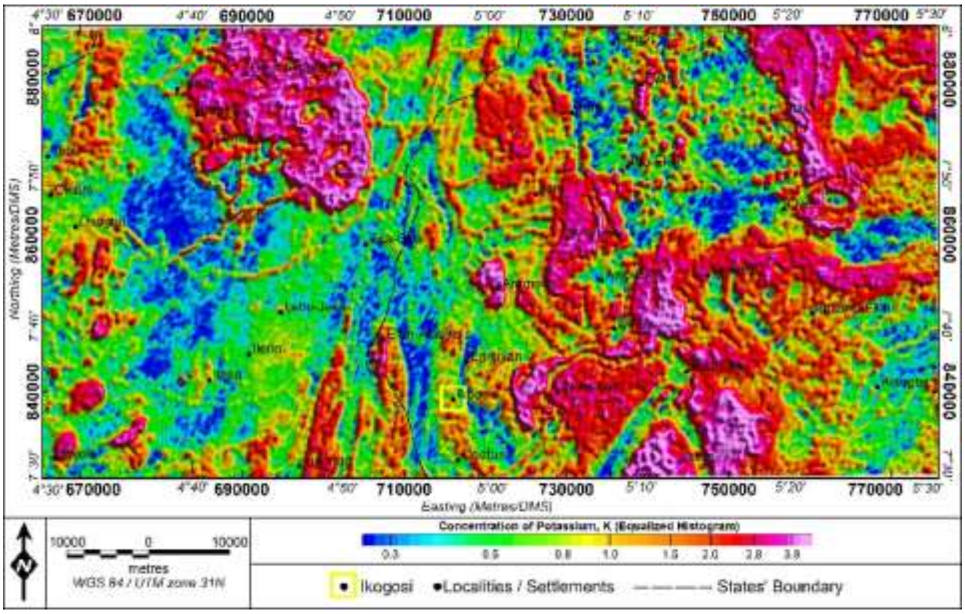

Figure 5, Map of the Distribution of Potassium Concentration in the Study Area

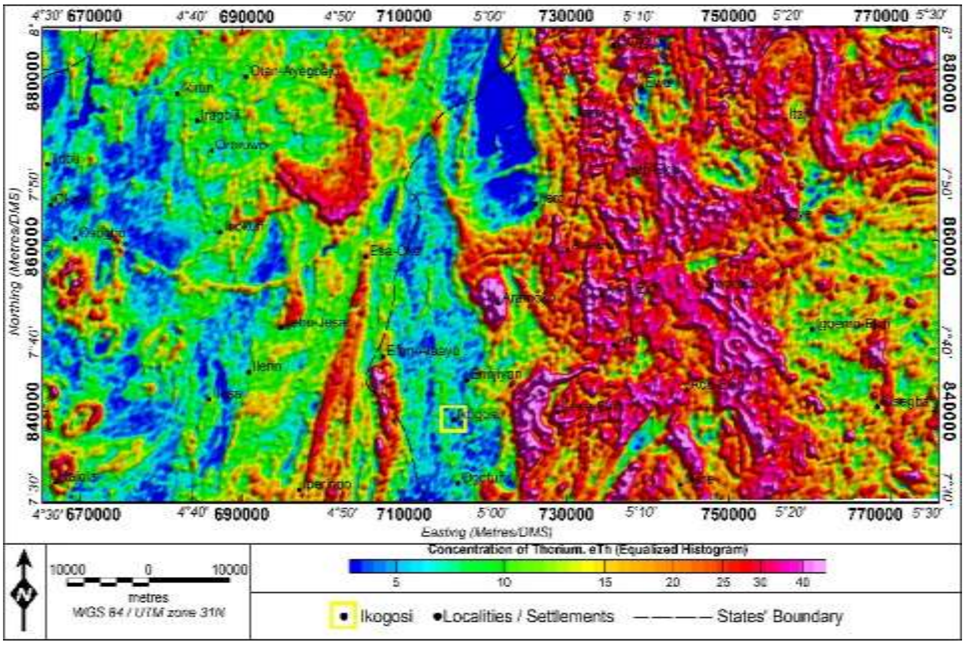

Figure 6, Map of the Distribution of Thorium Concentration in the Study Area

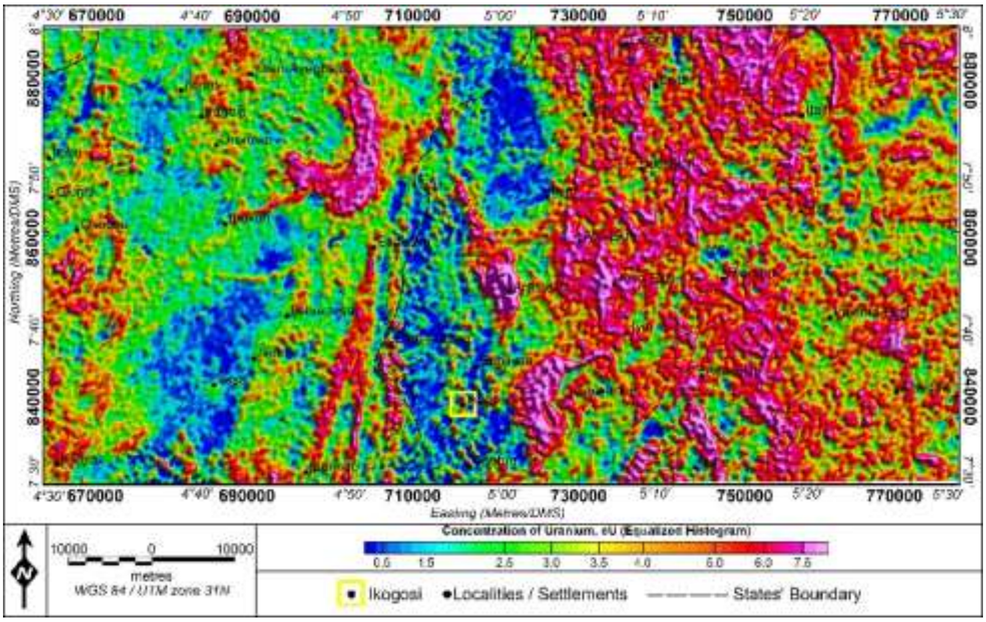

Figure 7, Map of the Distribution of Uranium Concentration in the Study Area

The ratios of concentration of Uranium to Potassium and Uranium to Thorium were respectively gridded suggesting the rock types assemblage in the study area such as charnockitic rock, pegmatite, granites, quartzite and gneisses. The ratio maps are consistent with the map of the density distribution of lithology in the study area. For this study, two ratios; Uranium/Potassium and Uranium/Thorium maps of radioactive elements were produced and presented in figures 8 and 9. The maps of the ratio reveal that the rocks in the study area are richer in Potassium than Uranium suggesting the abundance of granitic rocks and the minerals within them, particularly feldspar and mica in the study area. Thorium is also found richer than Uranium in the rocks indicating the possible occurrence of some accessory minerals like monazite and apatite.

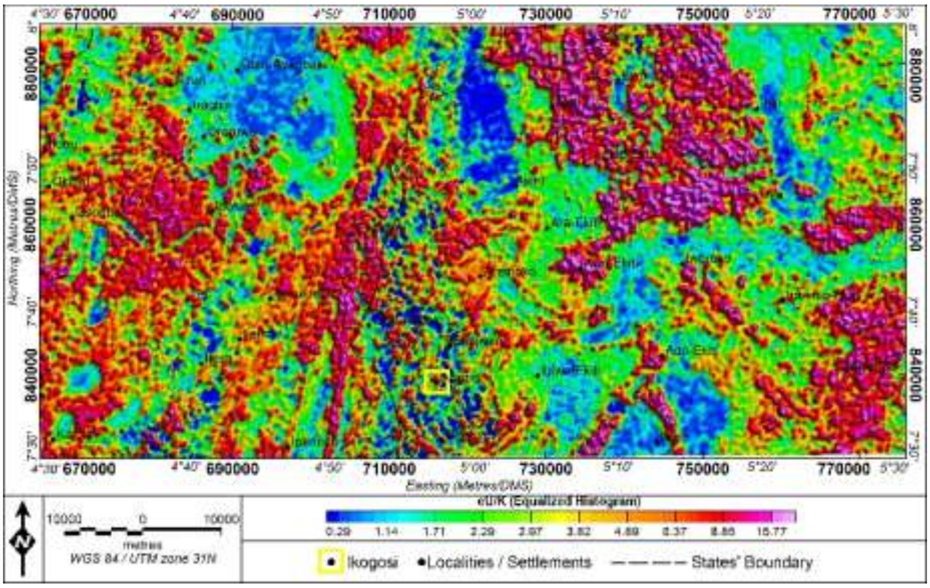

Figure 8, Map of Uranium Concentration to Potassium Concentration ratio in the Study Area

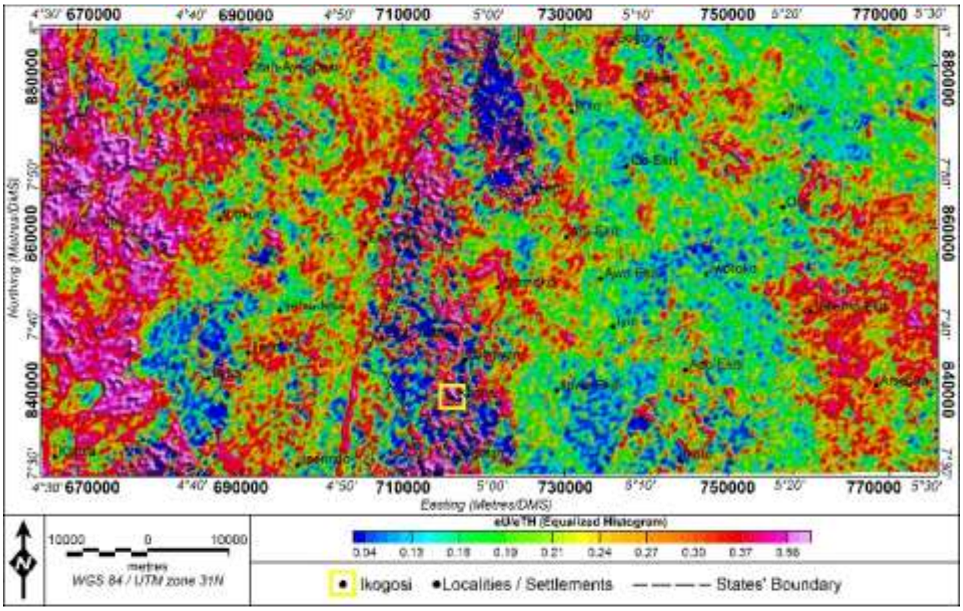

Figure 9, Map of Uranium Concentration to Thorium Concentration ratio in the Study Area

The ternary map of the distribution of Potassium, Uranium and Thorium (Figure 10) in the study area is a useful geological and mineral exploration tool for discriminating the zones of consistent lithology and contacts between contrasting lithologies. The resulting ternary grid of K, eTh and eU in the study area suggests the enrichment of these elements in the pegmatite, coarse grained porphyritic biotite and biotite hornblende granite, charnockite and charnokitic rocks, migmatite, granite gneiss and quarzitic rocks that characterized the geology of the study area.

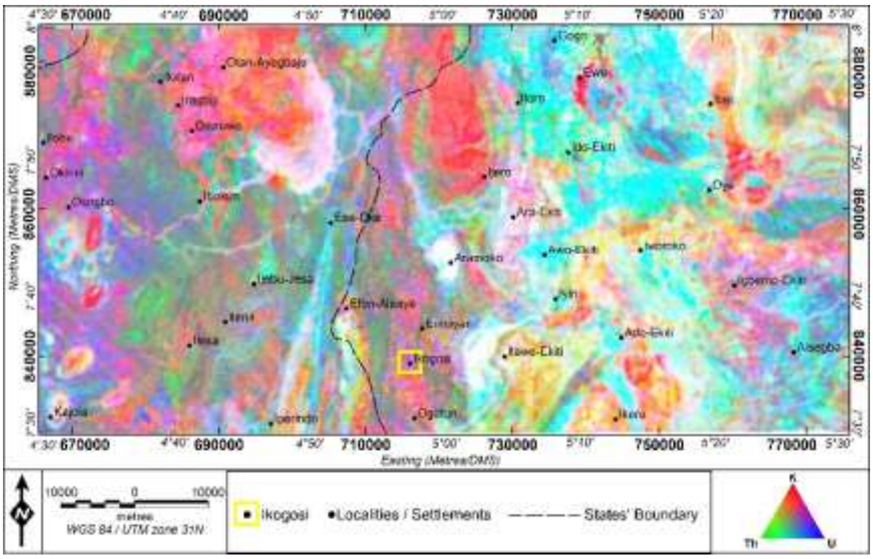

Figure 10, Ternary Map of the Distribution of Potassium, Uranium, and Thorium in the Study Area

The result of the estimated radiogenic heat production in this study shows value ranging from 0.8 to 5.44 µW/m3. The study reveals that radiogenic heat production is higher in the areas with assemblage of crystalline rocks in the study area resulted in an average RHP of 3.01 µW/m3 (this is higher than the global mean value of Radioactive Heat Production which is 2.8µWm^{-}) while section covered with metasediment quarzitic rocks has an average RHP of 1.26 µW/m3. This suggests that heat generated through radioactive decay around the study area might have contributed significantly to the thermal heating of Ikogosi warm spring. The radiogenic heat production map (Figure 11) supports the theory that significant quantity of heat contributing to the thermal activities within the subsurface in the study area may have been generated through the radioactive decay in the crystalline rocks assemblage predominantly located in the east and north-east direction of Ikogosi warm spring. The study area was divided into 55 overlapping spectral blocks, about 20 km x 20 km in size, and each spectral block overlapped the adjacent blocks by 50% which was utilized for recent study carried out by the authors using aeromagnetic data. The radiogenic heat production was computed at the center of each block with the assumption that the estimated result for each block represents the average radiogenic heat production of the respective blocks (Table 1).

Table 1, Estimated radiogenic heat production at the centers of the 55 blocks

Spectral Block's Number	Block's Centre		Potassium, K (%)	Uranium, $_eU$ (ppm)	Thorium, $_eTh$ (ppm)	Total Count, TC (Ur)	Radiogenic Heat Production (μW/m^3)
	X (m)	Y (m)					
1	674187	875428	0.95	2.02	9.53	1568.16	1.17
2	683757	875274	1.75	2.32	9.32	1972.25	1.39
3	692710	875428	3.53	3.07	8.34	2683.50	1.75
4	701817	875582	4.53	6.82	20.47	3951.11	3.50
5	711233	875428	0.31	1.30	7.90	978.98	0.97
6	720340	875428	2.26	0.17	-1.70	1065.07	0.30
7	729756	875582	2.74	4.01	16.03	2943.65	2.83
8	738555	875737	3.02	2.93	9.88	2459.68	1.23
9	748125	875582	1.54	5.16	26.74	2629.81	3.16
10	757078	875737	3.55	2.71	15.62	2500.64	2.23
11	766802	875582	1.66	6.15	30.99	4062.78	3.16
12	674187	866629	0.70	2.04	5.08	1113.53	1.02
13	683603	866475	0.27	1.03	5.45	849.35	0.67
14	692710	866629	0.31	3.50	10.94	1427.60	1.63
15	701972	866629	2.57	5.23	21.75	3081.57	3.05
16	711233	866784	0.53	5.15	5.92	975.29	1.41
17	720340	866784	2.17	-0.41	1.84	1234.93	0.35
18	729756	866629	1.94	7.62	27.88	3211.49	3.73
19	738709	866629	0.39	2.23	8.67	1066.93	0.81
20	748125	866938	0.23	5.24	16.81	2286.35	2.19
21	756923	866784	2.92	4.47	34.67	3917.55	3.69
22	766802	866938	1.92	5.36	17.85	2858.68	2.85
23	674341	857214	0.93	5.50	16.57	2011.14	2.72
24	683603	857214	0.34	2.30	9.09	1212.89	1.26
25	692710	857214	0.54	-0.28	1.83	477.50	0.12
26	701972	857214	0.45	2.93	12.43	1392.13	1.59
27	711079	857214	0.58	1.99	3.86	845.89	0.97
28	720495	857214	1.24	5.30	30.13	2546.34	3.06
29	729911	857214	3.31	7.94	36.80	5048.70	4.84
30	738863	857522	1.46	7.24	34.02	3352.08	4.43
31	748125	857368	1.60	1.51	9.07	1565.34	1.03
32	757232	857368	2.25	6.21	29.97	3423.61	3.86
33	766957	857214	0.20	3.16	11.95	1631.28	1.62
34	674341	848261	0.72	4.71	10.22	1622.84	1.83

35	683603	848261	0.41	0.53	8.13	867.84	0.86
36	692864	848261	0.61	2.30	11.08	1264.51	1.35
37	702126	848261	0.34	4.23	15.81	1576.50	1.59
38	711387	848261	0.59	1.70	5.66	878.92	0.80
39	720495	848106	0.45	3.64	13.48	1696.35	1.92
40	729911	848261	2.17	4.88	21.48	3088.32	2.91
41	738863	848261	2.92	4.70	20.19	2925.50	2.67
42	748125	848570	1.07	7.11	43.42	3990.13	4.91
43	757232	848570	1.91	3.68	13.89	2426.17	2.23
44	766802	848570	0.83	5.49	21.18	2307.98	2.95
45	674341	838536	0.41	3.31	4.98	875.91	1.31
46	683603	838382	0.75	0.93	9.16	1089.62	1.02
47	692864	838382	0.48	3.03	13.19	1607.67	1.66
48	701972	838691	2.33	0.70	7.55	1827.13	0.86
49	711387	838845	0.55	0.62	8.21	860.60	0.76
50	720649	838691	1.31	2.55	8.77	1651.81	1.47
51	729756	838536	3.20	6.47	51.50	5385.36	5.44
52	739018	838845	1.40	4.08	35.33	3917.18	3.91
53	748125	838845	3.57	2.28	13.64	2656.68	1.70
54	757386	838999	0.47	7.44	35.35	3505.80	4.79
55	766802	838999	0.56	4.26	23.10	2130.20	3.09

The result of this work suggests the contribution of radiogenic heat generated within subsurface through radioactivity to the geothermal potentials of Ikogosi warm spring area.

However, Sedara (2022) carried out radiometric survey in Ikogosi lake and showed the distribution of radionuclides and heat production in rocks. The radiogenic heat production study revealed that the contribution of heat from the different rock samples is dependent on the type of rocks (results from the radioactive decay of U238, Th232, and K40). The quartzite series contributes the highest followed by the granites and gneiss series. Since most of these rock samples were collected from surface outcrops, there is an uncertainty about the concentration of the radioactive elements with depth. His study resulted in RHP that varied between 1.8 and 3.5µW/m^3 with the high end seems underestimated.

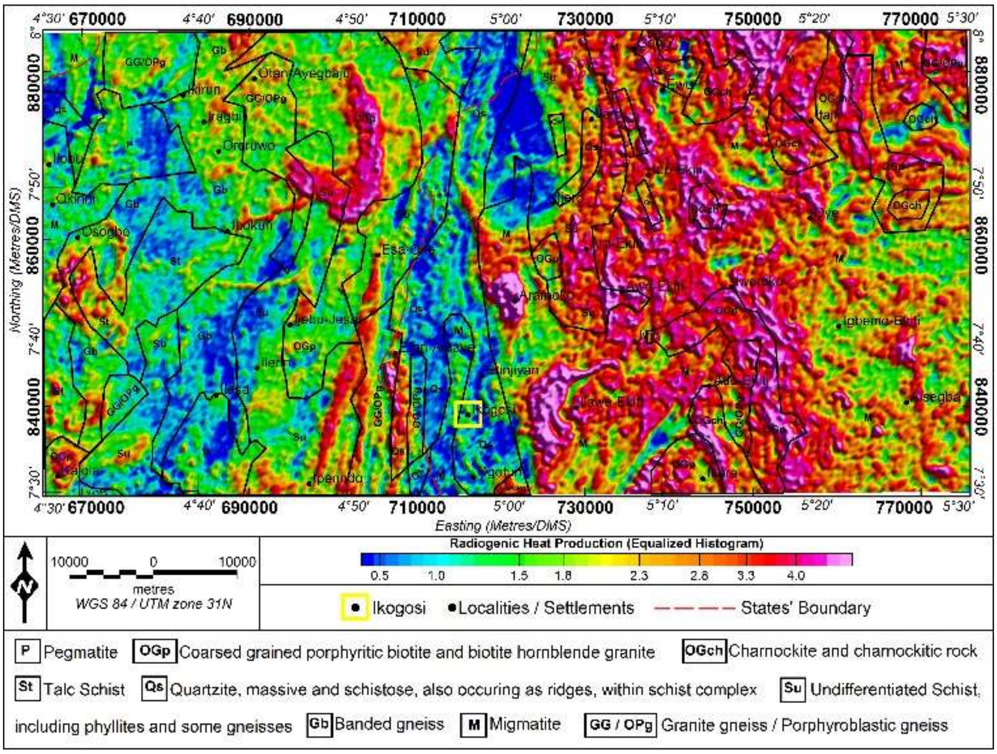

Figure 11, Radiogenic Heat Production Map of the Study Area superimposed with the Geological Map

V. Conclusion

The estimation of radiogenic heat production utilized in this work had been deployed at various locations comprising of diverse lithologies from crystalline to sedimentary lithologic units in Nigeria. This non-intrusive geophysical method was primarily used to explore the contribution of radioactivity in the rocks at Ikogosi warm spring to the geothermal potentials. The authors, having recently suggested with evaluation of aeromagnetic data, the existence of geothermal potentials at the study area deemed it necessary to further investigate other possible contributing factors to the geothermal resource considering the geology of the study area. The geothermal potentials that abound in Nigeria are still under explored without the establishment of a single geothermal plant despite the prevailing insufficient power generation. This work has further reinforced the sustainability of subsurface heat production that could favourably support a viable geothermal power plant at Ikogosi warm spring. The study reveals the average radiogenic heat production around Ikogosi warm spring to be about 3.01 $\mu W/m^3$ which is higher than the global mean value of Radioactive Heat Production of $2.8\mu Wm^{-3}$. This result is in addition to the geothermal heat flow that ranges between 179.51 to 211.96 mW/m^2 computed for Ikogosi warm spring from aero-magnetic data by Ayilola et.al (2025). Geothermal energy has been successfully harnessed globally contributing to their energy mix and providing numerous environmental and economic benefits. As Nigeria energy generation is currently considered to be grossly inadequate and cannot support the social economic activities of the country and too-much dependence on fossil fuel as sources of power generation is gradually becoming obsolete, hence the gradual paradigm shifts to more environmentally friendly and renewable energy sources such as the one this research has addressed is inevitable. Aside the consideration for the environment, the socio-economic impacts that the geothermal energy source will have on people around the study area is substantial. It is important to state that the new global initiatives towards cleaner energy is supported by this study.

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VII. Conflict of Interest Declaration

The authors had no conflict of interest in course of executing the study

VIII. References

1. Abraham, E. M., & Nkitnam, E. E. (2017). Review of geothermal energy research in Nigeria: The geo-science front. International Journal of Earth Science and Geophysics, 1(3). https://doi.org/10.35840/2631-5033/1815.
2. Adegbuyi, O., & Abimbola, A. F. (1997). Energy resource potential of Ikogosi Warm Spring Area, Ekiti State, Southwestern Nigeria. African Journal of Science, 1, 111-117.
3. Adeyemi, L. (2016, May 7). Ikogosi Warm Spring – Experience Nature with Fun. Travel and Tourism Article, The Guardian Nigeria. https://guardian.ng/saturday-magazine/ikogosi-warm-spring-experience-nature-with-fun.
4. Alsuhaibani, Z., & Hepbasli, A. (2013). Future aspects of geothermal energy in Saudi Arabia. Energy Sources Part A: Recovery, Utilization, and Environmental Effects, 35, 981–990. https://doi.org/10.1080/15567036.2010.512762.
5. Ayilola, O. O., Tamunobereton-ari, i., Amakiri, A. R. C. & Israel-Cookey, C. Spectral Depth Analysis and Source Parameter Imaging in the Investigation of Geothermal Potentials of Ikogosi Warm Spring, Ekiti State, Nigeria. Quest Journals, Journal of Research in Environmental and Earth Sciences Volume 11 ~ Issue 6 (June 2025) pp: 08-19 ISSN(Online) :2348-2532. https://doi.org/10.35629/2532-11060819.
6. Bako, A. S. J. (2010). Geothermal energy potential in the part of middle Benue Trough located in Nasarawa State [Master's thesis, Ahmadu Bello University, Zaria, Nigeria].
7. Braja, I. T. (2018). Application of radiometric method to determine radiogenic heat around Rafin Rewa Hot Spring, Lere, Kaduna State, Nigeria (Doctoral dissertation). Ahmadu Bello University, Zaria.
8. Bubu, A., & Ononugbo, C. P. (2018). Radiogenic heat production due to natural radionuclides in the sediments of Bonny River, Nigeria. Journal of Scientific Research & Reports, 17(6), 1–9. https://doi.org/10.9734/jsrr/2018/v17i630174.
9. Carey, B. (2010). Low enthalpy geothermal research – New Zealand. In Proceedings World Geothermal Congress (pp. 1–7). Bali, Indonesia.
10. Elueze, A. A. (1998). Promoting the development and exploitation of mineral resources in Nigeria. In Proceedings of the First Mining Nigeria Conference and Workshop of Solid Mineral Development, Federal Republic of Nigeria (pp. 922). NIMAMOP, Global Mineral Limited Publications.
11. Garba, M. L., Kurowska, E., Schoeneich, K., & Abdullahi, I. (2012). Rafin rewa warm spring: A new geothermal discovery. American International Journal of Contemporary Research, 2, 231-236.
12. Hepbasli, A. (2003). Current status of geothermal energy application in Turkey. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 25, 667-677.
13. Joshua, E., Ehinola, O. A., Akpanowo, M. A., & Oyebanjo, O. A. (2008). Radiogenic heat production in crustal rock samples of Southeastern Nigeria. European Journal of Scientific Research, 23(2), 305-316.
14. Kurowska, E., & Schoeneich, K. (2010). Geothermal exploration in Nigeria. Proceedings of World Geothermal Congress 2010, Indonesia, 25-29.
15. McGee, T. (2007). Finding geothermal energy just got easy. Retrieved August 17, 2013, from http://www.treehugger.com/corporate-responsibility/findinggeothermal-energy-just-got-easy.html
16. Neilson, G., Bignall, G., & Bradshaw, D. (2010). Whakarewarewa: A living thermal village in Rotorua, New Zealand. Proceedings World Geothermal Congress, Bali, Indonesia, 25 - 29 April 2010.

17. Nigerian Geological Survey Agency (NGSA). (2006). Geological map of Nigeria. The Authority of the Federal Republic of Nigeria.
18. Oladipo, A. A., Oluyemi, E. A., Tubosun, I. A., Fasisi, M. K., & Ibitoye, F. I. (2005). Chemical examination of Ikogosi warm spring in southwestern Nigeria. Journal of Applied Sciences, 5, 75-79.
19. Olorunsola, K., & Aigbogun, C. (2017). Assessment of aero-radiometric data of southern Anambra Basin for the prospect of radiogenic heat production. Journal of Applied Sciences and Environmental Management, 21(4), 743-748.
20. Omanga, U. S. A. (1998). Preliminary geophysical investigation of the source of heat of the Wikki warm spring, Bauchi, Nigeria (Master's thesis, Ahmadu Bello University, Zaria).
21. Oyinloye, A. O. (2011). Beyond petroleum resources: Solid minerals to the rescue: 31st inaugural lecture of the University of Ado-Ekiti, Nigeria Press, 1-36.
22. Pohatu, B., Warmenhoven, T., Rae, A., & Bradshaw, D. (2010). Low enthalpy geothermal research – New Zealand. Proceedings World Geothermal Congress, Bali, Indonesia, 25-29 April 2010.
23. Rashid, F. L., Abdullettif, A., & Hashim, M. (2012). Geothermal energy for electricity generation. British Journal of Science, 3(2), 118-130.
24. Reyes, A. G. (2010). Assessing the flow of thermal waters in low temperature mineral spring systems in South Island, New Zealand. Proceedings World Geothermal Congress, Bali, Indonesia, 25-29 April 2010.
25. Rogers, A. S., Imevbore, A. M. A., & Adegoke, O. S. (1969). Physical and chemical properties of Ikogosi warm spring, western Nigeria. Nigeria Journal of Mining and Geology, 4.
26. Salem, A., & Fairhead, D. (2011). Geothermal reconnaissance of Gebel Duwi area, Northern Red Sea, Egypt using airborne magnetic and spectral gamma ray data. Getech, 1–22.
27. Sedara, S. (2022). Geophysical analysis of thermo-physical properties of rocks in Ikogosi field for geothermal energy prospect. Turkish Journal of Geosciences, 3(1), 39-48.
28. Sokari, S. A., Gbarato, O. L., & Ononugbo, C. P. (2022). Radiogenic heat production due to natural radionuclides in soil and sediments of coastal communities of Okrika Local Government Area of Rivers State, Nigeria. Asian Journal of Research and Reviews in Physics, 6(1), 14-20.