



The offer of Geophysical Techniques in uncovering the geothermal energy potential reserves towards mitigating the formidable Energy crisis in Nigeria

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ABSTRACT

The Nigeria's challenging electrical energy requirements has been overwhelming, with the demands for such electrical energy exceeding generation capacity. The main Nigerian electrical energy generating source has been gas-fired thermal power stations and despite her increasing population of close to 200 million, Nigeria's present energy generation capacity still stood at 13,000 MW with only 5,500 MW distributable to the nation. Therefore, mitigating this formidable electrical energy challenge currently bedevilling the country where the demands for such energy exceed the attainability remains a very vital issue. Geothermal energy was considered being the most reliable, sustainable and stable source of optional energy compared to other renewable resources like wind and solar power. Reason being that it's always constantly availability for tapping in contrary to that of wind or solar energy that is occasionally scarce / absent with seasonal variations. Consequently, some notable geophysical techniques previously applied by researchers at various locations within Nigeria were reviewed with a particular focus on those researches that were targeted on geothermal energy prospecting. The aim was to appraise the geophysical contributions from such notable researches. Most of the researchers opined that there is inequitable access to the meagre and unstable generated electrical energy by the populace. The consequent of which is securing renewable geothermal energy sources as an alternative for the production of electricity. This geothermal energy option will present an attractive and cheaper alternative energy source for the nation. Numerous of such geothermal energy potential sites in the country showing surface heat manifestations were discovered through the exploit of the geophysical methods. The greatest achievement of the geophysical methods observed from this review is the methods' efficacy, reliability and cost-effectiveness when used to establish very useful information for the stake holders towards facilitating proper assessment, exploration and exploitation of geothermal energy resources in Nigeria which remains the best option towards resolving the national energy crisis.

Keywords: Electrical energy, Geothermal energy, Renewable energy, Nigeria

INTRODUCTION

The successfulness, buoyancy and sustainability of Nigerian economic growth is a function of the national Energy capacity and availability. Functionality of Energy is a key to the progress and development, as well as poverty eradication and security of any nation. Maintaining uninterrupted energy supply is a very serious challenging issue for all countries today and future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally user friendly. An insufficient or lack of access to energy contributes to poverty, deprivation and can contribute to a very serious economic crisis. Energy and poverty reduction are not only closely connected, but also with the

socioeconomic development, which involves productivity, income growth, education and health (Oyedepo, 2012). Nigeria has one of the lowest consumption rates of electricity per capita in Africa (PWC, 2016).

Nigeria now has an installed grid power generation capacity of 13,000 MW out of which the distribution system had the capacity to evacuate only 5,500 MW of power for a population close to 200 million people (Omokolade, 2020). This is grossly inadequate for such a population density that requires about 15,000 MW of power. When compared to Brazil

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with a similar population size that had a generation capacity of 150,338 MW with distribution capacity of 9,500 MW for its 211 million population density (Data commons 2021). These challenges emphasize the need to explore all available energy resources (especially renewable energy sources) to chart a new energy future for Nigeria. Geothermal energy is vital in the long-term vision of providing abundant, suitable, economical and clean sources of energy for Nigeria. Electricity consumption from residential and commercial sectors in Nigeria represents 80% of total electricity demand. As a result of high economic growth and demographic pressure, in 2008, the Energy Commission of Nigeria (ECN) together with the International Atomic Energy Agency (IAEA) projected a demand of 15,730 MW for 2010 and 119,200 MW for 2030 under the reference scenario (7% yearly economic growth) (Energypedia 2021). However, recent evaluation indicates that out of the Nigeria's 5,500 MW generating capability, 86 % of this capacity is from gas-fired thermal power stations. The remaining 14% is from the three Large Hydroelectric Power (LHP) stations in the Country (Akinsoji, 2016).

The renewable energy resources available in Nigeria are diverse and enormous. A summary of the Nigeria's renewable energy potentials is shown in Table 1 (Olaoye *et al.*, 2016). Geophysical methods have offered tremendous achievements in geothermal and nuclear power prospecting. However, despite such enamous geophysical contributions in revealing the Nigerian geothermal energy potential of the magnitude 500 MW (Table 1), it is sad that at present, there has not been any installed geothermal plants in Nigeria. However, the Renewable Energy Master Plan (REMP) in its second draft of November 2012 as prepared by the Energy Commission of Nigeria (ECN) sought to increase the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030 (ECN, 2013). Renewable electricity would then account for 10% of Nigerian total energy consumption by 2025 (ECN, 2012).

Table 1: Estimates of renewable energy potential in Nigeria (MW) (Olaoye et al. 2016).

Energy Source	Power (MW)
Small and Large Hydro	64,000
Geothermal	500
Onshore Wind	1600
Offshore Wind	800
Solar PV Panels	7000
Biomass	50
Nuclear Power	20,000
Total	93,950

The ascendancy of Geothermal Energy

Geothermal energy is more environmentally friendly than the conventional fuel sources such as coal and other fossil fuels. In addition, the carbon footprint of a geothermal power plant is low. Although there is still some pollution tendencies associated with the geothermal energy, these are relatively minimal when compared to fossil fuels. Geothermal energy is a source of renewable energy that can be used to generate electrical power. The hot reservoirs within the Earth are naturally replenished, making it both renewable and sustainable. It possess huge potential, worldwide energy consumption is currently around 15 terawatts, which is far from the total potential energy available from geothermal sources (Olaoye et al. 2016). While we can't currently use most reservoirs there is a hope that the number of exploitable geothermal resources will increase with on-going research and development in the industry. It is currently estimated that geothermal power plants could provide between 0.0035 and 2 terawatts of power (Olaoye *et al.*, 2016).

Geothermal provides a reliable, sustainable and stable source of energy as compared to other renewable resources such as wind and solar power. This is because the resource is always available to be tapped into, unlike with wind or solar energy. Energy generated from this resource is easy to calculate since it does not fluctuate in the same way as other energy sources, such as solar and wind.

This means we can predict the power output from a geothermal plant with a high degree of accuracy. Since geothermal energy is a naturally occurring resource there is no fuel required, such as with fossil fuels that are a finite resource which needs mining or otherwise extracting from the earth. There is a great deal of rapid evolution and exploration into geothermal energy at the moment, meaning that new technologies are being created to improve the energy exploration processes. There are an increasing number of projects to improve and grow this area of industry. With this rapid evolution many of the current cons of geothermal energy will be mitigated against.

This paper thus focuses on the contributions from the notable researches that have been conducted so far to predict / estimate the geothermal energy potential reserves across Nigeria using geophysical methods. However, this paper has been scoped to only the notable geo-scientific researches' from geophysical and geological perspective. These are by no means the entireties for the country. It is therefore hope that this paper will attract the interest and attention of the Nigerian government and other stakeholders within and outside the nation on the urgent need for a geothermal energy exploration in Nigeria. Also, it will further induce the geo-scientific community toward extensive research in the field with a view to resolving the existing incessant Nigerian energy crisis.

The offer of geophysical methods rooted from the inferences and interpretations of the subsurface heat experienced in the springs and lava flow from various geo-scientists reported in the Benue Trough and the Precambrian basement. Benue Trough houses 8 out of the 10 well known thermal or warm springs in Nigeria (Ema and Elijah 2017). These springs are populated in the northern and central portions of the trough. The warm springs in Nigeria includes Ikogosi Warm Springs, Kerang Springs, Ngeji Warm Springs, Nike Lake and Wikki Warm Springs. Other warm or thermal springs are Keana-Awe Thermal Springs, Lamurde Hot Spring also known as Ruwan Zafi Hot Spring, and the Rafin Rewa Warm Spring. The geothermal information across Nigeria has been largely derived from Bottom Hole Temperature (BHT) measurements, analysis of aeromagnetic data, and heat flow studies as well as some other geophysical and geo-scientific

techniques. The variations in the values of the geothermal gradient over the Nigerian geological provinces reflect different structural and stratigraphic settings.

For example, in the Anambra basin (A sub-basin of the southern Benue Trough), Albian and Maastrichtian sedimentation and fault controlled subsidence and the resultant lithospheric thinning was reported to have influenced the sediments thickness and the geothermal gradient within the basin (Garba et al. 2012). Geothermal gradient of 1.2 °C/100 m - 7.62 °C/100 m was obtained for the Niger Delta Basin from the analysis of subsurface temperatures obtained from borehole logs of six hundred oil wells (Garba et al. 2012). The information derived from the analysis of the Temperature log was used by Adedapo, et al. (2014) to predict the relationship between the geothermal gradient of the sedimentary basin and the subsurface temperature distribution of the oil-gas window. Emujakporue and Ekine (2014) carried out a similar study for the geothermal gradient of Niger Delta Basin using BHT data. They obtained values of 13.46 °C /km to 33.66 °C/km which they attribute to overburden thickness, lithology, tectonic activities (growth faults) and hydrodynamics of the Basin.

Contributions from the Subsurface Investigations using Geophysical Techniques

Quite good number of geophysical techniques applied in researches conducted within Nigeria with respect to geothermal energy prospecting involved depths determination using magnetic and resistivity anomaly field data. Other geophysical methods have not received as much usage as those two techniques. Magnetic anomalies are analysed for estimating the depths to the bottoms of magnetized bodies in the crust. These depths, when contoured for the entire area, could provide a model of the spatial variation of the Curie isotherm level or Curie Point Depth (CPD). This model should correlate to a significantly high degree with various known signatures of the geothermal activity of the study area. Ema and Elijah (2017) reported that Curie depth can be used to complement geothermal data in regions with the absence of deep boreholes.

Most Geophysical Researches conducted at different angles within Nigeria indicated the abundance of high potentials for geothermal energy in the country. Ranges in temperatures of

100 °C to 175 °C reported at 1200 to 2600 m below ground level along the Chad Basin in some part of the Nigerian is a great pointer to its geothermal potential (Mohammed and Ewa, 2018). Supportive records of the interpreted gravity data from the Nigeria's Chad Basin is another convincing index of large geothermal anomalies existing within the Basin at depth range of 23 to 26 km (Mohammed and Ewa 2018). The report also included the existence of some other known and unknown thermal springs within Nigerian crystalline province. It further revealed the occurrence of geothermal anomalies at warm springs in Akiri and Ruwan Zafi in Nigeria based on exhibited high temperature of about 54 °C.

In the subterranean, the thermal structure of the earth's crust is one of the main parameters that control processes of geodynamic. In most occasions, only proxy data are available to derive an idea about the thermal structure of the crust. One such important proxy data is the CPD by Abraham *et al.* (2014). Estimates of the thickness of the magnetized portion of the earth's crust according to them suggested two types of lower boundaries of the layer of the magnetized rocks. The first type of boundary corresponds to vertical changes in the crustal composition and the second type, where high temperatures at depth cause the rocks to lose their ferromagnetic properties *i.e.*, below the Curie - point depth. Crustal ferromagnetic rocks lose their magnetization at the Curie point temperature and become paramagnetic, and their ability to generate detectable magnetic anomalies disappears. The region with significant geothermal energy near the surface of the earth was characterized by an anomalously high geothermal gradient and heat flow. It is therefore expected that regardless of composition of the rocks, the region will be associated with a conspicuously shallow CPD relating to the adjoining regions isotherm (Ema and Elijah, 2017).

In the reviewed studies on the Subsurface temperature distribution in the southern part of sedimentary province within Nigeria by Ema and Elijah (2017), the corrected Bottom Hole Temperature (BHT) data measurements was used during the oil exploration wells drilled in Niger Delta and Anambra basins. The lowest values of geothermal gradient were found in the centre of Niger Delta within the thick Tertiary

sediments as 1.3 - 1.8 °C/100 m (Nwachukwu 1976) or 2.2-2.6 °C/100 m in Warri-Port Harcourt area (Avbovbo 1978). The diversity in the geothermal gradient within Anambra Basin was clearly shown. The values calculated in 17 points (wells) range from 2.5 to 4.9 °C/100 m and the heat flow estimated on the basis of these gradients was 48 -76 mW/m² which is a great vital geothermal energy resource revealed by the exploit of geophysical techniques.

The Ikogosi Warm Spring (IWS) is located in Ekiti State; it has average temperature of 38 °C near the foot of the eastern slope of a North-South trending ridge from a thin quartzite unit within a belt of quartzite. This particular location has become globally very popular due to the numerous academic geophysical and geological researches being conducted in the area which had revealed its beautiful geothermal energy and tourism potentials translating into its high national economic value. Notable amongst those researches includes; the works of Olorunfemi, *et al.* (2011), Abraham *et al.* (2011), Ojo *et al.* (2011), Abraham *et al.* (2014), Ema and Elijah (2017) *etc.* all the studies conclusively considered the IWS as housing a great potential for geothermal energy exploration and hence sets out to examine the depths, composition, temperatures and chemical content of the subsurface using various geophysical parameters. Olorunfemi *et al.* (2011) and Abraham, *et al.* (2012) had applied spectral analysis method using aeromagnetic data from the region in a bid to determine depths to the bottom of magnetic source (Curie Point Depth, CPD). While Olorunfemi *et al.* (2011) depth ranged between 4.68 and 11.38 km calculated from traverses taken across the maps from the region, Abraham *et al.* (2014) depth ranged between 2.5 and 12.5 km, calculated from data windows obtained by sampling targeted points on the aeromagnetic map.

Abraham *et al.* (2014) attempted their own contributions in the geothermal energy studies and elucidated the geothermal resources at IWS by the delineation of the structural setting of the area using geophysical techniques of analytic signal and Euler deconvolution. The technique was able to delineate the boundaries of geologic structures in the region and on superimposing the Euler solutions on the analytic signal map, the sizes and location of the geothermal sources were successfully confirmed. Ojo *et al.* (2011)

also appraised the geologic structure beneath the immediate vicinity of the IWS using an integration of resistivity and magnetic techniques. Their data was acquired through traverses and interpreted by applying inverse modelling procedure. Their inverse magnetic models were able to delineate fractured quartzite/faulted areas within fresh massive quartzite at varying depths. Their geo-electrical sections from Vertical Electrical Sounding (VES) data also delineated a subsurface sequence including fractured/faulted quartzite and fresh quartzite bedrock and a suggestion was made that the fractured/faulted quartzite may have acted as a conduit for movement of warm groundwater to the surface.

This similar deduction have also been made earlier by other authors (Loehnert, 1985; Adegbuyi et al. 1996). On the basis of thermal data collected during pumping tests in water wells, 70 to 500 m deep in the Bida (Nupe, Middle Niger) Basin as well as Borno and Sokoto Basins, geothermal gradient maps were constructed by Kurowska and Schoeneich (2010). The data from Borno Basin also included information from several deep oil wells. The database and the map showed that temperature gradient in Borno Basin ranged from 1.1 to 5.9 °C/100 m, in Sokoto Basin: 0.9 to 7.6 °C/100 m, thus in both cases the geothermal anomalies were indicated and clearly plotted on the map. Their result revealed a significant source of geothermal heat located below the sedimentary complex in the Precambrian basement and relates to some deep tectonic active structures. This is another very remarkable revelation on the assertion of the national geothermal energy potential.

Abraham *et al.* (2012) examined the reservoir permeability of the IWS area using data along fifteen profiles taken across the region. The detailed analysis led to the successful delineation of the boundaries of the geothermal reservoir. Boundary structures between magnetic units were mapped using tilt derivatives. Depths to geologic sources of magnetic field anomalies ranged between 0.6-1.15 km. In another robust study involving spectral analysis of aeromagnetic data, radiogenic composition, tectonics and equivalent depth extent of the IWS region, Abraham *et al.* (2014) arrived at another fascinating impact concerning the geothermal

potential of the IWS region. Their results revealed average CPD for the Ikogosi warm spring area as 15.1 ± 0.6 km and location centered on a host quartzite rock unit. The computed equivalent depth extent of heat production provided a depth value (14.5 km) which fell within the CPD margin and could indicate change in mineralogy.

Another remarkable geophysical contribution is from the various geophysical studies conducted on the Wikki Warm Spring (WWS) located in Bauchi State, North-eastern Nigeria. Such studies like that on the Preliminary geophysical investigation of the source of heat of the WWS conducted by Abraham *et al.* (2015). The electrical resistivity and radiometric methods were adopted employing VES and gamma ray spectrometry around the WWS area. Both the resistivity results and the high gamma activity radiometric measurements within the region were indicative of the importance of radiogenic heat activities within the WWS area and a pointer to the heat source probably due to radioactivity. Other appreciable ones are those on the estimates of CPD using spectral analysis of residual magnetic data carried-out by Obande *et al.* (2014) and Abraham *et al.* (2015) on same WWS region. The discoveries from all the studies based on the inferences drawn suggested that the WWS area was promising for geothermal energy exploration as temperatures greater than 100 °C could be reached at depths of less than 2 km. Such depth estimated by geophysical methods prior to drilling can be of enormous economic advantage in terms of exploration cost. Other documented contribution from the same region includes studies by Elleta and Udensi (2012) who also confirms the regions suitability for further geothermal energy research.

Geophysical contributions to geothermal energy studies on Locations around Atsuku, Takum and Wukari enlisted the areas among the earmarked promising potential geothermal energy areas. Such were evident from Kasidi and Nur (2013) who estimated the CPD values ranging between 24 and 28 km and heat flows of between 53 and 61 mW/m² over Jalingo and environs, north-eastern Nigeria using aeromagnetic data. The study identified low CPD regions as the geothermal energy potential regions.

Other contributions as reviewed by Ema and Elijah (2017) are those on a one-dimensional

spectral analysis and CPD isotherm of eastern Chad Basin of Nigeria performed by Anakwuba and Chinwuko (2015) where the a CPD in the geothermal promising region were of the range between 21.45 and 31.52 km. Bensen, et al. (2013) also identified two depth sources ranging from 2.81 to 3.24 km over a part of the southern Bida Basin, west-central Nigeria. More contributions are recorded also from a spectral analysis of aeromagnetic anomalies applied by Anakwuba *et al.* (2016) to estimate CPD and heat flow at eastern Chad Basin, Nigeria. For which the estimated CPD variation was between 21.45 km at the Mafa - Bama area and 31.52 km at the Maiduguri - Gwoza area of the region, the CPD analysis was suggested as a useful tool in estimating regional thermal structure of that region. The utilization of the subsurface temperature information from 19 oil wells, 24 water boreholes drilled to depths beyond 100 metres and atmospheric temperature from the Chad basin to ascertain the thermal potential of Nigeria sector of the Chad Basin for energy generation was also another geophysical technique contribution. The results indicated geothermal gradient range of 2.81 °C/100 m to 5.88 °C/100 m with an average of 3.71 °C/100 m and thermal conductivity average of 1.626 W/mK. This particular study not only contributed to the geothermal energy phenomena but also benefits the oil exploration activities in the region.

Abraham *et al.* (2019) conducted another one of the first studies to examine geothermal energy prospects in south-eastern Nigeria with the ultimate aim of locating and mapping regions of shallow Curie point depths (CPDs), crustal thickness, and geologic structures supportive of a geothermal system. Result reveals deeper

CPDs within central and southern regions of Okposi, Afikpo and Biase towns in an approximate range of 18.4 to 19.3 km. Shallow CPDs (9.8-17.4 km) was also delineated within Obubra and Abakaliki regions. The estimated geothermal gradient and heat flow values range between 29.0 and 45.0 °C and 52.2-101.5 mW/m², respectively, and fall within values evaluated from deep wells drilled for oil exploration within the adjoining Anambra Basin region. The study recommends the regions with shallow depths for possible geothermal power plant location. Gravity data evaluations also reveal significant subsurface intrusions within Ugboodo, Obubra and Abakaliki locations. In overall assessment, this certainly, was a right step forward towards a better evaluation of the geothermal energy resources potential of south-eastern Nigeria.

Contributions from the Geological Researches

The expressions of subsurface heat as manifested in the springs and lava flow have been documented largely in the Benue Trough and the Precambrian basement. Benue Trough houses the largest (8 out of the 10) well known thermal or warm springs in Nigeria (Kurowska *et al.* 2010). These springs are populated in the northern and central portions of the trough. The warm springs in Nigeria includes Ikogosi Warm Springs, Kerang Springs, Ngeji Warm Springs, Nike Lake and Wikki Warm Springs. Other warm or thermal springs are Keana-Awe Thermal Springs, Lamurde Hot Spring also known as Ruwan Zafi Hot Spring, and the Rafin Rewa Warm Spring (Garba *et al.*, 2012). The geological setting of some Nigerian geothermal features and resources are summarized in Table 2.

Table 2: Geological setting with ambient temperature of some notable geothermal potential reserves and geologic features within Nigeria (Garba *et al.*, 2012).

S/No.	Geothermal Feature	Geological Terrain	Geothermal Resources	Temperature of the Water	Current Economic Activity
1.	Kerang Volcanoes, Plateau State	Volcanic (lava Flow), Jos Plateau	Lava Flow, Water		Farming activities Tourist site, Table water
2.	Rafin Rewa Warm Spring	Precambrian Basement (Migmatite- gneiss) Fractured	Hot water	42.5 °C	
3.	Ikogosi Warm Spring	Precambrian Basement rocks (Quartzite-Schist)	Warm water	37 °C	Tourist site, Medicinal value
4.	Lamurde Hot Spring (Ruwan Zafi Hot Spring)	Cretaceous Benue Trough (Lamurde Anticlines)	Hot water	54 °C	UNESCO Heritage site
5.	Keana-Awe Thermal Springs	Cretaceous Benue Trough (Keana Anticline, and Awe Syncline)	Warm (salt) water	34 °C	Salt, Medicinal value
6.	Akiri Warm Spring	Cretaceous Benue Trough	Hot water	54 °C	Salt
7.	Wikki Warm Spring	Cretaceous Benue Trough (Gombe Sandstone)	Warm water	32 °C	Tourists site

Table 3: Geothermal gradients of some geological formations in Nigeria (Ema and Elijah 2017).

S/No.	Sedimentary Basin	Geothermal Gradient	Sediments Types and Thickness
1.	Niger Delta	1.3 - 4.7 °C/100 m	Cretaceous to recent sediments of Akata shale, Agbada sandstone and Benin Formation
2.	Anambra	3.2 - 5.5 °C/100 m	A cretaceous basin with sediment thickness of about 9 km including the Asu River Group, Eze-aku, Agwu, Nkporo and Mamu formations
3.	Chad	3.0 - 4.4 °C/100 m; 5.9 °C/100 m	Cretaceous to Quaternary sediments of about 4 to 7 km thick. The basin is made up of marine to continental sediments consisting of Bima Sandstone, Fika Shale, Kerri Kerri, Chad and Gongila Formations
4.	Sokoto	7.5 °C/100 m	
5.	Benue Trough	1.5 - 2.7 °C/100 m	The NE - SW trending synclinorium which contains about 5 km thick Cretaceous to recent marine and continental sediments

Most of the geological contributions via the geothermal information across Nigeria are largely derived from Bottom Hole Temperature (BHT) measurements, analysis of aeromagnetic data, and heat flow studies. The contributions by the variations in the values of the geothermal gradient over the Nigerian geological provinces reflected different structural and stratigraphic settings. For instance, in the Anambra basin (A sub-basin of the southern Benue Trough),

Albian and Maastrichtian sedimentation and fault controlled subsidence and the resultant lithospheric thinning influenced the sediments thickness and the geothermal gradient within the basin (Ema and Elijah 2017). The Geothermal gradient of 1.2 °C/100 m - 7.62 °C/100 m obtained by Adedapo *et al.* (2012) for the Niger Delta Basin from the analysis of subsurface temperatures obtained from borehole logs of six hundred oil wells was a great geological

contribution to the Nigerian geothermal energy potential prospecting. Emujakporue and Ekine (2014) carried out a similar study on the geothermal gradient of Niger Delta Basin using BHT data and obtained values of the Geothermal gradient of the range 13.46 °C /km to 33.66 °C/km. which was attributed to overburden thickness, lithology, tectonic activities (growth faults) and hydrodynamics of the Basin. The geothermal gradients of some geologic formations from the works of Akande, et al., (2011); Kurowska and Schoeneich (2010); & Nwankwo and Ekine (2009) using geological techniques have been summarized in Table 3.

Conclusion

The major problems and barriers to geothermal energy resource development in Nigeria include either lack of or little government focus, technical knowledge, expertise and exposure on the abundant geothermal energy resources in Nigeria. This resulted to limitations in local technological and human resource capacity exploitations and thereby increasing more pressure on the conventional energy resources. Such situation worsens the national energy crises. Despite many documented beautiful reports on the indicated geothermal energy and hydrogeological prospective resources beneath the deep sedimentary basins as well as in some other areas within the crystalline province, such potentials have been left unexploited.

Hence drawing conclusions on the viability of the geothermal energy prospecting, exploitations and exploration using the contributions from the notable geophysical techniques can easily be achieved. Conclusively, well enough evidences abound on the recorded tremendous successes achieved by the application of geophysical methods in the area of geothermal energy resources. This has made the geophysical methods to be an indispensable proxy and valuable tools for any geothermal energy resources exploration campaign.

There has been global increase in the awareness of adopting the geothermal energy as an alternative to other conventional energy sources. This has led to the development of new geophysical exploration techniques which are particularly designed to suit the expected targeted with optimum suitability, capability and convenience. Such notable suitable techniques like; large-scale electrical surveys, passive seismic surveys, analysis of magnetic data to

detect the depth to Curie-point effects, and soil and water geochemical studies etc. have been successfully applied at various locations within Nigeria to uncover and estimate the geothermal energy potentials. Such geophysically delineated areas includes Ikogosi Warm Springs, Kerang Springs, Ngeji Warm Springs, Nike Lake, Wikki Warm Springs, Keana-Awe Thermal Springs, Lamurde Hot Spring also known as Ruwan Zafi Hot Spring, the Rafin Rewa Warm Spring, etc.

Even though, more specific and detailed direct and indirect (geophysical) researches are still needed to ascertain the viability and sustainability of each of the identified geothermal energy potential areas. The clarification of the inception of hotness conveyed by the water to the surface and its general subsurface characterization are also vital requirements that need to be established. Such will provide by proxy an insight regarding those common phenomena and facilitate the investigation and estimation of the geothermal energy potential. This can be achieved by the utilization of the geothermal high temperatures from both the Sedimentary and Precambrian Regions in Nigeria. The outcomes from such further detailed investigation can identify with highest degree of accuracy, the most suitable and convenient Geothermal Energy renewable drill points. This will surely facilitate the opportunity with optimum convenience to establish geothermal energy system plants in order to resolve the Nigerian energy crisis.

It is unfortunate to note that despite the incessant energy crisis and abundant contributory research findings on the Nigerian geothermal energy potentials, yet, there has not been any notable direct application of geothermal energy in Nigeria, even for the production of electricity. However, plan talks have been on to facilitate the construction of geothermal plants in the nation, but it has been suffering serious political bottlenecks and has not yet seen the light of the day. Therefore, the way forward is to have a well-designed, viable Geothermal Energy plans and policies with proper, efficient and sustainable implementation strategies using the right professionals with full autonomy to design and implement the right Geothermal Energy decisions with a view to make the Nigeria energy crises a thing of the past. All these can only be achieved through the immediate establishment of a Nigerian geothermal energy

commission, adequate geothermal energy research funding and immediate installation of geothermal plants to exploit the abundant geothermal energy resources in Nigeria.

REFERENCES

- Abraham, E., Itumoh, O., Chukwu, C. and Rock, O. (2019). Geothermal Energy Reconnaissance of Southeastern Nigeria from Analysis of Aeromagnetic and Gravity Data. *Pure and Applied Geophysics*. Doi: 10.1007/s00024-018-2028-1
- Abraham E. M., Lawal K. M., Ekwe A. C., Alile O., Murana K. A. et al. (2014). Spectral analysis of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring – Ekiti State, southwestern Nigeria. *Geothermal Energy*. Volume 2, pp.1-21.
- Abraham E. M., Lawal K. M. and Akaolisa C. C. Z. (2012). Magnetic analysis to determine the permeability of a geothermal reservoir: Case study of the Ikogosi Warm Spring area, Ekiti, southwestern Nigeria. *Nigerian J Physics*. Volume 23, pp. 121-131.
- Abraham E. M., Owens A. and Murana K. A. (2014). Structural mapping of Ikogosi warm spring area using aeromagnetic derivatives and Euler depth estimates. *International Journal of Natural and Applied Science*. Volume 3, pp. 15-20.
- Abraham E. M., Lawal K. M., Ahmed A. L. and Chii E. C. (2011). Application of analytic signal technique to investigate the geothermal potential of Ikogosi warm spring in Ekiti area, southwestern Nigeria. *ADSU Journal of Scientific Research*. Volume 1, pp. 9-21.
- Abraham E. M., Lawal K. M. and Lawal A. A. (2011). Interpretation of aeromagnetic data for geothermal energy investigation of Ikogosi Warm Spring, Ekiti State, South Western Nigeria. *International Journal of Scientific Research*. Volume1, pp. 103-118.
- Abraham E. M., Obande E. G., Chukwu M., Chukwu C. G. and Onwe M. R. (2015). Estimating depth to the bottom of magnetic sources at Wikki Warm Spring region, northeast Nigeria using fractal distribution of sources approach. *Turkish Journal of Earth Sciences*. Volume 24, pp. 494-512.
- Adedapo J. O., Ikpokonte A. E., Schoeneich K. and Kurwoska E. (2014). An Estimate of Oil Window in Nigeria Niger Delta Basin from recent studies. *American Inter J Contemp Res*. Volume 4, pp. 114-121.
- Adegbuyi O., Ajayi O. S. and Odeyemi I. B. (1996). Prospect of a Hot Dry Rock (HDR) geothermal energy resource around the Ikogosi-Ekiti warm spring in Ondo State, Nigeria. *N J Renewable Energy*. Volume 4, pp. 58-64.
- Akande S. O., Ojo O. J., Adekeye O. A., Egenhoff S. O., Obaje N. G., et al. (2011). Stratigraphic evolution and petroleum potential of middle cretaceous sediments in the lower and middle Benue trough, Nigeria: *Insights from New Source Rock Facies Evaluation*. *Petroleum Technology Development Journal 1*.
- Akinsoji O. O. (2016). The Nigerian power sector investment opportunities and guidelines (Draft). *Federal Republic of Nigeria*.
- Anakwuba E. K. and Chinwuko A. I. (2015). One dimensional spectral analysis and Curie depth isotherm of eastern Chad Basin, Nigeria. *Journal of Natural Sciences Research*. Volume 5, pp. 14-22.
- Anakwuba E., Okeke H., Chinwuko I. and Onyekwelu C. (2016). Estimation of Curie isotherm and heat flow of eastern Chad basin, Nigeria from spectral analysis of aeromagnetic data. *SEG, International Conference and Exhibition, Barcelona, Spain*.
- Avbovbo A. A. (1978). Geothermal gradients in the Southern Nigerian Basin. *Bulletin of Canadian Petroleum Geology*. Volume 26, pp. 268-274.
- Bemsen I. E., Godwin O. A., Kenechukwu A. E., Ifeanyi C. A., Ojonugwa U. A., et al. (2013). Spectral analysis of aeromagnetic data over part of the southern Bida basin, west-central Nigeria. *International Journal of Fundamental Physical Sciences*. Volume 3, pp. 27-31.

- Data commons (2021). Brazil Country in South America Country in South America Population: 211,049,527 (2019) *datacatalog.worldbank.org*. Retrieved from: https://datacommons.org/place/country/BR-A?utm_medium=explore&mprop=count&opt=Person&hl=en
- ECN (2012). Energy Commission of Nigeria: Renewable Energy Master Plan. Abuja, Nigeria.
- ECN (2013). Energy Commission of Nigeria: Renewable Energy Master Plan. Abuja, Nigeria.
- Eletta B. E. and Udensi E. E. (2012). Investigation of the Curie point isotherm from the magnetic fields of eastern sector of central Nigeria. *Geosciences* 2: 101-106.
- Ema M. A. and Elijah E. N. (2017). Review of Geothermal Energy Research in Nigeria: The Geoscience Front. *International Journal of Earth Science and Geophysics*. Volume 3(15), pp.1-10.
- Emujakporue G.O. and Ekine A.S. (2014). Determination of geothermal gradient in the eastern Niger delta sedimentary basin from bottom hole temperature. *Journal of Earth Sciences and Geotechnical Engineering*. Volume 4, pp. 109-114.
- Energypedia (2021). Nigeria energy situation.
- Garba M. L., Kurowska E., Schoeneich K. and Abdullahi I (2012). Rafinrewa warm spring, a new geothermal discovery. *American International Journal of Contemporary Research*. Volume 2, pp. 231-236.
- Kasidi S. and Nur A. (2013). Estimation of Curie point depth, heat flow and geothermal gradient inferred from aeromagnetic data over Jalingo and environs, north-eastern Nigeria. *Int J Sci Emerging Tech*. Volume 6, pp. 294-301.
- Kurowska E. and Schoeneich K. (2010). Geothermal exploration in Nigeria. *Proceedings of World Geothermal Congress, Indonesia*, pp. 25-29.
- Kwaya M. Y., Kurowska E. and Arabi A. S. (2016). Geothermal gradient and heat flow in the Nigeria Sector of the Chad Basin, Nigeria. *Computational Water, Energy, and Environmental Engineering*. Volume 5, pp. 70-78
- Loehnert E. P. (1985). Hydrochemical and isotope data on Ikogosi warm spring southwestern Nigeria. In: *Geothermics, Thermal-Mineral Waters and Hydrology*. *Theophratus Publishers, SA Athens*. Pp. 97-109.
- Mohammed Y. K. and Ewa K. (2018). Geothermal Exploration in Nigeria – Country Update. *Proceedings, 7th African Rift Geothermal Conference Kigali, Rwanda*. pp. 1-11.
- Nwachukwu S. O. (1976). Approximate geothermal gradients in Niger delta sedimentary basin. *AAPG Bulletin*. Volume 60, pp. 1073-1077.
- Nwankwo C. N. and Ekine A. S. (2009). Geothermal gradients in the Chad Basin, Nigeria, from bottom hole temperature logs. *International Journal of Physical Sciences*. Volume 4, pp. 777-783.
- Obande G. E., Lawal K. M. and Ahmed L. A. (2014). Spectral analysis of aeromagnetic data for geothermal investigation of wikki warm spring, north-east Nigeria. *Geothermics*. Volume 50, pp. 85-90.
- Ojo J. S., Olorunfemi M. O. and Felabitta D. E. (2011). An appraisal of the geologic structure beneath the Ikogosi warm spring in southwestern Nigeria using integrated surface geophysical methods. *Earth Sci Res J*. Volume 15, pp. 27-34. 27.
- Omokolade A. (2020). Electricity: Nigeria now has an installed generation capacity of 13,000MW – Minister of Power. *Energy*. Retrieved from: <https://nairametrics.com/2020/10/29/electricity-nigeria-now-has-an-installed-generation-capacity-of-13000mw-minister-of-power/>
- Oyedepo S. O. (2012). Energy and sustainable development in Nigeria: The way forward. *Energy, Sustainability and Society*. Volume 2, pp. 1- 15.
- Olaoye T. Ajilore T. Akinluwade K. Omole F. Adetunji A. (2016). Energy crisis in Nigeria: Need for renewable energy mix. *American*

Journal of Electrical and Electronic Engineering. Volume 4, pp. 1-8.

Olorunfemi M. O., Adepelumi A. A., Falebita D. E., Alao O. A. (2011). Crustal thermal regime of Ikogosi warm spring, Nigeria inferred from aeromagnetic data. *Arabian J Geosciences*. Volume 24.

PWC (2016). Powering Nigeria for the future. *The Power Sector in Nigeria*.