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Review of Geothermal Energy Research in Nigeria: The Geoscience Front

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Abstract

We review geo-scientific research in Nigeria on geothermal energy prospecting. Nigeria's challenging energy needs is overwhelming, with demand exceeding generation. There is inequitable access by the populace to the meager and unstable electricity services in the country. With the main power generating source being gas-fired thermal power stations and despite her increasing population of over 170 million, Nigeria energy generation capacity dwindle to a record low of 2800 MW in year 2016. Alternative energy sources (preferably renewable) promises some form of relief to the current energy challenge. We focus on geothermal resources for the purpose of this study. A direct need in Nigeria for application of geothermal energy is the production of electricity and with numerous geothermal energy potential sites in the country, showing surface heat manifestations; the geothermal energy option presents an attractive and cheaper alternative energy source for Nigeria. In this review, we examine the various research conducted towards establishing useful information for stake holders to enable proper assessment, exploration and exploitation of geothermal energy resources in Nigeria.

Keywords

Review, Geothermal energy, Nigeria, Potentials

Introduction

Energy plays the most vital role in economic growth, progress, and development, as well as poverty eradication and security of any nation. Uninterrupted energy supply is a vital 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 friendly. A lack of access to energy contributes to poverty and deprivation and can contribute to economic decline. Energy and poverty reduction are not only closely connected, but also with the socioeconomic development, which involves productivity, income growth, education and health [1]. Nigeria has one of the lowest consumption rates of electricity per capita in Africa (Figure 1) [2].

In 2015, Nigeria produced around 4,000 MW for a population of over 170 million; with a similar population, Brazil generates 24 times as much. 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 important in the long-term vision of providing secure abundant, cost effective 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) [3]. However, recent evaluation indicates that Nigeria has generation capability of 5,700 MW, 86% of this capability is from gas-fired thermal power stations (Figure 2). The remaining 14% is from the three Large Hydroelectric

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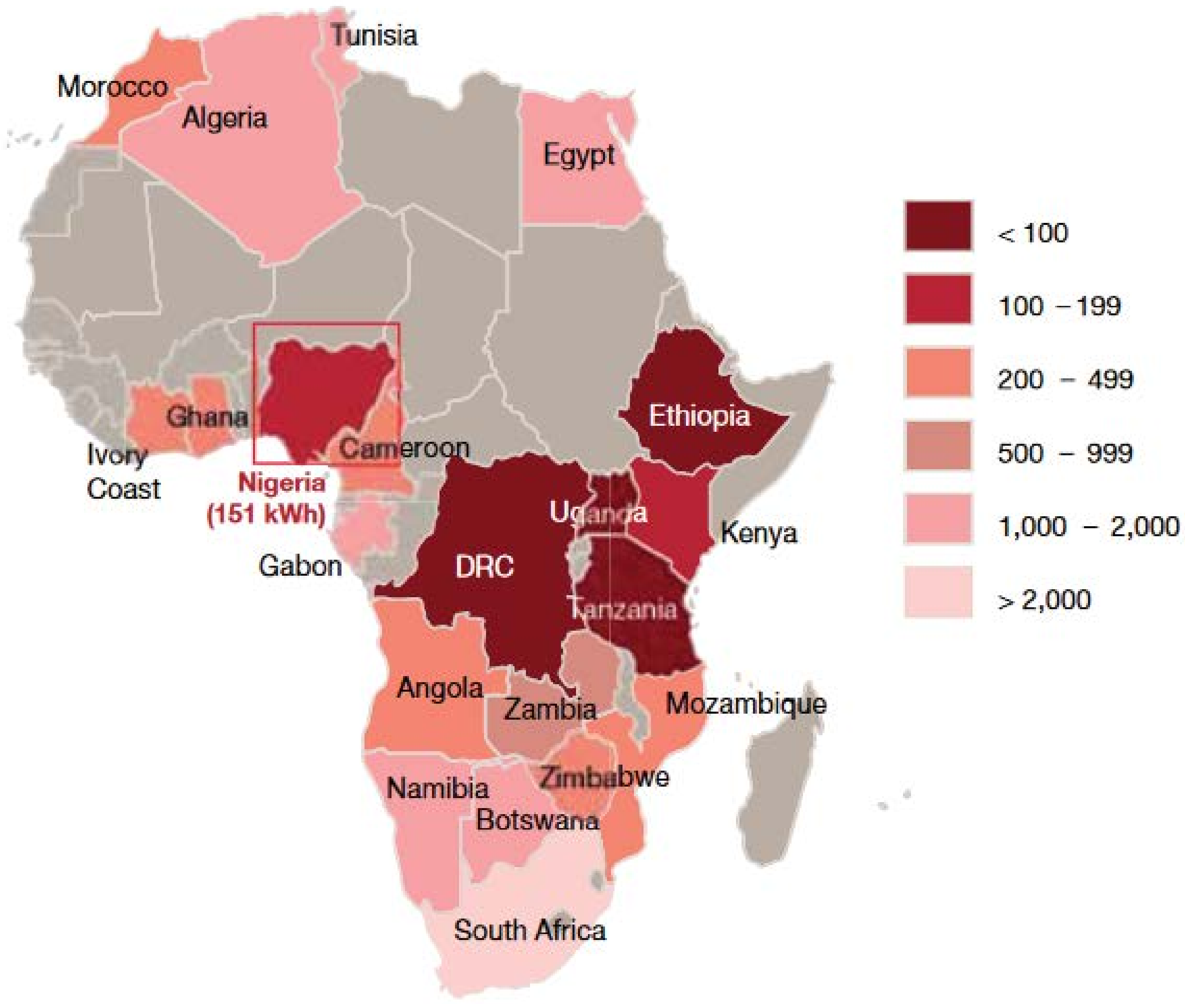

Figure 1: Annual per capita power consumption in selected African countries (kWh), 2015.

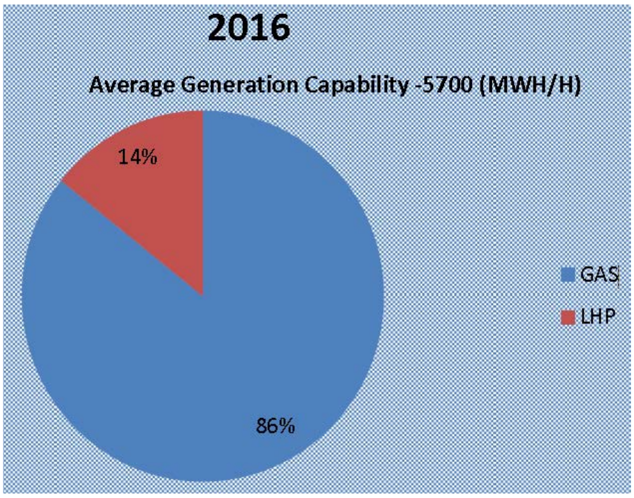

Figure 2: Electricity generation capability of Nigeria and sources [4].

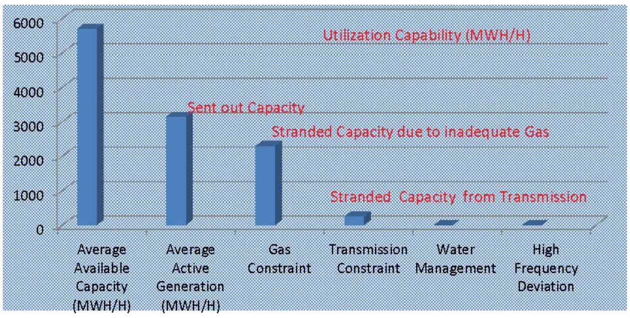

Figure 3: Average utilization capability [4].

Power (LHP) stations in the Country [4]. Figure 3 display the actual average utilization capability of the generated electricity.

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 [5]. At present, there are no 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. Renewable electricity would then account for 10% of Nigerian total energy consumption by 2025 [6]. Table 2 displays a breakdown of the renewable energy potentials with current utilization information according to the ECN 2013 [7] report.

Table 1: Estimates of renewable energy potential in Nigeria (MW) [5].

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**

This review focuses on the geothermal energy investigation in Nigeria with focus on researches that have been conducted so far, their outcome, challenges and the future through the geo-scientific oculus. While we endeavor to cover notable geo-scientific researches' from geological, geophysical and geochemical perspective, our reach is by no means its entirety for the country. It is our wish that this review would stimulate interest in geothermal energy in Nigeria and also invigorate the geo-scientific community toward extensive research in the field. This research should eventually lead to installation of geothermal plants to exploit the resource.

Geology

The geology of Nigeria is widely classified into the Sedimentary Basins and the Basement Complex Rocks (Figure 4). The sedimentary basins include the Benue

Table 2: Renewable energy potential with current utilization capacities in Nigeria [7].

Resource	Potential	Current Utilisation and Further Remarks
Large Hydropower	11,250 MW	1,900 MW exploited
Small Hydropower	3,500 MW	64.2 MW exploited
Solar	4.0 kWh/m²/day - 6.5 kWh/m²/day	15 MW dispersed solar PV installations (estimated)
Wind	2 - 4 m/s 10 m height mainland	Electronic Wind Information System (WIS) available
Biomass (non-fossil organic matter)	Municipal waste	18.5 million tonnes produced in 2005 and now estimated at 0.5 kg/capita/day
	Fuel wood	43.4 million tonnes/yr. fuel wood consumption
	Animal waste	245 million assorted animals in 2001
	Agricultural residues	91.4 million tonnes/yr. produced
	Energy crops	28.2 million hectares of arable land; 8.5% cultivated

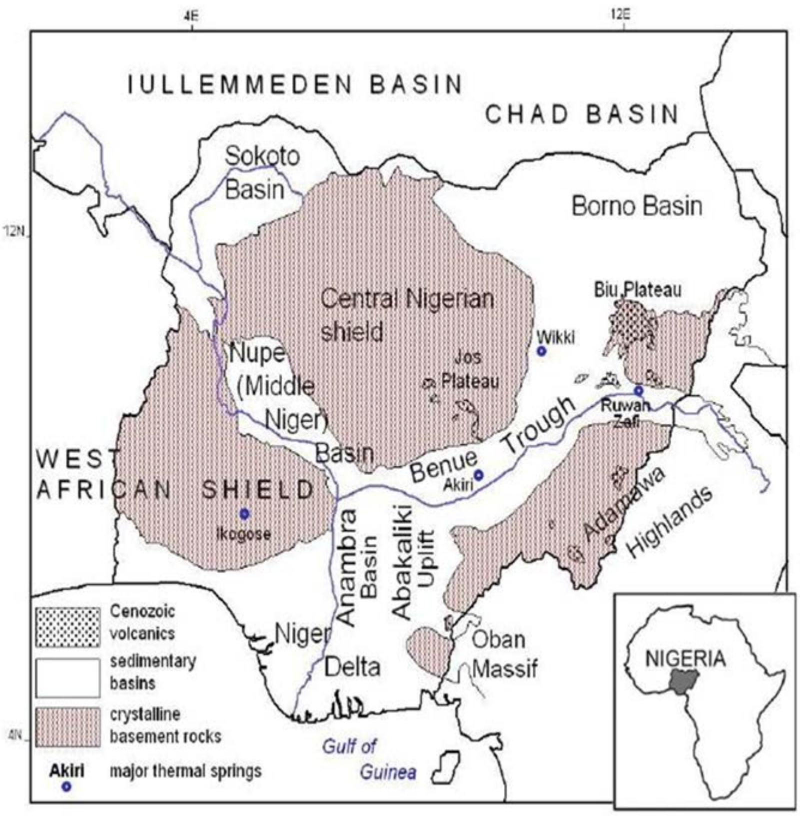

Figure 4: Geological Map of Nigeria showing major structural units and warm springs [9].

Table 3: Geological setting and ambient temperature of some geothermal features in Nigeria.

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)	Hot water	42.5 °C	
3.	Ikogosi Warm Spring	Fractured 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

Trough, a synclinorial structure trending NE-SW and the oil rich Niger Delta Basin as well as the Nupe or Bida, Sokoto and Chad or Borno Basins. The sediments of these basins are largely cretaceous to recent and occupy a Y-shape structure which extends from the north-western and north-eastern part of the country into the Atlantic Ocean where they form a delta. The Basement Complex rocks consist of Precambrian to Lower Palaeozoic igneous and metamorphic rocks with tertiary to recent volcanic rocks. The crystalline rocks are divided into the northern, south-western and south-eastern Basement Complex. The Schist belts (metasediments and metavolcanics) which overlay the basement are dominant in the south-western part of the country [8]. The Basement Complex is intruded by the Pan-African Granites (the Older Granites) and the Jurassic tin bearing granites (the Younger Granites).

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 8 out of the 10 well known thermal or warm springs in Nigeria. 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 [9,10]. The geological setting of some Nigerian geothermal features and resources are summarized in Table 3 (modified from [9,10]).

The geothermal information across Nigeria is largely derived from Bottom Hole Temperature (BHT) measurements, analysis of aeromagnetic data, and heat flow studies. 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 influences the sediments thickness and the geothermal gradient within the basin [11]. 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 [12]. The information derived from the analysis of the Temperature log was used by Adedapo, et al. [12] 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 [13] 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.

The thermal conductivity heterogeneities across the Niger Delta region in Nigeria arises from local variations in the basement heat flow, fluid circulation (groundwater) systems and differences in lithology. Areas with high percentage of sands show anomalously low geothermal gradient compare to those of shale. Low geothermal gradients occur over regions with thick sediment sequences as the rocks act as heat sink dissipating rising subsurface heat from the basement while regions with relatively thin overburden (basement high) have low geothermal gradients. Geothermal gradients of some formations have been summarized in Table 4 using information from Akande, et al., Kurowska and Schoeneich, Nwankwo and Ekine, Onuoha and Ekine [9,14-16].

Geophysics

Majority of geophysical research conducted in the country with respect to geothermal energy prospecting have involved depths determination using magnetic anomaly field data. Other geophysical methods have

Table 4: Geothermal gradients of some formations in Nigeria.

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

not received as much usage as magnetics in the country. Magnetic anomalies are analyzed for estimating the depths to the bottoms of magnetized bodies in the crust. These depths, when contoured for the entire area, could provide a picture of the spatial variation of the Curie isotherm level or Curie Point Depth (CPD). This picture should correlate to a significantly high degree with various known indices of geothermal activity in the area under consideration. Curie depth can be used to complement geothermal data in regions where deep boreholes are unavailable [17]. The thermal structure of the earth's crust is one of the main parameters that controls geodynamic processes. Often, only proxy data are available to derive an idea about the thermal structure of the crust. One important proxy data is the CPD [17,18]. Estimates of the thickness of the magnetized portion of the earth's crust suggest that there are two types of lower boundaries of the layer of 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 [19]. Crustal rocks lose their magnetization at the Curie point temperature. At this temperature, ferromagnetic rocks become paramagnetic, and their ability to generate detectable magnetic anomalies disappears. A region with significant geothermal energy near the surface of the earth is characterized by an anomalously high geothermal gradient and heat flow. It is therefore to be expected that regardless of composition of the rocks, the region will be associated with a conspicuously shallow CPD relating to the adjoining regions isotherm [20]. Subsurface temperature distribution in the southern part of sedimentary province in Nigeria was studied by Nwachukwu, Avbovbo and Onuoha and Ekine [16,21,22]. They used corrected Bottom Hole Temperature (BHT) data measured in 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) or 2.2-2.6 °C/100 m in Warri-Port Harcourt area (Avbovbo). Onuoha and Ekine [16] show diversity in geothermal gradient within Anambra Basin. 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/m^2. The Ikogosi Warm Spring (IWS) located in Ekiti State, issues with a 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 location has enjoyed a lot of academic probing from the geophysical perspective. Notable amongst them are the works of Olorunfemi, et al. [23], Abraham, et al., Ojo, et al., and Abraham, et al. [18,24-28]. These studies 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. [23] and Abraham, et al. [24] had applied spectral analysis method to aeromagnetic data from the region in a bid to determine depths to the bottom of magnetic source (assume Curie Point Depth, CPD). While Olorunfemi, et al. [23] depth ranged between 4.68 and 11.38 km calculated from traverses taken across the maps from the region, Abraham, et al. [24] depth ranged between 2.5 and 12.5 km, calculated from data windows obtained by sampling targeted points on the aeromagnetic map. Heat flow information was computed from the estimated depths using the basic relation for conductive heat transport [29]. In one-dimensional case under assumptions that the direction of the temperature variation is vertical and the temperature gradient dT/dz is constant. The relation for conductive heat transport (Fourier's law) takes the form

$$q = k\frac{dT}{dZ} \tag{1}$$

Where q is the heat flux and k is the coefficient of thermal conductivity. Tanaka, et al. [29] established that the Curie temperature (θ) can be obtained from the Curie point depth (Z_b) and the thermal gradient dT/dz using the following equation;

$$\theta = \left(\frac{dT}{dz}\right) z_b \quad (2)$$

In this equation, it is assumed that the dT/dz is constant. From equation (1) and equation (2)

$$z_b = k\frac{\theta}{q} \quad (3)$$

Any given depth to a thermal isotherm is inversely proportional to heat flow, where q is the heat flow.

The slight variation in depth values [24] may be due to the methods adopted. No independent data (e.g. borehole data) was available to compare results or evaluate the heat flow information from the region. Abraham, et al. [24] evaluated same data using additional parameter of Euler deconvolution, with the aim of mapping distinct geologic features and trends in the region. Abraham, et al. [25] attempted to elucidate the geothermal resources at IWS through delineating the structural setting of the area using geophysical techniques of analytic signal and Euler deconvolution. The analytic signal 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 sources were confirmed. Ojo, et al. [26] appraised the geologic structure beneath the immediate vicinity of the IWS using an integration of resistivity and magnetic methods. Their data was acquired through traverses and interpreted by applying inverse modeling procedure. Their inverse magnetic models were able to delineate fractured quartzite/faulted areas within fresh massive quartzite at varying depths. Their geoelectrical 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 ground water to the surface. This deduction have been made earlier by other authors [30,31].

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 [9]. The data from Borno Basin also included information from several deep oil wells. The data base and map shows 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 suggests a significant source of geothermal heat located below the sedimentary complex in the Precambrian basement and relates to some deep tectonic active structures.

Abraham, et al. [27] examined the reservoir permeability of the IWS area using data along fifteen profiles taken across the region. A detailed analysis of the hydrothermally demagnetized rocks thought to represent the extent of the geothermal reservoir was made. Their study showed that demagnetized rocks have good correlation with reservoir permeability and using this information, they were able to delineate the boundaries of the geothermal reservoir. Their study suggested that demagnetized rocks are mainly associated with high permeability in a geothermal system. Structural features at the IWS region were mapped using aeromagnetic data derivatives and Euler depth estimates by Abraham, et al. [28]. Boundary structures between magnetic units were mapped using tilt derivatives. Dominant trends in the region were identified as following NE - SW and E - W directions. Depths to geologic sources of magnetic field anomalies ranged between 0.6-1.15 km. Results reveal the structural complexity of the region and provided depth information for the mapped magnetic edges. In a robust study involving spectral analysis of aeromagnetic data, analysis of radiogenic composition, tectonics and equivalent depth extent of the IWS region, Abraham, et al. [18] arrived at fascinating results concerning the geothermal potential of the IWS region. Their results presented 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. The low Curie point depth observed at the warm spring source was attributed to magmatic intrusions at depth. They identified a visible older granite intrusion at Ikere - Ado-Ekiti area, with shallow Curie depths (12.37 ± 0.73 km) as evidence for their conclusion.

Another warm spring location in Nigeria that has received geophysical examination is the Wikki Warm Spring (WWS) located in Bauchi State, northeastern Nigeria. Preliminary geophysical investigation of the source of heat of the WWS was conducted by Omanga [32]. He used the electrical resistivity and radiometric methods, employing VES and gamma ray spectrometry around the WWS area. The ultimate aim was to investigate the source of heat at the WWS region. Within the WWS, fourteen (14) sounding were conducted using VES method and measurements of the concentrations of K, U, Th in the area were estimated. His resistivity results showed that rather 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. Estimates of CPD using spectral analysis of residual magnetic data was carried-out by Obande, et al. [33] and

Abraham, et al. [34] for the WWS region. Although the fractal method was adopted by Abraham, et al. [34] for their CPD determination, both studies, shows appreciable shallow CPD values for the WWS region. With an estimated average CPD value of 8 km, Obande, et al. [33] calculated the probable heat flow value as 170 mW/m^2. The fractal approach gave depth values of between 10.18 and 11.26 km and implied a heat flow value of 135.28 mW/m^2. Inferences drawn from both studies suggested that the WWS area was promising for geothermal exploration as temperatures greater than 100 °C could be reached at depths of less than 2 km.

Other notable CPD determinations from other parts of Nigeria (with some not on a geothermal active site) include studies by Elleta and Udensi [35] conducted on the eastern sector of central Nigeria. They adopted the spectral analysis approach to arrive at CPDs ranging between 2 and 8.4 km. This also confirms the regions suitability for further geothermal energy research. Locations around Atsuku, Takum and Wukari have been earmarked as promising areas. Kasidi and Nur [36] estimated CPD and heat flow over Jalingo and environs, northeastern Nigeria using aeromagnetic data. The geology of this region is made up of the Precambrian basement complex considered undifferentiated. The study gave the resulting CPD values ranging between 24 and 28 km and heat flows of between 53 and 61 mW/m^2. Their depths appear higher when compared with other CPD values obtained elsewhere in the country and could be confirmed by the lack of surface signatures in the region. Nevertheless, the study reveals regions of low CPD which could be adopted for further geothermal energy exploration. A one-dimensional spectral analysis and CPD isotherm of eastern Chad Basin of Nigeria was performed by Anakwuba and Chinwuko [37]. CPD realized in the region were of range between 21.45 and 31.52 km. Higher values of CPD on some locations in this region may not provide much hope for geothermal energy prospecting. Bemsen, et al. [38] also analyzed the spectra from aeromagnetic data processing over a part of the southern Bida Basin, west-central Nigeria. They concluded that their result show two depth sources in the area. While the deeper sources range from 2.81 to 3.24 km. lower CPD values betray high geothermal potential of an area.

Spectral analyses of aeromagnetic anomalies have been applied to estimate CPD and heat flow of eastern Chad Basin, Nigeria by Anakwuba, et al. [39]. Their estimated CPD varied between 21.45 km at the Mafa - Bama area and 31.52 km at the Maiduguri - Gwoza area of the region. They also inferred heat flow estimates from the CPD results and suggested that CPD analysis was a useful tool in estimating regional thermal structure of that region. To ascertain the thermal potential of Nigeria sector of the Chad Basin for energy generation, subsurface temperature information from 19 oil wells, 24 water boreholes drilled to depths beyond 100 metres and atmospheric temperature from the Chad basin were utilized by Kwaya, et al. [40]. Selected ditch cuttings from the wells were subjected to thermal conductivity test using Thermal Conductivity Scanner (TCS) at the Polish Geological Institute Laboratory in Warsaw. Their 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 type of study also benefits oil exploration activities in the region. One dimensional spectral analysis of aeromagnetic data over the Anambra Basin, a subsidiary depression within the Benue Trough of Nigeria was performed by Onwuemesi [41]. His CPD varied between 16 and 30 km and geothermal gradients of between 20 and 35 °C/km were computed.

Geochemistry

Adegbuyi and Abimbola [42] performed an extensive research on the energy resource potential of the Ikogosi Warm Spring area using the technique of Instrumental Neutron Activation Analysis (INAA). They investigated the radiochemical contents of Uranium (U), Thorium (Th) and Potassium (K) in surface rocks collection from the area. They predicted the source of the warm spring's heat to be radioactive probably acquired by meteoric water at depth from thorium bearing zones of the quartzite host rock of the spring. Accordingly, Adegbuyi [43] assessed the potential of developing a Hot-Dry-Rock (HDR) geothermal energy technology using 'hot' granites in the area. Samples of the warm spring water and host quartzite rock collected from the Ikogosi area were analysed for the fluid physio-chemical characteristics and rock radioactivity in a bid to predict the source of the water and the associated heat content [30,31,44]. The results were almost similar with predictions made about radioactivity and high geothermal gradient responsible for the heat of the Ikogosi Warm Spring. There is insufficient hydrochemical information on warm springs in Nigeria. Nevertheless, Ikudayisi, et al. [45] performed some hydrochemical analysis of the IWS and presented results as shown in Table 5. Their result showed hydrogen ion concentration (pH), alkalinity, hardness, calcium, magnesium, sodium, Iron, total dissolved solid and heavy metals.

Similar study conducted by Schoeneich [46] on the Rafin Rewa warm Spring produced variations in concentrations of elements (Table 6).

Talabi, et al. [47], in their study towards the sustainability and management of the IWS they evaluated the hydrochemical processes and recharge source of the IWS. Their study approach involved field sampling and *in-situ* measurements of physico-chemical parameters followed by laboratory hydrochemical and stable isotope analyses of the spring water samples. Their hydrochemical analysis revealed that water from IWS is alkaline in nature with values ranging between 7.4 and 9.0. The Total Dissolved Solid (TDS) ranged from 14.3 to 66.8 mg/L while Total Hardness (TH) ranged from 6.3 to 39.0 mg/L. They concluded that rock-water interactions were the dominant processes controlling the major ion composition of the spring while the dominant water was Ca (mg) - Cl type. Four out of the six identified sources of the warm springs around IWS showed close similarity in temperature, pH, dissolved solids, suspended solid, alkalinity, hardness and trace metals [48]. Further study by them had also revealed a time (distance) dependent atmospheric environmental induced variations in the area.

Table 5: Hydrochemical values of the IWS sample collected at source [45].

Parameter	Warm Spring
T °C	36.00
pH	6.37
Alkalinity (ppm $CaCo_3$)	10.0
Ca (ppm)	11.63
Mg (ppm)	6.69
K (ppm)	3.85
Na (ppm)	1.89
Fe (ppm)	0.56
Zn (ppm)	0.34
Pb (ppm)	0.16
TDS (ppm)	0.00
Cl (ppm)	10.65
Carbonate (ppm)	0.00
Bi-carbonate (ppm)	42.7
SS (ppm)	0.99
Hardness (ppm $CaCo_3$)	5.65

The Future

No access to power hinders the country's development in all sectors from education up to industrial production. In 2015, Nigeria produced around 4,000 MW for a population of over 170 million; with a similar population, Brazil generates 24 times as much. South Africa

Table 6: Results of laboratory analysis of Rafin Rewa warm Spring. Column three shows the Non-polluted hydrochemical background [46].

Parameter	Samples from Rafin Rewa Analysed by Glowny Instytut Gornictwa, Katowice	Non Polluted Hydrochemical Background - Meteoric Water from the Crystalline Hydrogeological Province of Nigeria
pH	8.10 (8.3*)	5.0 to 7.4, av. 6.4
Electro-conductivity	350 µS/cm	10 to 75, av. 35 µS/cm
Hardness, Permanent	0.0 mg/l $CaCO_3$	0.0 mg/l $CaCO_3$
Alkalinity "M"	3.40 meq/l	10 to 40, av. 20 mg/l $CaCO_3$
Metabolic Acid	0.093 mg/l	No data exist
Metasilic Acid	90.2 mg/l	No data exist
Total Dissolved Solids	214 (240*) mg/l	14 to 250, av. 60.0 mg/l
Calcium	1.50 mg/l	0.3 to 33.0, av. 10.0 mg/l
Magnesium	0.06 mg/l	0.1 to 5.8, av. 1.0 mg/l
Sodium	88.51 mg/l	0.8 to 20.0, av. 5.0 mg/l
Potassium	1.64 mg/l	0.3 to 6.0, av. 3.0 mg/l
Iron	0.03 mg/l	0.01 to 1.50, av. 0.30 mg/l
Manganese	0.001 mg/l	0.003 to 0.100, av. 0.02 mg/l
Ammonia	< 0.05 mg/l	0.04 to 10.50, av. 2.40 mg/l
Barium	< 0.005 mg/l	No data exist
Strontium	< 0.05 mg/l	0.00 to 0.02, av. 0.006 mg/l
Chloride	6.17 mg/l	0.00 to 6.00, av. 1.28 mg/l
Sulphate	3.66 mg/l	0.00 to 2.70, av. 0.60 mg/l
Sulphides	< 0.01 mg/l	No data exist
Carbonate	< 0.00 mg/l	0.02 to 0.04 mg/l
Bicarbonate	207.0 mg/l	8.00 to 100.00, av. 35 mg/l
Nitrate	1.73 mg/l	0.00 to 19.0, av. 3.0 mg/l
Nitrite	< 0.02 mg/l	0.00 to 0.006, av. 0.01 mg/l
Bromine	< 0.05 mg/l	< 0.005 mg/l
Iodine	< 0.1	
Fluoride	7.54 mg/l	0.000 to 1.20, av. 0.30 mg/l
Arsenic	< 0.005 mg/l	0.006 - 0.010 mg/l
Chromium	< 0.001 mg/l	0.000 - 0.040, av. 0.017 mg/l
Zinc	0.003 mg/l	0.002 - 0.007, av. 0.004 mg/l
Cadmium	< 0.001	0.0001 - 0.0021, av. 0.0004 mg/l

*Indicates *in situ* measurements [10].

consumes 55% more energy per capita than Nigeria [49]. Unreliable power supply leaves Nigeria with no other option than to explore alternative energy sources apart from the hydro and gas based power plants currently in use. A more detail investigation on thermal springs should explain the origin of heat transported by the water to the surface and the depth of water circulation. This can provide a panacea to the current energy challenge in the country. Nigerian Government should implement policies to encourage relevant agencies towards ensuring that more data and information relating to geothermal resource are obtained through Research and Development (R&D) programmes with a view to immediately commence utilizing this resource to generate power for her citizens. The future should bring with it the establishment of geothermal power plants in the country trough proper guidance from the various geothermal energy researches in the country-reliable information on possible potentials for usage of geothermal energy in Nigeria. Geothermal energy sources could provide a panacea to the current energy challenge in the country. Nigerian Government should implement policies to encourage relevant agencies towards ensuring that more data and information relating to geothermal resource are obtained through research and development (R&D) programmes with a view to immediately commence utilizing this resource to generate power for her citizens. The future should bring with it the establishment of geothermal power plants in the country trough proper guidance from the various geothermal energy researches in the country.

Conclusion

We have assessed the various researches conducted on geothermal energy prospects in Nigeria from the geo-scientific perspective. Geological assessment shows that geothermal manifestations in the Nigerian geological terrain can be broadly group into two settings: The basement complex and the sedimentary geothermal Provinces. The geology of the warm springs is associated with magmatic volcanism and faulting. The geophysical outlook presents varying depth information which could be used to proffer heat flow data for the locations investigated. However, proper inspection is advised to arrive at the final choice of depth information to adopt. The geochemical approach provided the compositional analysis of samples from some of the geothermal sites. This implies that not only energy generating information has been achieved; other usages could be obtained as useful compounds could be extracted from samples to assist in understanding the formation sequence, mineral content and transport network existing within the subsurface.

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