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# Geothermal Energy Resource Potential of Nigeria's Sedimentary Basins

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## ABSTRACT

The geology of Nigeria is dominated and made up of two main rock types: basement complex and sedimentary basins, which are equally dispersed. Minor formations are the volcanic plateaus and the river alluvium. The sedimentary rocks overlying the basement complex of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin. Oil exploration activities, especially in deep basins of the Niger Delta and the Chad Basin, has resulted in acquiring subsurface geo-information including well-log data in which some borehole temperature data have been recorded among others. Research studies and analysis of data from the oil exploratory wells indicate potential for geothermal energy in some of the basins. The geothermal gradients of the Eastern Niger Delta obtained from bottom hole temperature vary from 13.46°C/km to 33.66°C/km with an average of 23.56°C/km. Other studies in the Niger Delta indicate geothermal gradient in the basin ranges from 1.2°C to 7.56°C/100m. More than ten authors working in the Chad Basin over the last three decades had reported an established regional average geothermal gradient of 3°C/100m and above, in some places the gradient is up to 5.88°C/100m. Temperatures of 100°C to 175°C were obtained at 1200 to 2600 meters below ground level (m b.g.l.) in some part of the Nigerian sector of the Chad Basin, the results also indicate temperature of up to 250°C at the top of the basement complex, up to 85°C at the Cenozoic unconformity, up to 200°C at depth of 3000m b.g.l. and up to 320°C at the depth of 5000m b.g.l. A geothermal gradient value of about 5.5°C/100m was also reported in the Anambra Basin. In the Sokoto Basin geothermal gradient reported varies between 20.84 and 52.11 °C/km with an average of 33.99 °C/km.The subsurface temperature analyses let to assess some geothermal resources, especially for the Nigerian sector of the Chad Basin. The Cenozoic formation contains the unit geothermal resources ranging from 5GJ/m$^2$ to 85GJ/m$^2$ and the subsurface rock interval down to the accessible depth of 3000m b.g.l. contains resource value of 400GJ/m$^2$ to about 1200GJ/m$^2$. The geothermal resources in the Chad Basin area stored in the rock mass down to the deepest considered level (5000m) were estimated at 1.908E+23J. This paper presents the status of knowledge as for geothermal energy exploration and potential in some Nigeria's deep sedimentary basins. The geothermal analysis based on geothermal gradients indicated geothermal anomalies within sedimentary basins. The areas of geothermal anomalies with gradients above 5°C/100m might be prospective for geothermal energy utilization. So far there is no electricity generation from geothermal resources in Nigeria and it is the most needed application of geothermal energy in the country. However, there are the sites where the recreational centers were developed on the basis of well-known geothermal springs which must be categorized as the geothermal direct use in Nigeria. These are Ikogosi Warm Springs Resort in Ikogosi town, Ekiti State (SW Nigeria) and Wiki Spring Resort in Yankari National Park, Bauchi State (NE Nigeria).

## 1. INTRODUCTION

Nigeria is a Federal Republic with presidential system of government, the Federal government comprises of legislative, executive and judicial arms whose powers are assigned by the constitution of Nigeria, the National Assembly, the president and the Federal Courts. The president exercised the executive power.

On electricity production in Nigeria, there are 23 grid-connected generating plants in operation in the Nigerian Electricity Supply Industry (NESI) with a total installed capacity of 10,396.0 MW and available capacity of 6,056 MW. Most generation is thermal based, with an installed capacity of 8,457.6 MW (81% of the total) and an available capacity of 4,996 MW (83% of the total). Hydropower from three major plants accounts for 1,938.4 MW of total installed capacity (and an available capacity of 1,060 MW), (Onochie et al 2015).Different sources of energy in Nigeria are presented in Figure 1.

Geothermal resources exploration in Nigeria is still at it infancy. Geothermal energy which is an alternative source that may contribute to the Nigeria energy source have not been given due consideration.

In 2012 selected staff of the Energy Commission of Nigeria (ECN) were invited to Kenya to attend the "Short course VII on Exploration for Geothermal Resources" organized by the United Nations University–Geothermal Training Programme (UNU-GTP), in collaboration with Kenya Electricity Generation Company (KenGen) and Geothermal Development Company (GDC). This feat is among the steps that prompted Nigeria to join the global quest for geothermal resources. A Geothermal Unit was then established at the National Centre for Petroleum Research and Development (NCPRD) in the year 2013. The Geothermal Unit was primarily saddled with the responsibility of promoting the development of geothermal energy in Nigeria, collaborating with national and international stakeholders, and serving as a repository for geothermal researches.

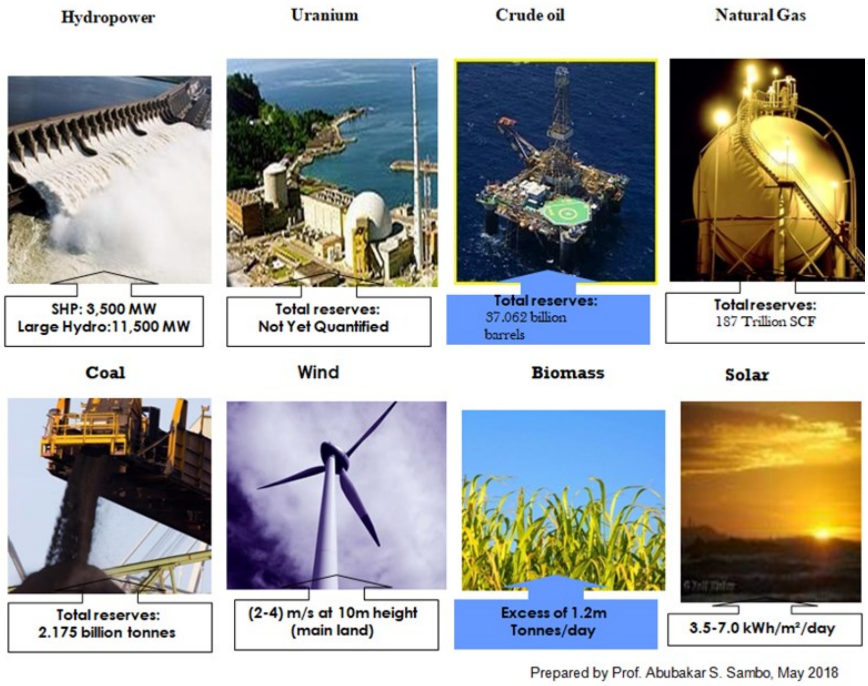


**Figure 1: Energy resources in Nigeria.**

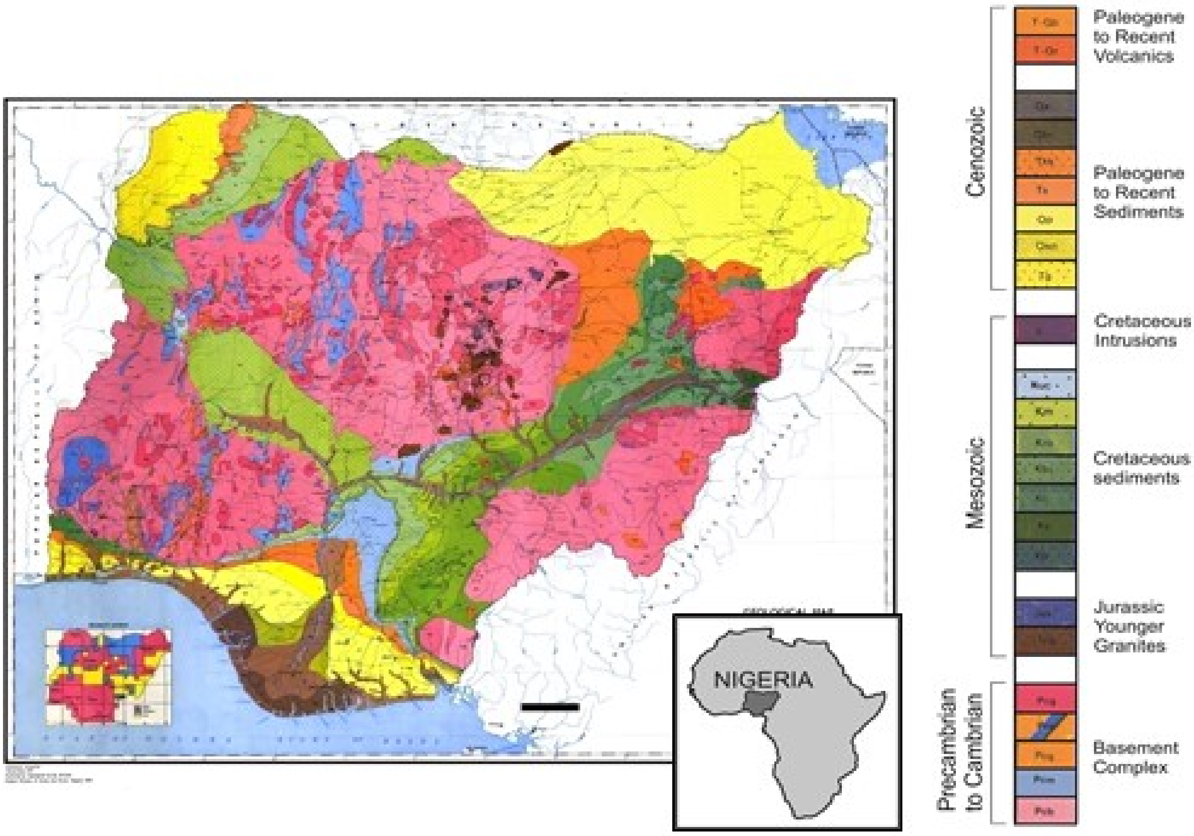


**Figure 2: Geology of Nigeria (after Nigeria Geological Survey, 1974, slightly modified).**

## 2. GEOLOGICAL SETTINGS

Nigeria is lying within the Pan African mobile belt in between the West African and Congo cratons, geologically Nigeria is dominated and made up of two main rock types: Precambrian and Mesozoic to Tertiary Basement complex and volcanic rocks and the Mesozoic to Tertiary sedimentary basins, which are equally dispersed (Figure 2). Other minor formations are younger granites which comprise several Jurassic magmatic ring complexes centered around Jos and other parts of north-central Nigeria. They are structurally and petrologically distinct from the Older Granites (Obaje, 2009).Along the river channels there are Quaternary to Recent alluvial deposits. In the basement complex terrain rock types are predominantly of migmatitic and granitic gneisses, quartzites, slightly migmatised to unmigmatised metasedimentary schists and dioritic rocks (Rahaman,1989). The sedimentary rocks overlying the basement complex consists of arkosic, gravely, poorly sorted and cross-bedded sandstones (Cretaceous and Tertiary).The sedimentary basins, containing sediment fill of Cretaceous to Tertiary ages, comprise the Niger Delta, the Anambra Basin, the Lower, Middle and Upper Benue Trough, the Chad Basin, the Sokoto Basin, the Mid-Niger (Bida-Nupe) Basin and the Dahomey Basin. Many research studies from many angles indicates potentials for geothermal resources in the Nigeria's deep sedimentary Basins and some thermal springs even within the crystalline province.

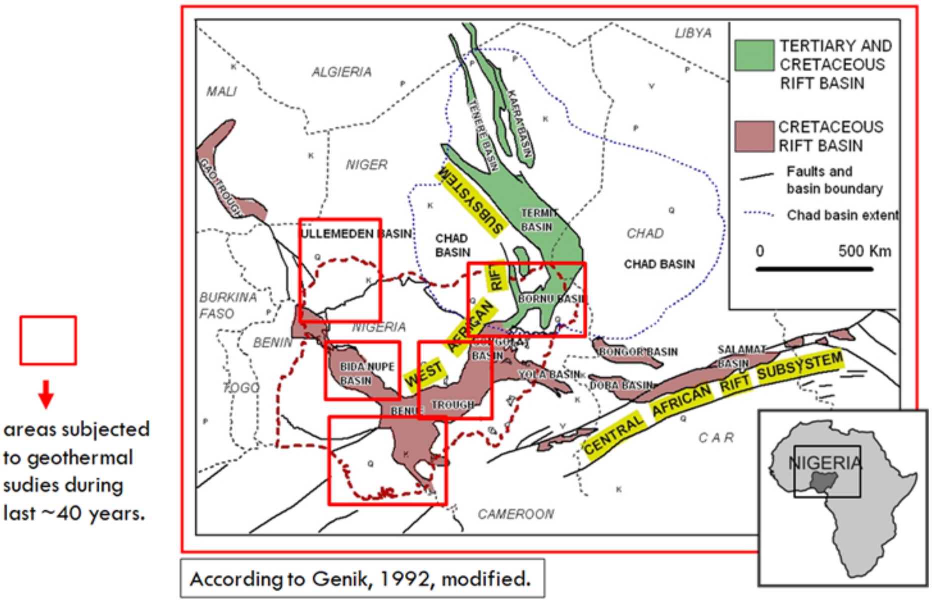


**Figure 3: Regional geological setting of Nigeria with rift subsystems.**

## 3. GEOTHERMAL RESOURCES AND POTENTIAL

The sedimentary basins investigated for geothermal occurrence include: Chad Basin, Sokoto Basin, Niger Delta Basin, Anambra Basin and Middle Benue Trough (Figure 3).There are several known and unknown thermal springs in Nigerian; few were reported within the crystalline province and some within the Middle Benue Through.

More than ten authors working in the Nigerian Chad Basin over the last three decades had reported an established regional average geothermal gradient of 3˚C/100m and above, Figure 4. Some of the reported geothermal gradients in the Chad Basin are shown in Table 1 below.

Temperatures of 100°C to 175°C were obtained at 1200 to 2600 meters below ground level (m b.g.l.) in some part of the Nigerian sector of the Chad Basin, the results also indicate temperature of up to 250°C at the top of the basement complex,(figure 5) up to 85°C at the Cenozoic unconformity,(figure 6) up to 200°C at depth of 3000m b.g.l. and up to 320°C at the depth of 5000m b.g.l. (Figure 7).

**Table 1: Some reported geothermal gradients in the Chad Basin.**

| Authors | Geothermal gradient |
|---|---|
| Askira and Schoeneich,1987 | 3°C/100m to 6.44°C/100m |
| Kwaya et al, 2005; 2016 | 2.81˚C/100 m to 5.88˚C/100m |
| Nwazeapu, 1990 | 2.16˚C/100m to 5.26˚C/100m |
| Nwankwo et al, 2009 | 3.0˚C/100m to 4.4˚C/100m |
| Olugbemiro and Ligous,1999 | 3.1˚C/100m to 4.2˚C/100m |
| Nwankwo and Ekine, 2010 | 3.4˚C/100m (mean) |
| Umar, 1999 | 3.31˚C/100m (mean) |

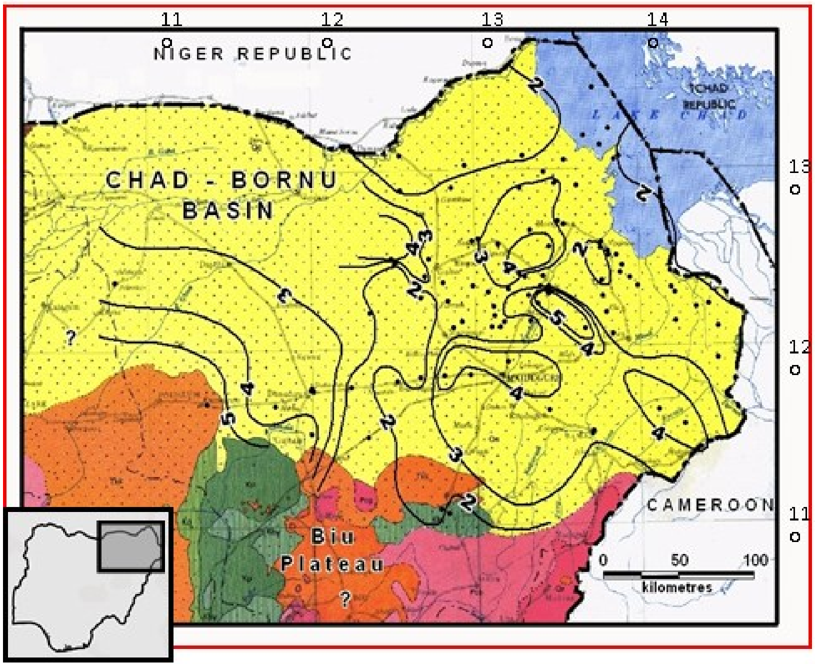


**Figure 4: Geothermal gradient in Nigerian sector of Chad Basin on a background of Geological Map of Nigeria by Geological Survey Division, Federal Ministry of Mines and Power, Nigeria, 1974. Based on temperature data from water wells and oil exploration wells collected by Askira&Schoeneich, 1987; Kwaya et al, 2005.**

The Cenozoic formation contains the unit geothermal resources ranging from 5GJ/m$^2$ to 85GJ/m$^2$ and the subsurface rock interval down to the accessible depth of 3000m b.g.l. contains resource value of 400GJ/m$^2$ to about 1200GJ/m$^2$(table 2). The geothermal resources in the Chad Basin area stored in the rock mass down to the deepest considered level (5000m) were estimated at 1.908E+23J.

Map of geothermal gradient in the Nigerian part of the Iullemmeden Basin based on temperature data from 76 water wells collected by Olatunji, 1989 is presented in Figure 8.Olatunji reported that "peak of the geothermal gradient is marked by the geothermal gradient of 13˚C/100m compared to a general value of about 4˚C/100m outside the anomalous zone.The Niger Delta geothermics was investigated by Nwachukwu (1976), Avbovbo (1978), Onuoha and Ekine (1999), (Figure 9). Later, Idara (2009) used two hundred and sixty wells in the Niger Delta to determine thermal rock properties and heat flow. According to his findings thermal conductivity varies with depth due to variable lithology and water content, from 8W/mK in the Benin formation to 5 W/mK in the marine shale formation. Thermal conductivity calculations were based on assumed matrix conductivity of sand 6.1W/mK and shale 2.1W/mK, predominant lithologies in the Niger Delta. Heat flow derived from thermal conductivity estimates at the central part of the Delta is 20 – 30 mW/m$^2$, it increases both seaward and northward to 40 - 55 mW/m$^2$. Olumide (2013) also analyzed temperature data from boreholes of the Niger Delta and created series of geothermal maps – the map of geothermal gradient is presented in Figure 6. The values range from 1.2°C/100m to 7.56°C/100m. Six geothermal anomalies were observed. His preliminary estimates of geothermal energy resources in depth interval 0-4000 m in the Niger Delta indicated a range of resource value between 400 GJ/m$^2$ to 1250 GJ/m$^2$. Based on sub-surface temperature (bottom hole temperature) from oil wells, Otobong and Onovugve (2016) derived a geothermal gradient of 1.3°C to 5.5°C/100m in the Niger Delta. A geothermal gradient value of about 5.5$^o$C/100m was obtained in the Anambra Basin by Onuoha and Ekine (1999) (Figure 9).

Bako (2010) intensively documented the surface geothermal manifestations in the Middle Benue Trough in Nasarawa State; 150 boreholes and seven thermal springs were studied. Thermal springs investigated and reported includes; Akiri, Awe, Keana, Ribi, Kanje and Azara, and thermal free flowing boreholes in Assakio and Giza. Akiri thermal spring has the highest temperature 53.5$^o$C. Water from the thermal springs was sampled and analyzed, apart from Azara and Kanje thermal springs that are of meteoric origin, the remaining (5) are of connate origin with mineralization as high as 6644-50736 mg/l. Water of warm spring in Akiri (Middle Benue Trough) as well as Ruwan Zafi (Upper Benue Trough) in Nigeria have the temperature of about 54$^o$C suggesting occurrence of some geothermal anomalies Kurowska and Schoeneich, 2010). Bako (2010) further plotted the results in form of geothermal gradient map and several positive geothermal anomalies were observed with the highest (9.3 °C/100m) around the Awe anticline. These springs are indicators of probable high geothermal potential within the sedimentary hydrogeological province of the Middle Benue Trough of Nigeria. It is worth mentioning that the warm springs of the Middle Benue Trough were also investigated in terms of suitability for curative purposes by Nghargbu et al (2011; 2017). The recreational use of the geothermal waters is known worldwide, even in Nigeria (in Ikogosi and Wikki areas).

There are several known and unknown thermal springs in Nigeria; the two warm springs were reported within the crystalline province: Rafin Rewa near Saminaka (Garba et al, 2012) and Ikogosi; and some occur within the Middle and Upper Benue Through (they were mentioned above). Ikogosi warm spring in Ekiti State and the Wikki warm spring in Bauchi State are the best known warm springs in Nigeria.

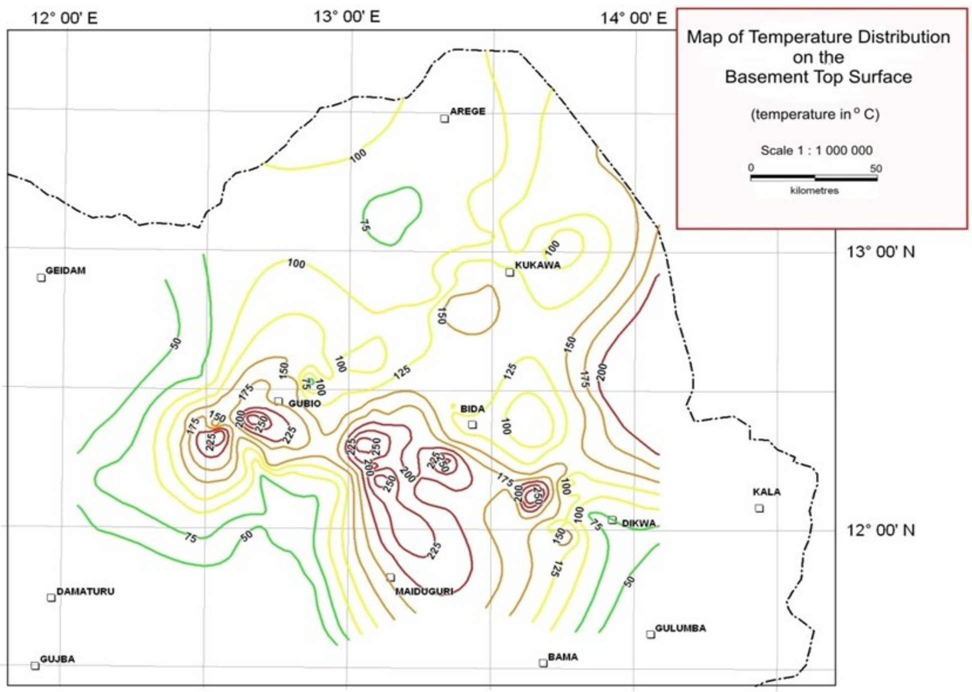


**Figure 5: Temperature distribution on the Basement top surface in the Nigerian Chad Basin**

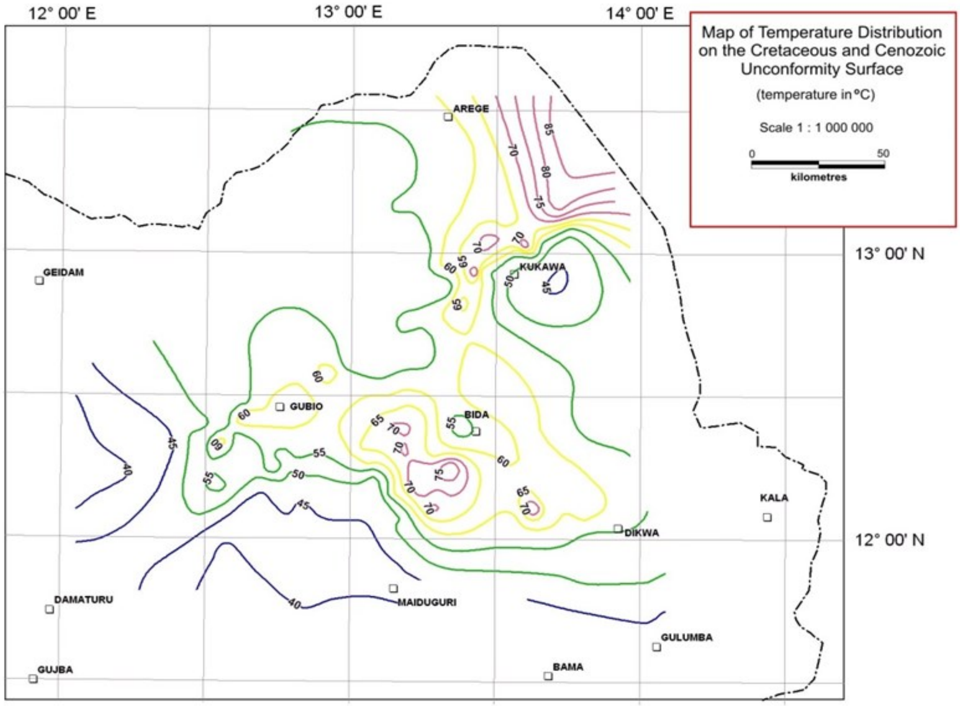


**Figure 6: Temperature distribution on the Cretaceous and Cenozoic unconformity in the Nigerian Chad Basin**

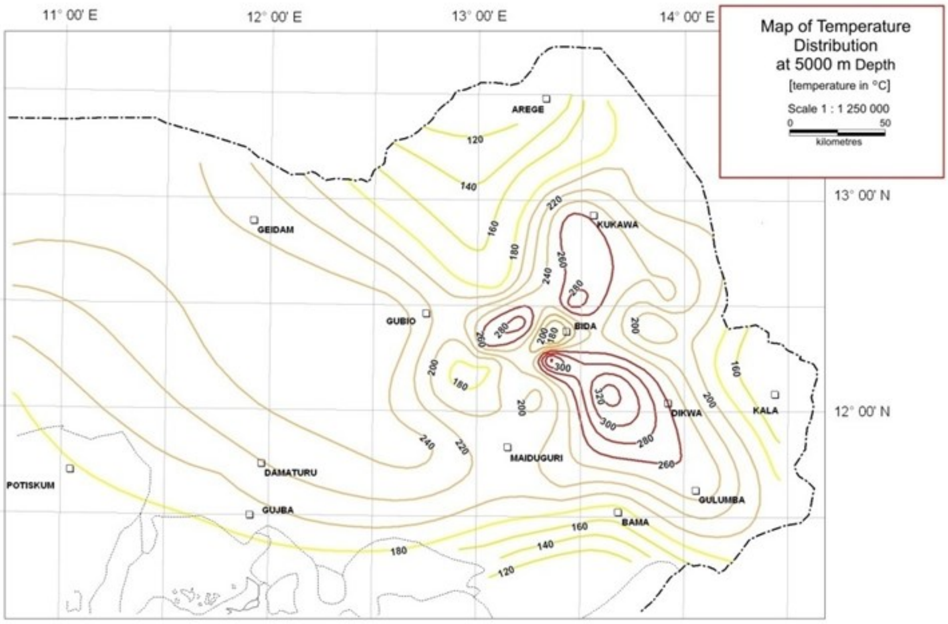


**Figure 7: Temperature distribution at 5000 m depth in the Nigerian Chad Basin**

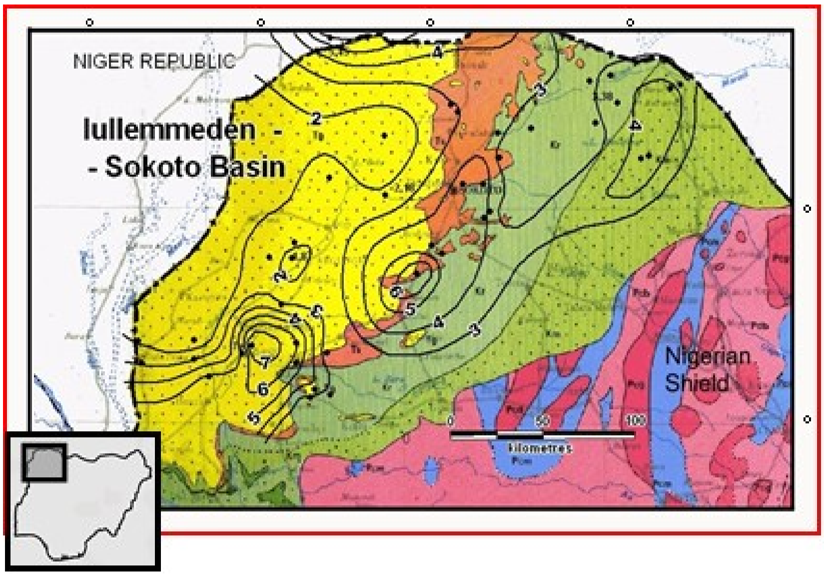


**Figure 8: Geothermal gradient in Nigerian part of Iullemmeden Basin (Sokoto) based on temperature data from water wells collected by Olatunji (1989), geological background by Nigeria Geological Survey, 1974.**

**Table 2: Results showing various values of geothermal resources in the Nigerian Chad Basin.**

| **Geothermal resources** | **Complete value** ( J ) | **Range of unit values (per square metre)**( GJ/$m^2$ ) |
|---|---|---|
| Accessible geothermal resources down to 1000m b.g.l. | 1.023E+22 | 75 – 150 |
| Accessible geothermal resources down to 3000m b.g.l. | 7.260E+22 | 400 - 1200 |
| Accessible geothermal resources down to 5000m b.g.l. | 1.908E+23 | 750 - 3000 |
| Total geothermal resources stored in sedimentary rock mass in the central part of Nigerian sector of Chad Basin | 8.760E+21 | 100 - 1250 |
| Total geothermal resources stored in Cenozoic sediments in the central part of Nigerian sector of Chad Basin | 9.779E+20 | 5 - 85 |

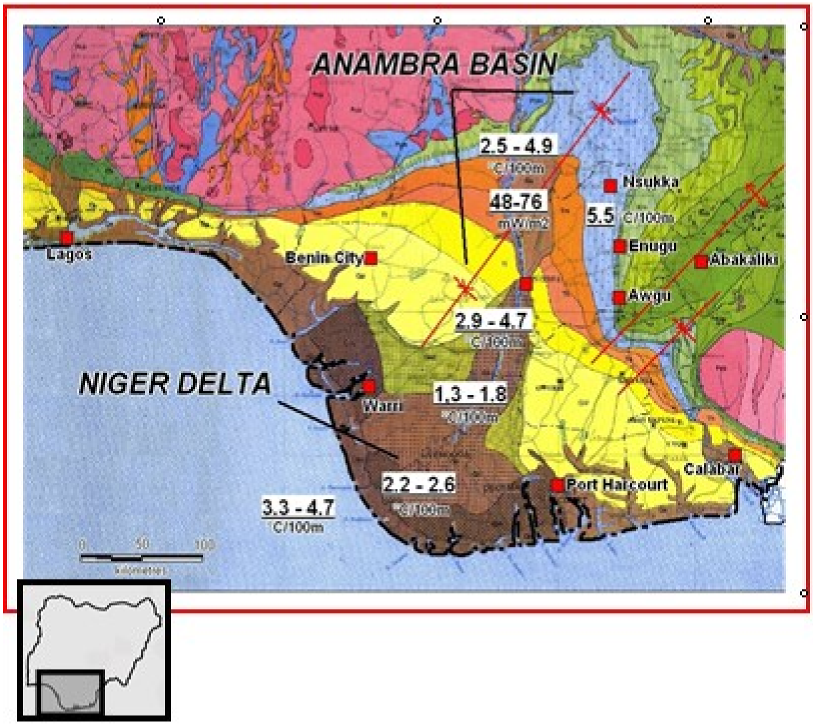


**Figure 9: Geothermal gradients in southern Nigeria. Gradient calculations by Nwachukwu (1976), Avbovbo (1978), Onuoha and Ekine (1999) on the background of Geological Map by Nigerian Geological Survey, 1974.**

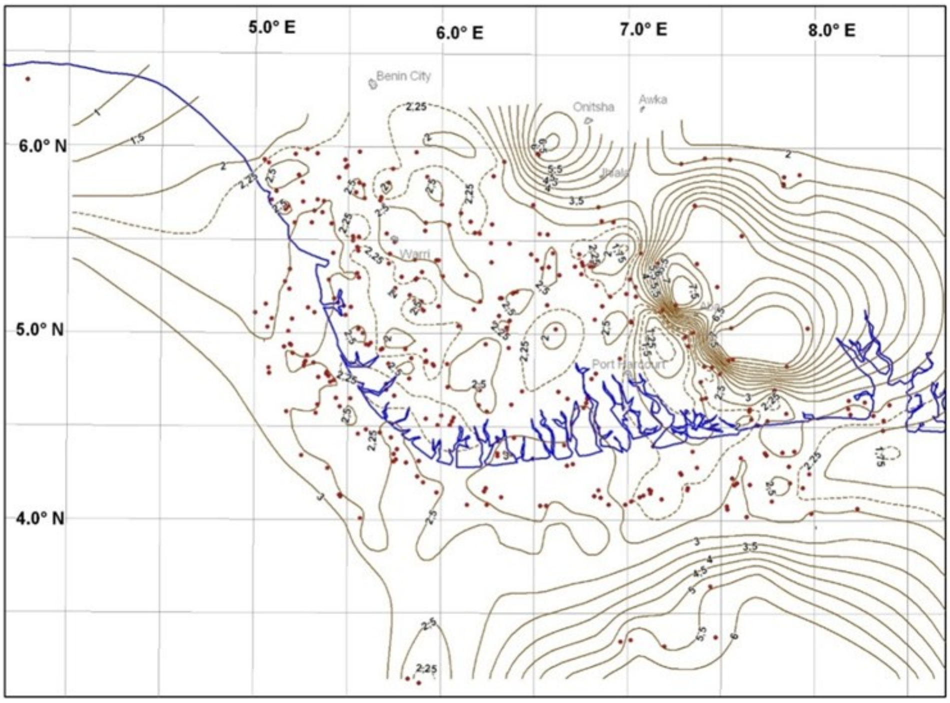


**Figure 10: Geothermal gradient map of Niger Delta Basin (in °C/100m) and location of boreholes with temperature data used for the construction of this map (Olumide, 2014).**

## 4. GEOTHERMAL DIRECT UTILIZATION

The most needed application of geothermal energy in Nigeria would be production of electricity, but there is no electricity generation from geothermal resources in Nigeria up to this moment.

However, there are the sites where the recreational centers were developed on the basis of well- known geothermal springs which must be categorized as the geothermal direct use examples in Nigeria. These are Ikogosi Warm Spring Resort in Ikogosi town, Ekiti State (SW Nigeria) and Wiki Spring Resortin in Yankari National Park, Bauchi State (NE Nigeria).

The Ikogosi warm spring has a temperature of about $70^{o}$C at the source and $37^{o}$C after meeting water stream from another cold spring. The meeting point of the warm and cold springs is a unique attraction to tourists. There is a swimming pool filled with the water from the spring as well as accommodation facilities for tourist in the resort.

The Wikki warm spring has a temperature $32^{o}$C and the swimming place for the tourists is developed directly by the cave from which the water is flowing. The banks of the stream providing water directly from the spring are strengthened by the concrete as it is shown in Figure 11. The Wikki spring is one of the many extraordinary attractions in the resort (the other ones are the wildlife, forest, remnants of the primitives life). There is the hotel – holiday cabins in co-called Wikki camp for tourists visiting the site.

Out of the water temperature, another unique quality of the Ikogosi and Wikki warm springs is the acclaimed curative power. It is widely-believed to have some kind of therapeutic effect which relieves body aches and all sorts of ailments. The beauty of the areas, peculiarity of the geothermal spring phenomenon and belief on the curative properties of the water make tourists come in large number to the resorts.

**Figure 11: Wikki warm spring in Yankari National Park, Bauchi Nigeria.**

**Figure 12: Ikogosi warm spring, Ekiti, Nigeria (photo by Laaro Babatunde).**

## 5.CONCLUSION, PROSPECT FOR FUTURE DEVELOPMENT AND WAY FORWARD

Most sedimentary fills of the Nigerian sedimentary basins are deep enough for attainment of geothermal field, many geological structures suggest same, the temperature gradient and subsurface temperatures are adequate for geothermal resource that might be exploited and used for some purposes. Different useful temperatures at varying depths and locations suggest occurrence of geothermal resources for different applications.

Geothermal Exploration in Nigeria is only skeletal and mostly academic researches. The most needed application of geothermal energy in Nigeria would be production of electricity, but the real possibility of that and potential assessment need further research. The possibility of electricity production is not obvious, as there is no active volcanic zones in Nigeria. However, the technology known as 'geothermal binary power generation system' might be feasible, if the area with proper geothermal and hydrogeological conditions is found, especially on the already discovered geothermal anomalies on Nigeria's deep and hot sedimentary basins.

More detail investigation on thermal springs should explain the origin of heat carried by the water to the surface and the depth of water circulation. It will give an idea about those natural phenomena and contribute to the exploration for possibilities of use of geothermal heat from both sedimentary and Precambrian Provinces in Nigeria

As geothermal energy is not widely known in Nigeria, public outreach and acceptance associated with this energy is a key factor for its Exploration and Exploitation. Government should put in place a project with a time frame that will come out with a Strategic Geothermal Resource assessment in Nigeria. Geothermal Energy Resources to be integrated in the national energy development plan. The private sector should be encouraged to participate in geothermal energy development projects. It is necessary to establish a geothermal Energy research center in few and capable Universities with the vision for the Centre to provide urgent, forward looking research, development and support for establishment of geothermal energy as a clean energy option through a program of research.

Further activities that may lead to a practical use of geothermal energy should comprise drilling or recovery of old borehole aimed at recognition of the geological, hydrogeological and thermal parameters necessary for geothermal modelling and design.

There is a reliable possibility of development the recreational and curative use of the very low temperature geothermal waters as it meets great interest from the society in those places where such type of activity has been already built up.

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**APPENDIX**

**TABLE A. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY IN NIGERIA.**

| | Geothermal | | Fossil Fuels | | Hydro | | Nuclear | | Other Renewables (specify) | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr | Capacity MWe | Gross Prod. GWh/yr |
| In operation in December 2019 | 0 | 0 | 9 602 | 25 494 | 1 563 | 4 150 | 0 | 0 | 0 | 0 | 11 165 | 29 644 |
| Under construction in December 2019 | 0 | 0 | 690 | 3 022 | 3 830 | 16 775 | 0 | 0 | 0 | 0 | 4 520 | 19 798 |
| Funds committed, but not yet under construction in December 2019 | 0 | 0 | 0 | 0 | 40 | 175 | 0 | 0 | 30 | 131 | 70 | 307 |
| Estimated total projected use by 2020 | NA | NA | 20 000 | 87 600 | 5 690 | 24 922 | NA | NA | 1 000 | 4 380 | 26 690 | 116 902 |

**TABLE B. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT IN NIGERIA AS OF 31 DECEMBER 2019 (other than heat pumps)**

| Locality | | Type[1] | Maximum Utilization | | | | | Capacity[3] | Annual Utilization | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Flow Rate | Temperature (ºC) | | Enthalpy[2] (kJ/kg) | | | Ave. Flow | Energy[4] | Capacity |
| | | | (kg/s) | Inlet | Outlet | Inlet | Outlet | (MWt) | (kg/s) | (TJ/yr) | Factor[5] |
| Yankari National Park, Wikki Camp | Bauchi State | B | natural flow unknown | 32 | probably 30 | | | | | | |
| Ikogosi Warm Spring Resort in Ikogosi | Ekiti State | B | 56.64 kg/s | 37 | probably 35 | | | | | | |
| **TOTAL** | | | | | | | | | | | |

[1] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting
H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)