An Overview of Geothermal Energy Resources in Nigeria

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Abstract
The epileptic electricity power supply has become a fundamental issue affecting the economic development of Nigeria. Geothermal energy, which results from the radioactive decay of minerals within the Earth's core and solar energy absorbed at the surface, have been discovered and are being utilized by several countries. Nigeria is still far behind in tapping the abundance of geothermal energy resources. Ikogosi warm spring in Southwestern Nigeria is a good geological evidence of potential geothermal energy. Hydrothermal reservoirs can serve as a sustainable potential source of energy because it is renewable. To bring the water or steam from such reservoir to the surface, wells are drilled into them. If the fluid is hot enough, steam bubbles will occur and cause the water to flow naturally to the surface as hot/warm springs, fumaroles and geysers. Ikogosi and other warm springs are visible evidence of geothermal energy in Nigeria. Nigeria may have her energy problem solved if the abundance of geothermal resources, especially one with temperature high enough to generate electricity is utilized. The geological features and subsurface temperature data of oil and shallow water wells from both Northern and Southern part of the Country point to the possible presence of geothermal energy due to the thermal gradient. If tapped, this will serve as alternative energy, as being utilized by several other countries since it can produce base load electricity which is reliable and sustainable unlike many other renewable technologies that are affected by weather and seasonal variations.

***Keywords*: Warm Spring, Geothermal Energy, Bottom hole temperature, Electricity, Geological features, Volcanic, Oil well.**

Introduction
The first use of geothermal energy for electric power production was in Italy with the experimental work of Prince Gionori Conti between 1904 and 1905. The installed geothermoelectric capacity had reached 127, 650 kwe. In 1958, a small geothermal plant began operation in New Zealand; in 1959, another began in Mexico. In 1960, USA followed suit (Dickson and Fanelli, 2004). This shows how long geothermal exploration has been in existence.

In Nigeria, human population and consequent demands on the Earth's natural resources continue to grow daily while experiencing insufficient production of electricity and poor energy distribution and transmission system. Scientific and societal concerns over resource depletion and the early manifestations of global warming are rising. Proposed as a future source to meet the region's growing energy needs, geothermal production brings both potential energy and economic benefits as well as reducing ecological and health problems. This paper thereby reviews the possible areas in Nigeria where geothermal energy can be sourced.

Origin and Nature of Geothermal Energy

Heat is a form of energy and geothermal energy is, literally, the heat contained within the Earth. Geothermal energy is derived from the natural heat of the earth. It is generated in the earth's core, some miles below the surface. The word geothermal was coined from two Greek words, *"geo",* which means earth, and *"thermos",* meaning heat. Thus, geothermal energy originates from solar inundation, Original heat of formation of the earth, and radioactive heat production (alpha, beta and gamma) from radioactive decay of minerals within the Earth's core.

From time immemorial, geothermal hot springs have long been used for bathing, heating, and cooking- not only by man but other animal species such as monkeys in Asia.

Geological setting of geothermal fields are numerous and varied. They include the following;

Volcanoes

Volcanic activity has always been associated with tectonic plate movement on earth which has been going on for millions of years. Volcanoes are associated with five different zones which occur within or on the edge of each tectonic plate. They are: hotspot, continental margin, island Arcs, mid oceanic ridges and continental rifts.

Sedimentary environment

Sedimentary environment produces higher temperature resources than the surrounding formations due to their low thermal conductivity or high heat flow or both. Natural radioactivity in sediments is also said to influence the temperature of the sediments through time. This could produce geothermal gradients >30˚C/km. These generally extend over large areas and are typical of the Madison Formation of North Dakota, South Dakota, Montana and Wyoming area of the northern United States and the Pannonian Basin of Central Europe where it has been used extensively in Hungary.

Geothermal reservoir

The most active geothermal resources are usually found along major plate boundaries where earthquakes and volcanoes are concentrated. When magma comes close to the surface it heats ground water found trapped in porous rock or water running along fractured rock surfaces and faults. Such hydrothermal resources have two common ingredients: water (hydro) and heat (thermal). Therefore, a geothermal (or hydrothermal) reservoir is a subsurface mass of fractured rock that is saturated with hot water or steam. Geothermal reservoirs are a potential source of energy. To bring the water or steam to the surface, wells are drilled into them. If the fluid is hot enough steam bubbles will occur and cause the water to flow naturally to the surface as hot/warm springs, fumaroles and geysers. A good example of such warm spring is the Ikogosi warm spring in Southwestern Nigeria. If the fluid is not hot enough then the wells may need a pump. Power plants utilize the hot water or steam from the wells by directing it to a turbine and generator to produce power (electricity), working much like any conventional power plant.

Classification of Geothermal Energy

Utilization of geothermal fluid depends heavily on its thermodynamic characteristics and chemistry. These factors are determined by the geothermal system from which the fluid originated. Geothermal fluids have been classified differently by different authors. Some authors have done so by using temperatures while others have used enthalpy (Dickson and Fanelli, 2004). Enthalpy, which can be considered more or less proportional to temperature, is used to express the heat (thermal energy) content of the fluids, and gives a rough idea of their 'value'. The resources are divided into low, medium and high enthalpy (or temperature) resources, according to criteria that are generally based on the energy content of the fluids and their potential forms of utilization. Table 1 reports the classifications proposed by a number of authors with classifications from their view, theory and results, using certain range of values.

Table 1: Classification of geothermal resources (°C)

Items	(a)	(b)	(c)	(d)	(e)
Low enthalpy resources	< 90	<125	<100		
Intermediate enthalpy resources	90-150	125-225	100-200	-	-
High enthalpy resources	>150	>225	>200	>150	>190

Source: (a) Muffler and Cataldi (1978). Source: (b) Hochstein (1990).
Source: (c) Benderitter and Cormy (1990). Source: (d) Nicholson (1993).
Source: (e) Axelsson and Gunnlaugsson (2000)

Principal Components of Geothermal Field

Most geothermal reservoirs are deep underground with no visible clues showing above ground. When geothermal energy finds its way to the surface, they occur in the form of: volcanoes, warm springs, hot springs, among others.

A geothermal system is made up of three major components: a heat source, a reservoir and a fluid, which is the carrier that transfers the heat. The heat source is a very high temperature magmatic intrusion that has reached relatively shallow depths and increases with depth. The reservoir, which is the permeable portion of the geothermal system, is overlain by impermeable rocks and are connected to a surficial recharge area through which the meteoric waters can replace the fluids that escape from the reservoir through springs which can be extracted by boreholes. The geothermal fluid is meteoric water in the liquid or vapour which is dependent on its temperature and pressure.

Out of all the components of geothermal field, the heat source is the only one that need be natural while fluids can be recycled through injection wells so that the natural recharge is sustained by artificial recharge.

Utilization of Geothermal Energy

Under appropriate conditions, high-, intermediate- and low-temperature geothermal fields can be utilized for both power generation and the direct use of heat (Tester *et al*., 2005). The acceptable geology of the geothermal energy is that heat from the earth's own molten core is conducted to the adjacent rocks and eventually is transferred to underground water reservoirs through convection.

The resulting steam/hot water heated produced by the geothermal heat can be tapped using different technologies and channeled for various uses accordingly. Utilization of geothermal fluid depends heavily on its thermodynamic characteristics and chemistry. These factors are determined by the geothermal system from which the fluid originated.

Electricity generation is the most important form of utilization of geothermal resources. High to medium resources are used for this purpose. The oldest, most versatile and also the most common form of utilization of geothermal energy is the direct-use. Low to medium temperature geothermal resources are better suited for this non-electric (direct)
application. Direct-use of geothermal resources is primarily for direct heating and cooling. The main utilization categories are: swimming, bathing and balneology; space heating and cooling including district energy systems; agricultural applications such as greenhouse and soil heating; aquaculture application such as pond and raceway water heating; industrial applications such as mineral extraction, food and grain drying; paper production; and Geothermal (ground-source) heat pumps (GHP), used for both heating and cooling. The various uses for domestic hot water include dish washing, laundry, bathing and hand washing.

Geothermal energy production utilizes natural heating in the earth, most accessible along active fault lines. Geothermal power plants harness the Earth's heat by utilizing natural hot springs, drilling a well into a hot aquifer (a subsurface layer of fluid bearing rock), or creating artificial aquifers by pumping high pressure water into the hot rock (see Enhanced Geothermal Systems). The power plants route the steam or hot liquid from the geothermal reservoir through turbine/generator units (either directly or through heat exchangers). The heated fluid is used to drive turbines to produce electricity.
Direct-use in all its forms is far more efficient than electricity generation and places less demanding temperature requirements on the heat resource. The warm springs can be used for agricultural and industrial applications.

Merits and Demerits of Geothermal Energy

Worldwide, geothermal plants have the capacity to generate about 10 GW of electricity as of 2007, and in practice supply 0.3% of global electricity demand. An additional 28 GW of direct geothermal heating capacity is installed for district heating, space heating, industrial processes, desalination and agricultural applications (Fridleifsson *et al*, 2008).
The following are the advantages of geothermal energy:

i. It has a natural source.
ii. Because of the near limitless ability of the earth to produce magma, and the continuous transfer of heat between subsurface rock and water, geothermal energy is considered a renewable resource (Rybach, 2007).
iii. Geothermal energy produces base load electricity as it is available 24 hours a day, 365 days a year, unlike many other renewable energy resources that are affected by weather and seasonal variations.
iv. It is also cost effective
v. It is reliable, sustainable, and environmentally friendly
vi. Geothermal power has the potential to help mitigate global warming if widely deployed in place of fossil fuels.

vii. Binary plants have essentially zero Greenhouse gases (GHG) emissions, as all of the geothermal fluid is returned to the reservoir and the secondary fluid is also in a closed loop cycle that is not exposed to the atmosphere. Even open loop steam plants, which are considered to have the highest levels of air emissions amongst geothermal systems, are far more environmentally benign than fossil fuels – a coal fired plant emits about 25 times more CO_2 per MWh than a dry steam geothermal plant and over 36 times more than a flash steam plant. If there were any GHG emissions in connection with a geothermal carbon offset project, these would be monitored and included in any calculations.

In spite of all the merits of geothermal energy highlighted above, only few countries have been able to utilize geothermal energy. This is because geothermal energy has been limited to areas near tectonic plate boundaries. Depth to the geothermal reservoir is another demerit, since it is generated in the earth's core, about 4,000 miles below the surface. However, there are several environmental impacts that must be considered during utilization that are usually mitigated. The most challenging environmental impacts of geothermal energy is H_2S and CO_2 contamination if released to the atmosphere in the course of exploration. These are harmful gases that affect water use and quality, land use, and impact on wildlife and vegetation (Kagel *et al*., 2005).

Geological Controls of Geothermal Energy in Nigeria

The Nigerian Precambrian Basement complex covers 48% of the total land area in the country whereas the remaining 52% of the land is covered by cretaceous to recent sediments deposited within several basins (Figure 1).

The geological setting in which geothermal reservoir is found can vary widely from rocks of limestone to shale, volcanic rock and granite. The most common rock type in which geothermal reservoir is found is volcanic rocks. The geothermal systems are associated with fracture and heat flow instead of specific lithology.

The geological structure and history in Nigeria influences geothermal exploration within each geological province. The products of magmatic and volcanic activities, for instance, are numerous within the Benue trough. Biu plateau has over 80 volcanoes and Jos plateau with extensive basaltic lava flows (Grant *et al.*, 1972; Turner, 1978).

The developed geothermal reservoir around the world also occur in convectional systems in which hot water rises from deep of the earth and is trapped in reservoirs whose caprock has been formed by silification precipitation of other mineral elements. Sedimentary basins in Nigeria have been explored for hydrocarbons for several decades, thus the oil companies possess large suite of subsurface temperature data. Data sets from the oil wells and water well have revealed that geothermal gradient in Niger Delta ranges from 1.3 to 4.7°C/100m.
Another good source of information about subsurface temperatures is water boreholes. The temperature measured during pumping tests is close to the real temperature of water bearing rock formation. However, such wells are usually shallow; especially water wells drilled within crystalline areas in Nigeria usually are not deeper than 30 meters. In the sedimentary areas water boreholes are usually deeper, even down to 500 meters and many of them can be used as the source of geothermal data.

With the availability of several warm/hot springs and seepages in Nigeria, most of which are located within sedimentary basin of Benue Trough, there may be potential geothermal resources within this part as these features are geological phenomena appearing as visible manifestation of geothermal energy within the subsurface.

Ikogosi warm spring is located in the south-western part of Nigeria. This is a thermal spring located within quartzite-schist formation of Nigerian basement complex. The spring water temperature is 37°C (Kurowska and Schoeneich, 2010). It serves as a local tourist center till date and it is used for swimming pool. This is probably the only direct-use of geothermal energy in Nigeria at the moment.

There is another warm spring in Rafin Reewa, near Lere, to the north-west of Jos Plateau (central shield). The temperature of spring water is 42°C and it flows from migmatic and gneissic rock formations. Several springs have been presently known in Jos Plateau and all of them provide cold, fresh water, commonly used by local community. The existence of Ikogosi warm spring and the recent discovery suggest that distribution of geothermal heat within Precambrian basement formations in Nigeria can be diversified due to local anomalies (Kurowska and Schoeneich, 2010).

Subsurface temperature distribution in the southern part of sedimentary province in Nigeria was studied by Nwachukwu (1976), Avbovbo (1978) and Onuoha and Ekine (1999). They used corrected bottom hole temperature (BHT) data measured in oil exploration wells drilled in Niger Delta and Anambra basins. The geothermal gradients in off-shore parts of Niger Delta calculated by Avbovbo (1978) were between 3.3 – 4.7 °C/100m. The latter research by Onuoha and Ekine (1999) shows diversity in geothermal gradient within Anambra Basin. The values calculated in 17 points (wells) range from 2.5 to 4.9°C/100m and the heat flow estimated on the basis of these gradients was 48-76 MW/m2. Anambra Basin (directly to the north) can reach 5.5°C/100m.

Geothermal characteristics of the Bida Basin as well as Borno and Sokoto basins was studied on the basis of thermal data collected during pumping tests in water wells. According to Kurowska and Schoeneich (2010), the water temperature data collected in these northern sedimentary basins have been reviewed, corrected and used for compiling the map of geothermal gradient as shown in Figures 2 and 3. The temperature data from water wells 70 m to 500 m deep were taken. The data base and the map show that temperature gradient in Borno Basin ranges from 1.1 to 5.9 °C/100m whereas Sokoto Basin has 0.9 to 7.6 °C/100m. The values of geothermal gradients found to the north of Nigeria, within the other part of Iullemmeden Basin in Niger, are even higher than in Sokoto Basin as shown in Figure 3 (Kurowska and Schoeneich, 2010). Illustration of subsurface temperature of the Chad Basin is given in Figure 4.

The few temperature data from Bida Basin taken in more than 100m deep water wells revealed that in the SE part of the basin the geothermal gradient is about 2-2.5 °C/100m. The springs in Middle Benue Trough flow from the Cretaceous, porous sandstones, some of them are located within areas famous for barite mining and traditional salt production based on salty sediments. In such area, one of the hottest springs (53.5°C) is located near Akiri. However the most famous Nigerian warm spring is Wikki (32°C) flowing from Gombe Sandstone in Yankari Game Reserve.

Another hot spring (54°C) is located in the North of Benue Trough, within a huge tectonic structure called the Lamurde anticline. This is close to Numan and is called Ruwan Zafi Spring. Within the Middle Benue Trough, several minor thermal seepages were found near Awe where the temperature of the water ranges from 34 to 38.5°C which may reach up to the temperature about 54°C. All these suggest the occurrence of some geothermal anomalies.

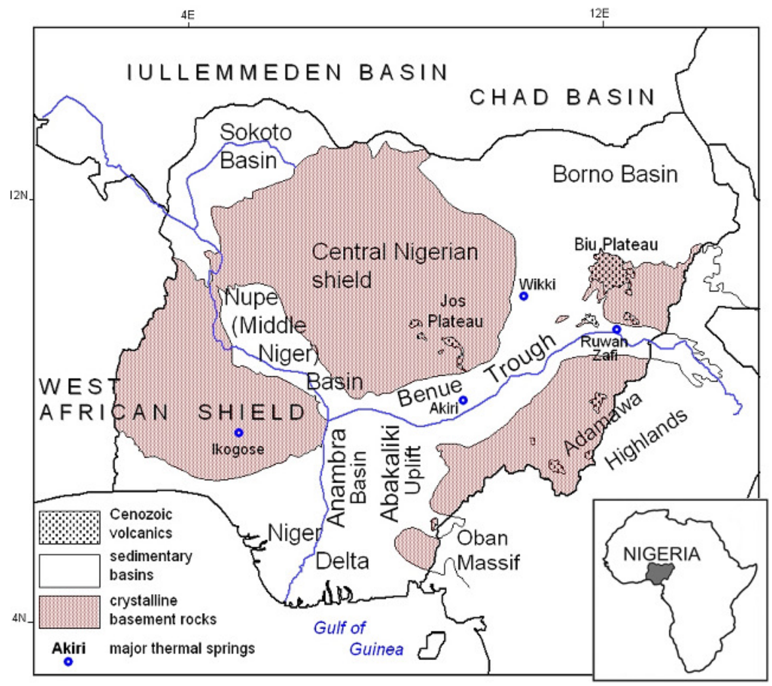

Fig. 1: Geological setting and location of areas with major geothermal anomaly in Nigeria.
Source:(Kurowska and Schoeneich, 2010)

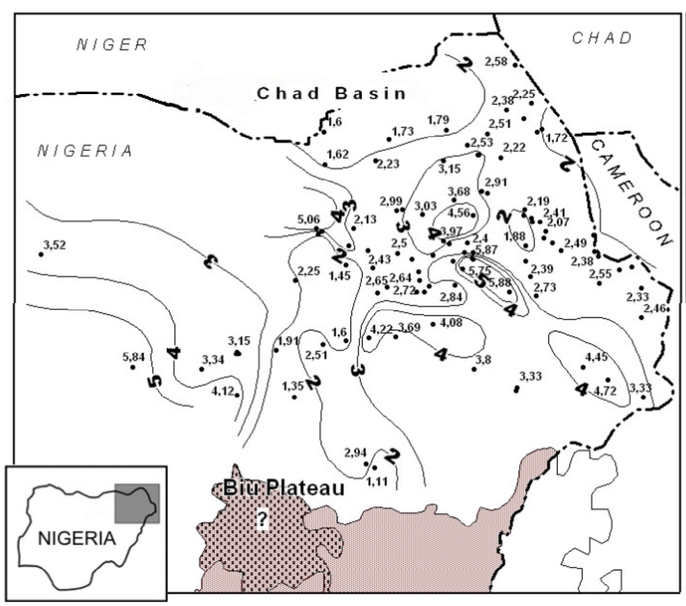

Fig. 2: Map of geothermal gradients (°C/100m) within the part of Chad (Borno) Basin.
Source: (Kurowska and Schoeneich, 2010)

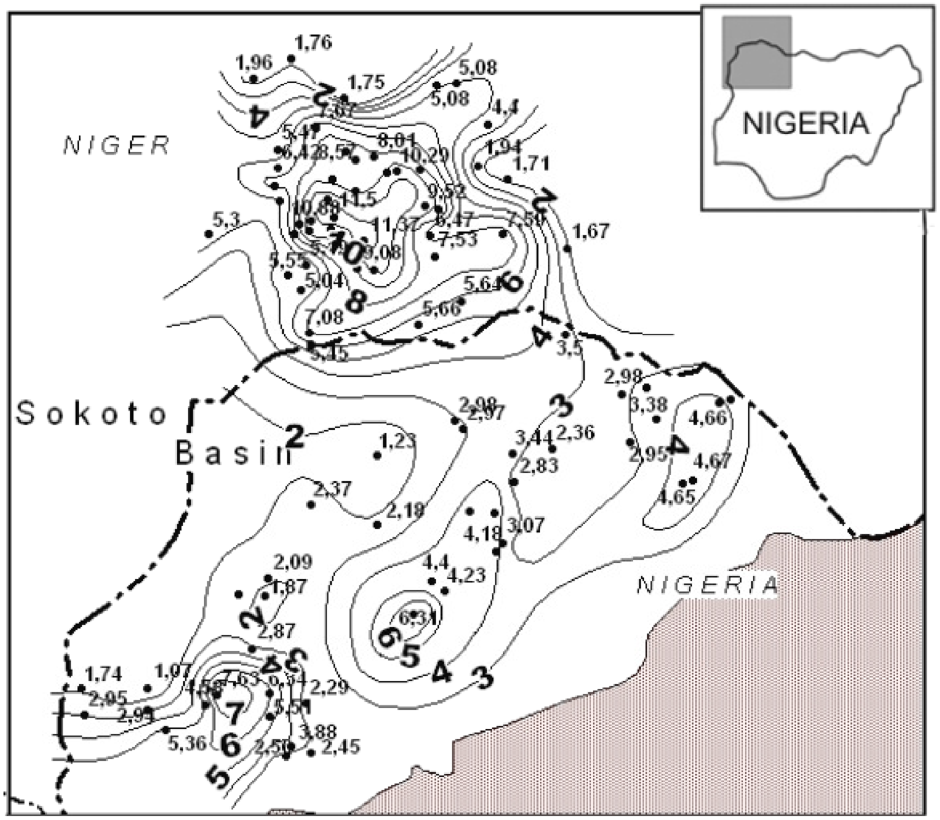

Fig. 3: Map of geothermal gradients (°C/100m) within the part of Iullemmeden basin.
Source: (Kurowska and Schoeneich 2010)

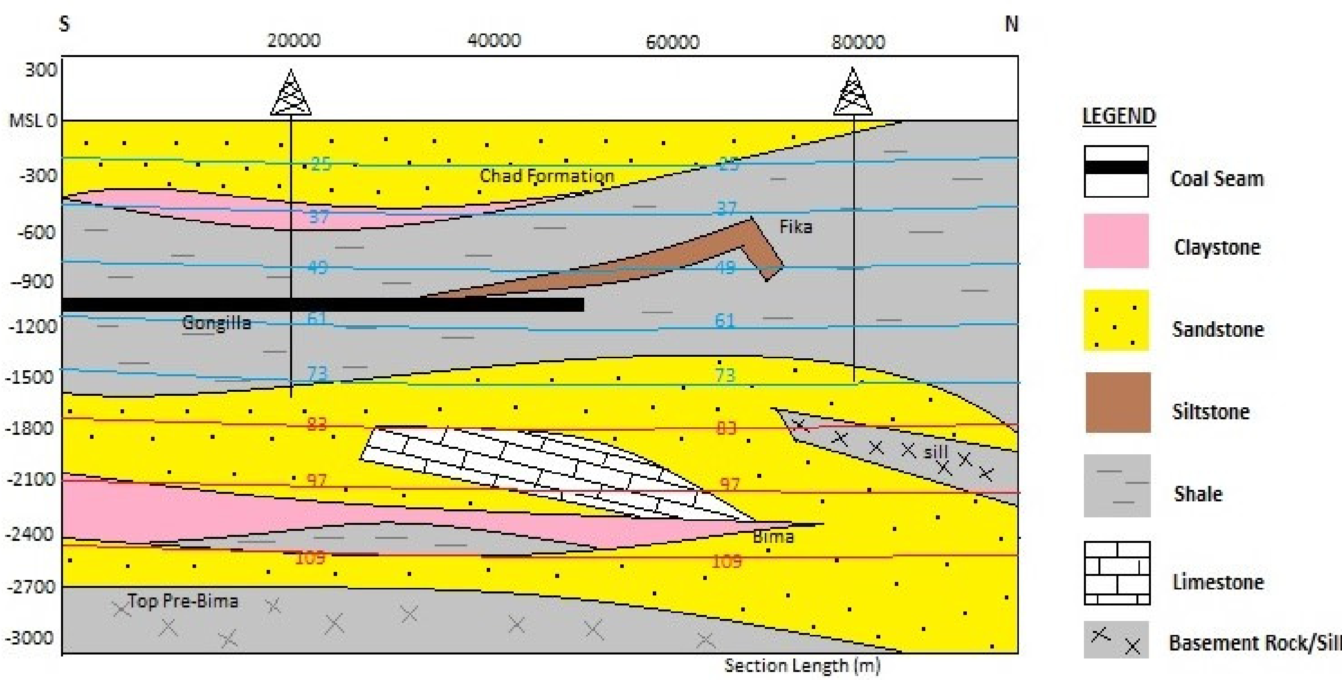

Figure 4: Subsurface temperature at the top of Bima Formation of the Chad Basin.

Aside the discovered springs, two artesian wells in this region also supply warm water to the surface. Temperatures of the water flowing from those wells are 43.5°C and 34°C (Kurowska and Schoeneich, 2010).

Geothermal Exploration Probable Methodology

Geological and hydrogeological studies are the starting point of any exploration programme, and their basic function is that of identifying the location and extension of the areas worth investigating in greater detail and of recommending the most suitable exploration methods for these areas (Dickson and Fanelli, 2004). They provide the background information for interpreting the data obtained with the other exploration methods and, finally, for constructing a realistic model of the geothermal system and assessing the potential of the resource. The information obtained from the geological and hydrogeological studies may also be used in the production phase as this will provide valuable information for the reservoir and production engineers.

Geochemical surveys are a useful means of determining whether the geothermal system is water or vapour dominated. They are used for estimating the minimum temperature expected at depth, for estimating the homogeneity of the water supply, for inferring the chemical characteristics of the deep fluid, and of determining the source of recharge water.

Geophysical surveys are directed at obtaining indirectly, from the surface or from depth intervals close to the surface, the physical parameters of deep geological formations. These physical parameters may include: temperature (from thermal survey); electrical conductivity (electrical and electromagnetic methods); propagation velocity of elastic waves (seismic method); density (gravity method); and magnetic susceptibility (magnetic method). Some of these techniques (such as seismic, gravity and magnetics) which are adopted in oil research, can give valuable information on the shape, size, depth and other important characteristics of the deep geological structures that could constitute a geothermal reservoir, but they give little or no indication as to whether the identified structures actually contain the fluids (Hot water or steam) that are the primary objective of research. These methodologies are, therefore, more suited to defining details during the final stages of exploration. Most especially before the exploratory wells are sited. Information on the existence of geothermal fluids in the geological structures can be obtained using the Electrical and Electromagnetic Prospecting. These methods are more sensitive to the presence of these fluids and to variations in temperature than the other surveys. These two techniques have been applied widely with satisfactory results.

Thermal techniques involving temperature measurements, determination of geothermal gradient and terrestrial heat flow can often provide a good approximation of the temperature of the reservoir from top.

Drilling of exploratory wells is usually the final phase of any geothermal exploration programme as this is the only means of determining the real characteristics of the geothermal reservoir and to assess its potential (Combs and Muffler, 1973). The resulting data of any exploratory well should be capable of verifying all the hypotheses and models deduced from the results of surface exploration. This therefore will reduce ambiguity and help to confirm that the reservoir is productive and that it contains enough fluids of adequate characteristics for the utilization for which it is intended.

The exploration programme is usually developed on a step-by-step basis: From Reconnaissance to Pre-feasibility and then Feasibility. During each of these phases, the less interesting areas will gradually be eliminated, concentrating on the most promising ones until the whole exploration program is completed.

Conclusions

Geothermal energy has proved to be very economical and reliable since it has very high availability (>90%). In Africa, except Kenya, geothermal energy has not been widely used for both direct uses and electricity generation. However, as the prices of fossil fuels continue to increase and as more and more focus goes to the utilization of renewable energy sources to address the climate change, Nigeria as a highly populous nation should probe into possible availability of such renewable, reliable, sustainable, cost effective and environmentally friendly resources which if available, can supply the energy need of the nation. Geophysical methods and hydrogeological methods, coupled with thermal studies which play a great role in exploration of geothermal energy can be adopted in search for this resource. Hot/warm springs mentioned above are visible indicators for a possibility of harnessing geothermal power in Nigeria since this will boost the economic power of the country.

Based on the available information extracted from the geology and mineral maps of Nigeria, three major potential geothermal sources are available. These are; the Biu Plateau, Pindiga Formation of the Benue trough and the Gombe sandstones (containing the Wikki springs). The Biu plateau has volcanic points representing a shallow depth to the mantle. This can, however, provide an enormous amount of energy for generation of electricity while the other point (Wikki warm springs) will provide enormous amount of water for heating and other domestic purposes.

Considering the result obtained from the temperature studies and the geothermal potential of the northeastern Nigeria, It is recommended that more geological exploration be carried out in the cited regions of the country in order to reveal the details of geothermal energy that are not currently available. Qualitative evaluation should also be done to evaluate the performance of each source and the percentage it can contribute to the national grid because the temperature encountered at these shallow depths investigated suggest that temperatures deep beneath will be relatively higher.

With the present energy crisis in the country, geothermal energy can serve as a future source of energy if exploited. This will put less pressure on fossil fuels and hence address the imminent negative consequences of global warming.

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