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Potentials for Geothermal Energy Applications and Quality of Hot Water from EU-Niger Delta Support Programme Boreholes, Ovia-South-West LGA Edo State

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Abstract

The temperature of hot water and other physico-chemical indicators from EU-Niger Delta Support Programme-Component 3 (Water and Sanitation) boreholes in Ovia-south-west L.G.A, Edo State were analysed for potential geothermal energy development and suitability for domestic purposes. Water sampling and in-situ measurements were carried out in September 2021 at the EU-borehole projects at Obaretin and Ofumwengbe communities in Ovia South West, Edo State. The study found that temperature values of water were 57.2^{0}C and 53.8^{0}C in Obaretin and Ofumwengbe boreholes respectively. Iron, lead, chromium and cadmium contents of water from the boreholes were slightly higher than acceptable limits. The pH values of EU-borehole were also acidic. With mean temperature values of 55.5 ^{0}C at the discharge points, it was concluded that the hot water EU-project is not suitable for electricity generation which requires a temperature of 200°C and, or medium application (150-200°C). Similarly, the hot water from the EU-borehole is best classified as sedimentary geothermal systems. In view of the water temperature, it is recommended that the hot water may be used for other direct applications such as resort or recreational centre and agro-businesses as these economic activities will contribute to economic development of the agrarian community. Findings from the study have implications for sustainable policy creation as well as may influence investor's decisions towards development of geothermal energy applications

1. Introduction

Energy plays a vital role in ensuring sustainable development of countries. Unfortunately, Nigeria has experienced decades of drawbacks as power demands are increasing at a rate greater than supply. The rapid growth in energy demand is attributed to a significant increase in population, urbanization, industrialization, and technological advancement in energy-demanding application. Researches have shown that peak energy demand grew from 10,144 in 2013 to 19,100 MW in 2018, which account for about 46% rise in energy demand and energy deficit increased from 57% in 2013 to 82% in 2018 [1,2,3]. At the moment, the installed generation capacity in the country is about 12,500

GW [4, 3]. Of this capacity, hydropower and fossil fuels contribute about 12.5%, while thermal power sources accounted for 87.5% [3], yet only 3,500 to 5,000 MW is available for supply [5]. On the whole, studies have found that only 45% of the Nigerian population are connected to the national electricity grid [6,7&8], while the remaining population rely on biomass or other sources of fuels for energy . Even with this connection 24 hours access to electricity is a mirage for most part of the country, while the rural and semi-urban areas are worst hit. The electrification rate in Nigeria is estimated at 45%, which is far low when compared to 99.6% and 85% electrification rates in Egypt and South Africa, respectively [5]. As a result, greater population of the country now rely on fuel wood and private use of a costly backup generator, both of which are linked to destruction of natural environment and emission of greenhouse gases (GHG) and other related toxic pollutants. The energy crisis in Nigeria has been implicated in the wide spread of poverty via paralyzing industrial and commercial activities. The Council for Renewable Energy of Nigeria in their report estimates that power outages brought about a loss of 126 billion naira (US$ 984.38 million) annually (Council for Renewable Energy, Nigeria [9]. In addition, climate change impacts have also intensified due to deployment of 'backyard generators' and the exposure to carbon emissions. According to World Energy Council report, global electricity demand will peak in 2030 [10]. Nigeria is ranks number seven (7) in the list of countries by population (Department of Economic and Social Affairs Population Dynamics, [11] and this has implications for achieving SDGs and national economic development.

If the country is to meet key sustainable development goals, in particular, zero poverty by 2030, climate action, affordable and clean energy, there is need for intensify research and development efforts into alternate sources for generating electricity. Common renewable energy sources in Nigeria include biomass resources, solar, hydropower, and wind [4, 12]. Unfortunately the development and deployment of geothermal energy in the country is grossly scanty with the only reported cases been the Ikogosi Warm Spring Resort in Ikogosi town, Ekiti State, Wiki Spring Resort in Yankari National Park, Bauchi State and the warm spring in Rafin Reewa, near Lere, to the north-west of Jos Plateau [13-15]. According to Koontz [16], geothermal energy is a clean and sustainable source of energy beneath the surface of about 1500 – 4000 meters, super-hot gas and molten are constantly being replenished. Geothermal energy was considered as a key option that could assist in reaching the goal of the Paris Agreement to limit the atmospheric temperature increase to 2^0C or less [17]. Furthermore, 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 [18]. Dickson and Fanelli, [19] also documented that geothermal heat can 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. Beside electricity production which is limited to temperature of over 200^0C and reservoirs at depths below 2 km direct geothermal heat applications in agriculture, industry and the built environment can already be realized from reservoirs at depths of less than 2 km; for agriculture this is even the case for shallow depths of less than 200 m [20, 21]. Space cooling applications are only possible in the south of Spain, Italy, Greece and Turkey, since only in those parts of Europe minimum average surface temperatures are above 15^0C. Cooling applications in these countries typically require geothermal resources at depths below 2 km [22]. In south-south Nigeria where this study was carried out the main source of energy distribution is the national grid which is neither stable of consistent, a development which has forced over 90% of the population to rely on power generating plants and another 40% to rely of fuel woods for cooking and heating [12]. Other renewable energy sources in the area include biomass resources and solar energy technologies which are most times either capital intensive or have some environmental consequences. Nevertheless, the hot water from EU-Niger Delta Support Programme-Component 3 (Water and Sanitation) in Edo State, presents evidence of geothermal energy applications and this necessitate the need for the present study.

2. Materials and Methods

2.1 Study Area

The study area is Ovia southwest Local Government Area, which houses the two (2) EU-Niger Delta Support Programme-Component 3 (Water and Sanitation) Projects, one at Obaretin community and the second at Ofunmwegbe community. The water scheme project which was commissioned in 2019, is part of the water Supply and Sanitation Project (RWSSP) implementing Component 3, Water and Sanitation of the Niger Delta Support Programme in two Local Government Areas in Edo State as in other four states in southern Nigeria. The project is aimed as providing wholesome drinking water using a small town small community municipal treatment plant. The boreholes have depth of about depth of 354 metres (1160ft). Obaretin is 40 kilometers from the Ring road in Benin City. The community extends from Ofunmwegbe along the Benin Lagos express way and shares borders with Iguobanor, Ugbokun, Ofunmwegbe communities. Ovia Southwest lies within the co-ordinate 5.2796903°E 6.5951587°N and 5.4073769°E 6.7347231°N (Figure 1). The elevation ranges between 37 and 66 m above mean sea level with relatively flat and gentle geomorphology. The region consist of surface and ground water resources. The surface water resources include major rivers and streams such as Okada River, Igbogo River, Iguevinyoba River and Siloko River.

The geological structure of Edo State composed basically of both crystalline Basement rocks (Precambrian age) occupying the Northern part of the state and sedimentary rocks, spanning from Cretaceous to Recent in age. The sedimentary rock is ubiquitous across the state with major dominance in the south. Figure 2 displays the major local geology or the region. The occurrence of warm ground water resource in this region are of major interest as they occurs within very interesting geological settings. The regions consist of clay – shale which is part of the Imo shale outcrop that is an arcuate belt from Western Nigeria to the East. It lies conformably on the Maaestrichtian Abeokuta and Nsukka Formation [23]. The Imo Formation is essentially thick clayey shale, fine textured, dark grey to bluish grey with occasional admixture of clay ironstone and thin sandstone beds. The Imo shale range from Paleocene to lower Eocene in age. The Formation is typically dark, very thinly laminated fissile and contains abundant pyrite crystals but poorly fossiliferous [24]. The Imo Formation in the eastern part is a lateral equivalent of the Akinbo Formation in Western Nigeria. The Imo Formation outcrops at Okada as Okada shale. Okada clay-shale is therefore part of Imo Formation.

The study area is located in the humid tropical rain forest belt of Nigeria with a mean annual rainfall ranging from 2050 mm to 2161 mm. Temperature values in the area are usually high throughout the year with a minimum annual temperature of 21.90 °C and a mean annual maximum temperature of

25.10 °C. The vegetation of the area is rain forest, however the original vegetation has been undergoing modifications due to settlement expansion, mining and industrial activities.

Figure 1: Satellite image map of study location

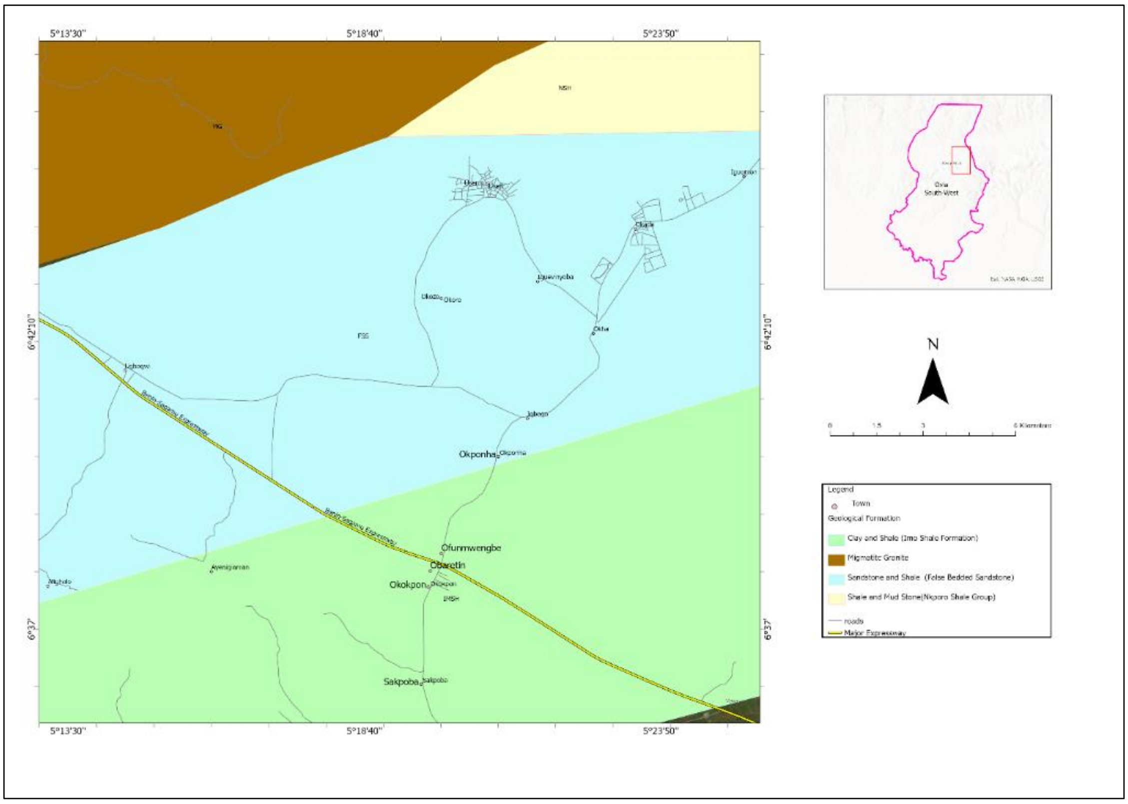

Figure 2: Local geology of the study area (arrowed) (Modified after NGSA)

2.2 Field Sampling

2.2.1 Field Sampling

Field data collection was carried out following established standard procedures and practices for environmental data collection in Nigeria by FMENV and recognizing the relevant sections of the Edo State Ministry of Environment guidelines [25].

2.2.2 Water Sampling Techniques

Borehole water from the EU-Borehole projects and surface water sampled which served as control were collected for analysis. For the EU-Boreholes, samples were collected from hot water from discharge points (This is the point where water is flowing freely without mechanical pressure from machine). The borehole projects are situated on a pressurized aquifer and hence there is constant flow of hot water even with pressure from a mechanical pump.

For surface water, three (03) sampling stations were established along Okokpon stream and two along Ofunmwengbe stream. The water samples were collected randomly using the grab sampling method by dipping a 250 ml plastic bottle 30 cm below the water surface at each selected sampling point (Plate 1 & 2). The sample bottles were labelled with the appropriate source and date of collection before being transported to the laboratory for analysis. In each stream and borehole, at least one (1) sample was collected over the period of the study (September 2021), making it a total of four (04) samples. Collected samples preserved prior to physic-chemical and heavy metal analysis.

Plate 1&2 In-situ measurement of physical parameters of water quality at discharge point/surface water

2.3 Data Analysis

2.3.1 Laboratory Measurement/Testing of water quality

Water samples were analysed at Earthquest International Limited, Warri Delta State and Port Harcourt Office, Rivers States. Samples brought to the laboratory were analysed using standard analytical methods. Parameters analyzed include pH, EC, TDS, Salinity, Temperature, TSS, Turbidity, Chlorine, Sulphate, Nitrate, Nitrite, Hardness, Phosphate, Ammonia, DO, BOD. Cd. Cu, Pb, Fe, Mn, Co, Zn. Water samples and in-situ measurements were carried out between 9am -10 morning in the morning. The choice of the time was to prevent the effects of after temperature on the water temperature.

3. Results and Discussion

3.1 Water quality of EU-Borehole and surface water

The summary of the physicochemical, heavy metals and microbial analyses for the surface water samples is presented in Tables 1 – 3. Most parameters were generally within limit for the acceptability of water for domestic purpose except for temperature, cadmium, iron, lead and chromium which were slightly higher than permissible limits (Tables 1 & 3). The temperature of hot water at discharge points were 57.2 ºC and 53.4 ºC at Obaretin and Ofumwengbe EU-Boreholes respectively. Cadmium occurs naturally in zinc, in lead and copper ores, in coal and other fossil fuels, in Shales and is released during volcanic action [26]. These deposits can serve as sources to ground and surface waters, especially when in contact with low total dissolved solids (TDS) and acidic waters [26]. The study area is underlain by the Imo shale sedimentary rock and thus this may be linked to the level of cadmium in the study area. Cadmium has no biological functions to humans, it has been linked to a number of health problems including renal tubular dysfunction, pulmonary emphysema and possibly Osteomalacia, a situation where calcium in the bones is replaced by Cd in humans which results to cancer of the bones [27]. Target organs include liver, placenta, kidneys, lungs, brain and bones [28]. The high concentration of iron, cadmium and lead in both surface water and EU-Boreholes, above permissible limits may be attributed to geology of the bedrock and other sources of pollution such as such as agricultural and industrial effluents [29]

In drinking-water supplies, iron (II) salts are unstable and are precipitated as insoluble iron (III) hydroxide, which settles out as a rust-coloured silt [30]. Anaerobic ground waters may contain iron (II) at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well, although turbidity and colour may develop in piped systems at iron levels above 0.05–0.1 mg/litre. Staining of laundry and plumbing may occur at concentrations above 0.3 mg/litre [31]. Iron is an essential element in human nutrition [26]. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and it ranges from about 10 to 50 mg/day (12). The average lethal dose of iron is 200–250 mg/kg of body weight, but death has occurred following the ingestion of doses as low as 40 mg/kg of body weight [32]. Autopsies have shown haemorrhagic necrosis and sloughing of areas of mucosa in the stomach with extension into the submucosa [30]. Chronic iron overload results primarily from a genetic disorder (haemochromatosis) characterized by increased iron absorption and from diseases that require frequent transfusions [33]. Chromium is a metal found in natural deposits of ores containing other elements, mostly as chrome iron ore [34]. It is also widely present in soil and plants. Under most conditions, natural chromium in the environment occurs as Cr^3. Under oxidizing conditions, alkaline pH range, presence of MnO_2 and minerals containing chromium, part of it may occur as Cr^6 dissolved in groundwater [35]. Naturally occurring Cr^6 may be associated with serpentinite-containing rock or chromium containing geologic formations [34]. Chromium (Cr) is very toxic and mutagenic when inhaled and is a known human carcinogen, and breathing high levels can cause irritation to the lining of the nose, runny nose and breathing problems [36] . The presence of Pb poses a high health risk of Pb poisoning as the element is known to be toxic even at low levels [37]. The higher levels of Pb observed in the surface water from the dam might be due to the closeness of some parts of the surface water to the high way receiving pollutants that are related to vehicle emission. Some effects of Pb poisoning include deficiency in cognitive function due to destruction of the central nervous system, abdominal pain and discomfort, formation of weak bones as Pb replaces calcium and causes anaemia due to reduction of enzymes concerned with synthesis of red blood cells [38]. Elsewhere in the sub-Sahara Africa studies have reported higher than the recommended limit of 0.01mg/l for drinking water [39, 40]. Wachira [39] reported that the water from Nairobi River was unsuitable for domestic use and attributed the higher level to discharge of untreated industrial and urban effluent to the river.

Table 1: Physical quality of water samples from EU-Borehole and surface water (Control)

Parameter	EU-B/OB	EU-B/OF	OB/SW Contr	OF/SW Contr	NSDWQ	WHO
pH	4.5	5.5	5.5	6.7	6.50-8.50	6.50-8.50
EC uS/cm	168	380	30	207	1000.00	NG
TDS mg/l	84.4	191.4	15.6	110.5	500.00	1000.00
Salinity o/oo	0.07	0.06	0.01	0.06		
Temp ^{0}C	57.2	53.8	22.5	23.8	25	25
TSS mg/l	34	33	25	54.0		600
Turbidity NTU	38.6	37.3	29.3	71	5.0	0.2

EU_B OB: EU Borehole Obaretin; EU_OF: EU Borehole Ofumwengbe; OB/Sw, Obaretin surface water; OF/Sw, Ofumwengbe surface water

Table 2: Chemical quality of water samples from EU-Borehole and surface water (Control)

Parameter	EU-B/OB	EU-B/OF	OB/SW Contr	OF/SW Contr	NSDWQ	WHO
Chlorine mg/l	35.4	31.6	5.41	29	250.00	250.00
Sulphate mg/l	11.3	13.3	0.084	6.05	100	250
Nitrate mg/l	0.34	0.037	0.146	0.011	50.00	50.00
Nitrite mg/l	0.037	0.015	0.073	0.009	0.20	3.00
Hardness	215	567	41.0	428	150	
Phosphate mg/l	0.011	0.0001	0.011	0.051	-	-
Ammonia mg/l	0.32	0.25	0.32	0.412	-	-

Table 3: Heavy metals Level in water samples from EU-Borehole and surface water (Control)

Parameter	EU-B/OB	EU-B/OF	OB/SW Contr	OF/SW Contr	NSDWQ	WHO
Cd mg/l	0.003	0.007*	0.002	0.008*	0.003	0.003
Cu mg/l	0.01	<0.001	0.007	0.003	1.0	2.0
Pb mg/l	<0.001	<0.001	0.001	0.012*	0.01	0.01
Fe mg/l	3.208*	0.554*	0.114	1.45*	0.3	0.3
Mn mg/l	0.089	0.555	0.034	0.121	20	0.5
Co mg/l	0.024	0.05	0.057	0.051		
Zn mg/l	0.016	0.009	0.016	0.017	3.0	3.0
Cr mg/l	0.072*	<0.001	-	-	0.05	0.05

- Exceeded permissible limit for drinking water

In Table 4, types and uses of geothermal resources are presented according to classification method proposed by Energy Sector Management Assistance Program (ESMAP) [41]. From the table geothermal resources are classified in various ways based on heat source, type of heat transfer, reservoir temperature, physical state, utilization, and geological settings. When defined on the basis of the nature of the geological system from which they originate, the different categories include volcanic geothermal system, convective fracture controlled systems, Sedimentary geothermal systems, Geo-pressured systems, Hot dry rock (HDR) or enhanced (engineered) geothermal systems [42, 41].

Adopting the classification, it can be inferred that the hot water from the EU-Borehole did not merit to be classified as volcanic geothermal systems (associated with volcanic activity), convective fracture controlled systems (tectonically active areas, with above average heat flow) or Geo-pressured systems (associated with geo-pressured oil and gas reservoirs). Instead the observed geothermal reservoirs in the study area is best classified as sedimentary geothermal systems (with respect to the study area, the Imo Formation), a category is found in many of the world's major sedimentary basins. These systems owe their existence to the occurrence of permeable sedimentary layers at great depths (> 1 km) and above average geothermal gradients (> 30^0 C/km) [42].

These systems are conductive in nature rather than convective, even though fractures and faults play a role in some cases. Some convective systems (such as convective fracture controlled systems) may, however, be embedded in sedimentary rocks. Similarly, the use of geothermal resources is strongly influenced by the nature of the system that produces them. Hot volcanic systems are utilized primarily for electric power generation, whereas the resources of lower temperature systems are utilized mostly for space heating and other direct uses [41, 42]. High temperature fields are all related to volcanism whereas low temperature fields draw heat from the general heat content of the crust and from the heat flow through the crust [41, 42]. Medium temperature fields have temperatures between 150° and 200°C and are they can be utilized for power generation by binary power plants (Table 2).

Table 4: Types and Uses of Geothermal Resources (ESMAP [41])

Resource type based on temperature	**Geographical and geological location**	**Use / Technology**
High: >200°C	Globally around boundaries of tectonic plates, n hot spots and volcanic areas	Power generation with conventional steam, flash, double flash, or dry steam technology
Medium: 150-200°C	Globally mainly in sedimentary geology or adjacent to high temperature resources	Power generation with binary power plants, e.g., ORC or Kalina technology
Low: <150°C	Exist in most countries (average temperature gradient of 30^0C/km means that resources of about 150°C can be found at depths of about 5 km)	Direct uses (space and process heating, etc.) and, depending on location and power tariff offered, power generation with binary power plant

In a similar finding, Oyedepo [43] augured that geothermal Resource can be made viable for electricity development first, if Hot emission fluid with low mineral and gas content from the earth and second, if the Hot fluid temperature is as high as 300^0F (148.9^0C), although plants are operating on fluid temperature as low as 210^0F (98.88^0C). In view of the study borehole temperature, it can be concluded that the observed potential geothermal resource in study are cannot support electricity generation, but instead maybe suitable for direct uses such direct heating, hot water and steam for bathing (recreation), agro-businesses and ground source heating and cooling or small hydropower plant as currently being practiced in most developing counties [44-46].

4. Conclusion and Recommendations

The aim of the study is to undertake a pre-feasibility assessment of geothermal energy potentials in Ovia-south-west L.G.A, Edo State. Temperature of water from the EU-borehole projects were 57.2^{0}C and 53.8^{0}C in Obaretin and Ofumwengbe borehole sites respectively, both of which exceeded the 25 ^{0}C standard for drinking water. With mean temperature of water 55.5 ^{0}C at the discharge point the hot water from the EU-project is not suitable for electricity generation which requires a temperature of 200°C and, or medium application (150-200°C). The hot water from the EU-borehole is best classified as sedimentary geothermal systems, with respect to the study area, the Imo Formation. More so, the temperature of water from the boreholes were very high and above permissible limits for drinking water, while Iron, lead, chromium and cadmium contents of water were slightly higher than acceptable limits. In addition, water from the EU-borehole was acidic with pH values of 4.50 (Obaretin) and 5.50 (Ofumwungbe). This make the water unfit for human consumption without further treatment. However, the hot water can be harnessed for recreation activities or other direct uses. Apart from harnessing recreational the hot water can also be harnessed for agro-businesses. Finally, findings from the study have implications for sustainable policy creation as well as may influence investor's decisions towards development of geothermal energy applications in the agrarian community.

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