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RESEARCH ARTICLE

GEOELECTRICAL ASSESSMENT OF GROUNDWATER POTENTIAL OF KEANA AREA NORTHCENTRAL NIGERIA

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ABSTRACT

This work was undertaken to unravel the hydro geophysical characteristics of Keana metropolis Nasarawa State, northcentral Nigeria. This study aims to assess and determine the sustainability of groundwater resources in Keana Town by using geoelectric techniques to collect data and analyze subsurface characteristics that can assist identify suitable sites for groundwater extraction. Once accomplished, it will give useful information for groundwater resource management and contribute to Keana's long-term growth. Fifteen (15) Vertical Electrical Sounding (VES) data with a maximum electrode spacing of (AB/2) of 200 meters were acquired using the Schlumberger electrode configuration. The VES data were interpreted using the conventional partial curve matching technique to obtain initial model parameters, which were used as input for computer iterative modelling using the IPI2WIN™ software. The study revealed three (3) to six (6) geo-electric layers with underlying indurated sandstone and shale beds in some areas. In the study area, the apparent resistivity of the aquifer ranges from 32.4 to 407 m, with a depth ranging from 30 to 120m. Information extracted from iso-resistivity models and geoelectric cross sections revealed sandy strata with an exception around the northern portion i.e., around Federal Government Girls College Keana (FGGC) where a thick layer of shale is envisaged, extending to over 150 m depth with an average apparent resistivity value of 35Ω m. Thus, making the section fair to poor groundwater potential. However, this research has aided in delineating the groundwater potential of the area into three distinct zones.

KEYWORDS

Aquifer, Geo-electric, Groundwater, Keana, Resistivity

1. INTRODUCTION

The availability of safe and potable water in an environment is a veritable index of a tremendous role in the development and growth of a community. Over the years Keana as a municipal has witnessed an increase in the population of various groups of people. In most cases, the inhabitants of the area live on subsistence farming and rely on perennial streams to provide them with water for their domestic needs. Borehole projects have been undertaken by private organizations, communities, and individuals to have feasible portable water. Several boreholes and wells have failed due to a lack of reasonable quantity of underground water in some areas. This has posed a serious challenge to some residents of the Keana community about these unproductive boreholes in some areas. The citing of several of these projects was inaccurate; some of these project's function seasonally, while others have been abandoned. Due to the lack of detailed geophysical surveys in the Keana area, that could have identified aquifers and groundwater potential zones. Additionally, there is little understanding of the geology of the study area.

It is known that certain rock properties vary greatly with water content, which is why geophysical methods are used to determine groundwater aquifers. The pores in soils or eroded/fragmented rocks, (water bearing rock), are where groundwater can be found, therefore groundwater is crucial to human survival since it is used extensively in agriculture, sanitization, residential, and industrial processes (Umar et al., 2019). There is a specific resistivity range in these rock formations and sediments, a given medium's electrical resistivity is influenced by properties including particle size, water content, and porosity. Rock resistance is controlled by porosity, which typically reduces as resistivity rises, and vice versa (Uchenna, 2013). Several authors have therefore delineated aquifers and estimated aquifer hydraulic parameters using surface geophysical methods in different parts of the world (Ekwe et al., 2012; Onyekeru, 2010).

Hence, the unique application of geoelectric investigation to assess the groundwater potential in Keana Town also lies in the identification and interpretation of geoelectric parameters to provide valuable insights into the underground aquifers, their characteristics and their potential for supplying adequate and safe drinking water to the local community. No or little research work has been carried out on the groundwater prospect of the study area, but few studies have been done on the quality status of groundwater in the area (Chukwu, 2008; Amadi et al., 1989). Therefore, Keana town, like many other communities, relies extensively on groundwater as a key source of drinking water as well as for a variety of agricultural and industrial applications. Assessing the groundwater potential in this area is critical for sustaining the water supply and satisfying local population needs. The geoelectric examination technique used in the study provide useful insights into subsurface properties such as aquifer presence, depth, and yield or quantity of groundwater reserves.

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This data assists in the optimal planning and management of water resources, ensuring their long-term use. More importantly, the discoveries of this research can improve broader scientific knowledge and understanding of groundwater exploration techniques in similar geological settings. It can also serve as an overview for researchers and professionals engaged in groundwater evaluation and development projects not only in Keana Town but also in other regions facing similar difficulties. The findings from the study can help local governments and organizations in charge of water resource management make decisions. The investigation's findings can help lead to the development of appropriate approaches and regulations for the protection, conservation, and equitable distribution of groundwater resources.

Hence, using geoelectric investigations to assess Keana Town's groundwater potential has an important significance for ensuring sustainable water supplies, supporting scientific knowledge, facilitating effective resource management, and guiding decision-making processes for the benefit of the local community and the broader region. It has therefore become necessary to study the groundwater potentials of the area for proper planning and execution of water projects. This paper attempts to highlight some of the hydrogeological parameters that could be useful in this direction. The results obtained would also add to the scanty hydrogeological information in the study area.

1.1 Regional Geology

One of the most notable geologic features in West Africa is the Nigerian Benue Trough. It stretches over an area of 800 km, with a length that trends NNE-SSW from the Niger Delta to the Lake Chad basin's southwest, and a width that varies from 130 to 250 km (Obaje, 2009). Due to the large regional extent, studies in the Trough are often divided geographically (though arbitrarily) into upper, middle and lower regions. In the Middle Benue Trough, six Upper Cretaceous lithogenic Formations (Asu River Group, Keana Formation, Awe Formation, Ezeaku Formation, Awgu Formation and Lafia Formation) comprise the stratigraphic succession after Obaje, 2009 (Figure 1). The Asu River Group consists of Albian Arufu, Uomba and Gboko Formations (Offodile, 1976; Nwajide, 1990). These are overlain by the Cenomanian-Turonian Keana and Awe Formations and followed by the Ezeaku Formation which shares a common boundary with the Konshisha River Group and the Wadata Limestone in the Makurdi area. The Late Turonian-Early Santonian coal-bearing Awgu Formation lies conformably on the Ezeaku Formation. The Middle Benue Trough's sedimentation was terminated by the Campano-Maastrichtian Lafia Formation, and in the Tertiary, widespread volcanic activity took over (Obaje, 2009).

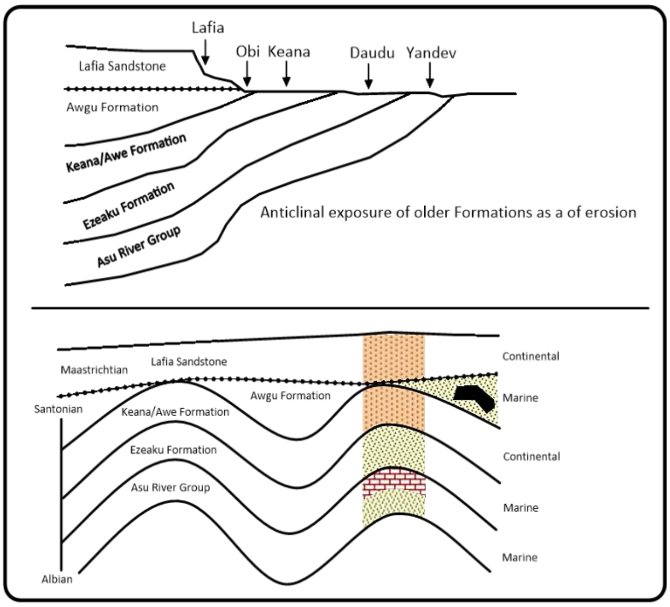

Figure 1: Stratigraphic succession in the Middle Benue Trough (Modified after Obaje, 2009)

1.2 Local Geology

A good understanding of the geology of the study areas is necessary for a thorough assessment of the characteristics of the sub-surface rocks and formation fluid. Available information indicates that the Keana area falls within the Middle Benue Trough, underlain by the following geological sequence; Asu River Group, Ezeaku, Keana, Awe and Awgu Formations and finally the Lafia Sandstone. The sedimentary Formations listed above are underlain by the Basement complex of Precambrian age. The Keana Formation overlies the Awe Formation, the contact between the two being variously described as gradational and unconformably (Offodile, 1976; 1984; Reyment and Offodile, 1976). Thickly bedded, cross-bedded, fine to extremely coarse-grained, occasionally conglomeratic, gritty arkosic sandstone and bands of shale with an inferred fluvial or deltaic origin make up the majority of the Keana Formation and Offodile and Reyment described the Keana Formation as in some places lying below beds referred to as the Ezeaku Formation and elsewhere interfingering with them (Keana et al., 1976; Murat, 1972; Offodile, 1976).

Although not directly dated, the Keana Formation has generally been regarded as late Albian to Cenomanian and represents the southern part of a fluvial-deltaic system discharging into the receding sea. Its literal equivalent to the north is the “Muri sandstone” (Cratchley and Jones, 1965; Benkhelil et al., 1989). To the South, the Keana Formation passes laterally into Makurdi Formation (Nwajide, 1985; Benkhelil et al., 1989). Keana Formation is a good aquifer but it's limited. The sandstone near the core of the Keana anticline is hard and less permeable than the one in the synclinal area. However, Keana together with Ezeaku Formations form a very thick productive aquifer when encountered in a borehole (Figure 2).

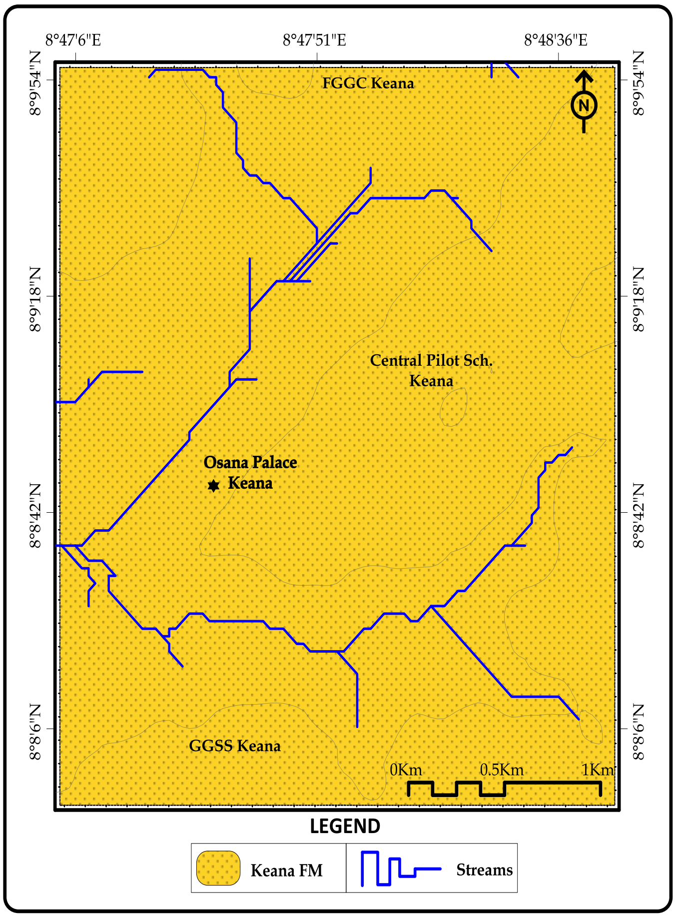

Figure 2: Geological Map of the Study Area

2. Study Location

The study area is located in Keana local Government Areas in the south-eastern part of Nasarawa State. The study area is approximately 12.4 km² in size, bounded by latitudes $8^0$07'53.00" N to $8^0$09'56" N and longitudes $08^0$47'2.30" E to $08^0$48'47.10" E. The area is accessible by the Lafia-Obi Road down to local communities of Benue State and to other localities within a minor road and lots of footpaths. The research area shares the same two (2) main and distinct seasons as northcentral Nigeria, which are the wet season, which typically lasts from March to October, and the dry season, which commonly lasts from November to February. Vegetation of the areas is of the guinea savannah type, with dense (gallery) forests fringing some of the rivers (Figure 3).

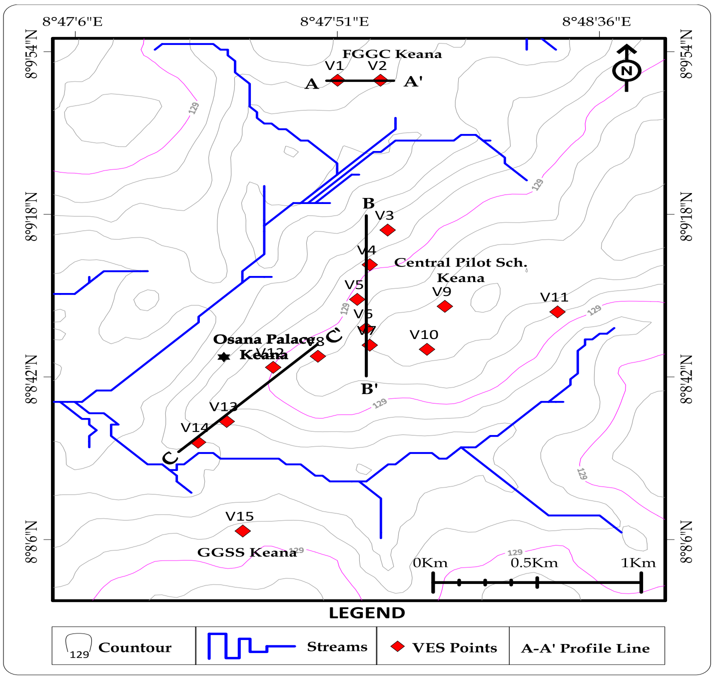

Figure 3: Location and Drainage map showing VES points of the Study Area

3. Material and Methods

The geophysical method adopted for delineating the depth of aquiferous zones of the study areas is the electrical resistivity technique of Vertical Electrical Sounding (VES). A total of fifteen (15) VES were carried out in the study areas. The Schlumberger configuration was adopted with a current electrode spread (AB/2) of 200m while the potential electrode separation (MN/2) was maintained between 0.5 and 20m (Figure 4). The resistance values obtained at each measurement are multiplied by a geometric factor appropriate to the electrode spacing. An interpretation of the curve using appropriate software gives an estimated thickness based on the resistivity values of the subsurface strata encountered. The VES curves were quantitatively interpreted by partial curve matching and computer iteration techniques based on linear filter theory using IPI2win™ computer software. Although various geophysical techniques are commonly employed for groundwater investigation, electrical resistivity is the most unique for its ability to detect an increase in the conductivity of an aquifer that results from increases in porewater (Loke, 1999). This method can also be used to determine the nature, geometry and thickness of geological formations (Telford et al., 1977; Oteri, 1977).

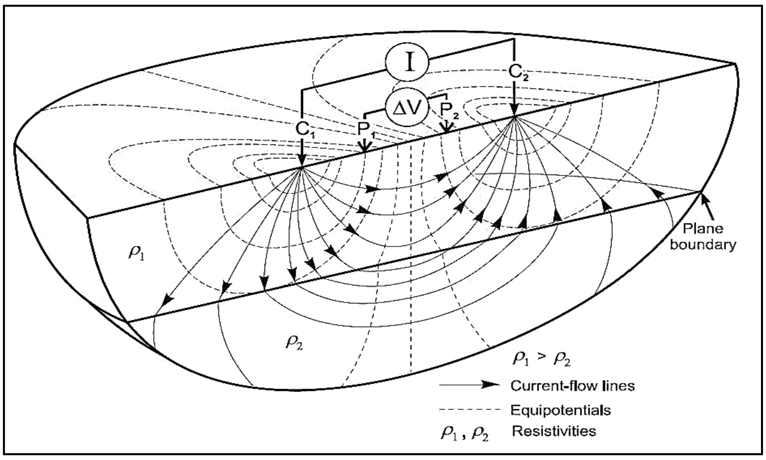

Figure 4: Principle of resistivity measurement with a four-electrode array (Knödel et al., 2007)

Furthermore, several indices were utilized to estimate the groundwater potential in Keana town. These indices aided in the analysis of geoelectric data and the drawing of conclusions concerning groundwater supply. The following indices were evaluated in the study; *Resistivity values,* the resistivity of subsurface materials provides information about their water-bearing capacity. It can also be used to calculate the depth and thickness of subsurface layers. Differences in apparent resistivity can aid in the identification of potentially water-bearing strata. Lower resistivity readings frequently indicate the presence of potential aquifers, while elevated readings may indicate marginalized groundwater conditions. *Lithology*, the geological composition of the area has a considerable impact on groundwater potential. Different rock types and formations can have varied water-holding capacities, permeability, and porosity, influencing groundwater availability. *Geoelectric sections and sounding curves,* these provide vital information about the subsurface layers' characteristics by visualizing resistivity data obtained from geophysical surveys. These illustrations aid in the interpretation of probable groundwater-bearing formations. The synthesis and review of these indices aid in analyzing the groundwater potential in Keana town, as well as providing vital information for water resource management and planning.

4. Results and Discussion

4.1 Geoelectrical Characteristics

The results of the data obtained from the field are characterized and presented in form of tables, sounding curves, geo-electric sections and contour maps. Thus, subjecting this data to qualitative and quantitative analysis has enabled the classification of the VES data into curve types. This is because the shape of a VES curve depends on the number of layers in the subsurface, the thickness of each layer, and the ratio of the resistivity of the layers (Schwarz, 1988). The classification ranged from simple three electrical layers to six-layered curves arising from the layer resistivity combinations. The field curves obtained includes; H, A, Q, HK and HQ types, with the H-type being the dominant (see Table 1). The typical VES curve types are shown in Figure 5.

Table 1: Summary Modelling of Vertical Electrical Sounding Results

VES Points	Layers Number	Resistivity (Ohm)	Thickness (m)	Depth (m)	Curve Types	Lithology
1	1	927	2.6	2.6	Q	Top Soil
	2	32	58.7	61.3		Shale
	3	32.4	Infinity	Infinity		Sandy Shale
2	1	274	1.09	1.09	Q	Top Soil
	2	20.1	17.6	18.6		Shale
	3	38.3	Infinity	Infinity		Sandy Shale
3	1	1063	2.893	2.893	Q	Top Soil
	2	38.36	3.098	5.991		Lateritic clay
	3	427.8	5.188	11.18		Sandstone
	4	60.05	Infinity	Infinity		Sands (Aquifer)
4	1	297	9.26	9.26	H	Top Soil
	2	132	38	47.3		Lateritic Soils
	3	4071	6.23	53.5		Sandstone
	4	64336	26.5	80		Sandstone
	5	4077	Infinity	Infinity		Sands (Aquifer)
5	1	132	9.58	9.58	HK	Top Soil
	2	210	12	21.6		Lateritic Soil
	3	21.4	28.9	50.6		Sands
	4	1621	49.475	100		Sands (Aquifer)
	5	8475	Infinity	Infinity		Sandstone
6	1	84.5	1.04	1.04	H	Top Soil
	2	44.2	17.1	18.1		Lateritic Clay
	3	164	11.1	29.2		Sands
	4	812	40.8	70		Sandstone
	5	145	Infinity	Infinity		Sands (Aquifer)
7	1	506	2.12	2.12	Q	Top Soil
	2	44.8	7.14	9.27		Lateritic Soil
	3	300	9.52	18.8		Sands
	4	13.2	23.9	42.7		Sandy clay
	5	564	57.3	100		Sands (Aquifer)
	6	5329	Infinity	Infinity		Sandstone
8	1	120	6.2	6.2	H	Top Soil
	2	802	3.49	9.69		Lateritic Soil
	3	88.9	10.8	20.5		Sandy Clay
	4	476	26.4	46.9		Sandstone
	5	72.3	90.4	137		Sands (Aquifer)
	6	985	Infinity	Infinity		Sandstone
9	1	51.8	2.13	2.13	H	Top Soil
	2	74.2	35.7	37.8		Lateritic clay
	3	31762	33.8	71.7		Sandstone
	4	600	Infinity	Infinity		Sands (Aquifer)
10	1	22.5	3.19	3.19	H	Top Soil
	2	208	10.5	13.6		Lateritic Soil
	3	431	47.6	61.2		Sandstone
	4	53	Infinity	Infinity		Sands (Aquifer)
11	1	2428	1.59	1.59	H	Top Soil
	2	24.75	5.791	7.381		Lateritic Soils
	3	221	10.38	17.76		Sandstone
	4	158.8	33.57	51.33		Sands (Aquifer)
	5	183.8	Infinity	Infinity		Sands (Aquifer)
12	1	70.1	3.42	3.42	A	Top Soil
	2	36.1	5.09	8.51		Lateritic clay
	3	1952	9.44	17.9		Sandstone
	4	131	34.5	52.4		Sands (Aquifer)
	5	1302	Infinity	Infinity		Sandstone
13	1	93.2	4.39	4.39	H	Top Soil
	2	78	7.21	11.6		Lateritic clay
	3	46.6	15	26.6		Sandy clay
	4	332	53.3	79.9		Sands (Aquifer)
	5	5768	Infinity	Infinity		Sandstone
14	1	321	1.48	1.48	H	Top Soil
	2	137	14.4	15.9		Lateritic clay
	3	485	45.6	61.5		Sands (Aquifer)
	4	12.1	Infinity	Infinity		Shale
15	1	366	2.12	2.12	QH	Top Soil
	2	17.8	14.6	16.8		Lateritic clay
	3	153	24.4	41.1		Sands (Aquifer)
	4	2.16	Infinity	Infinity		Shale

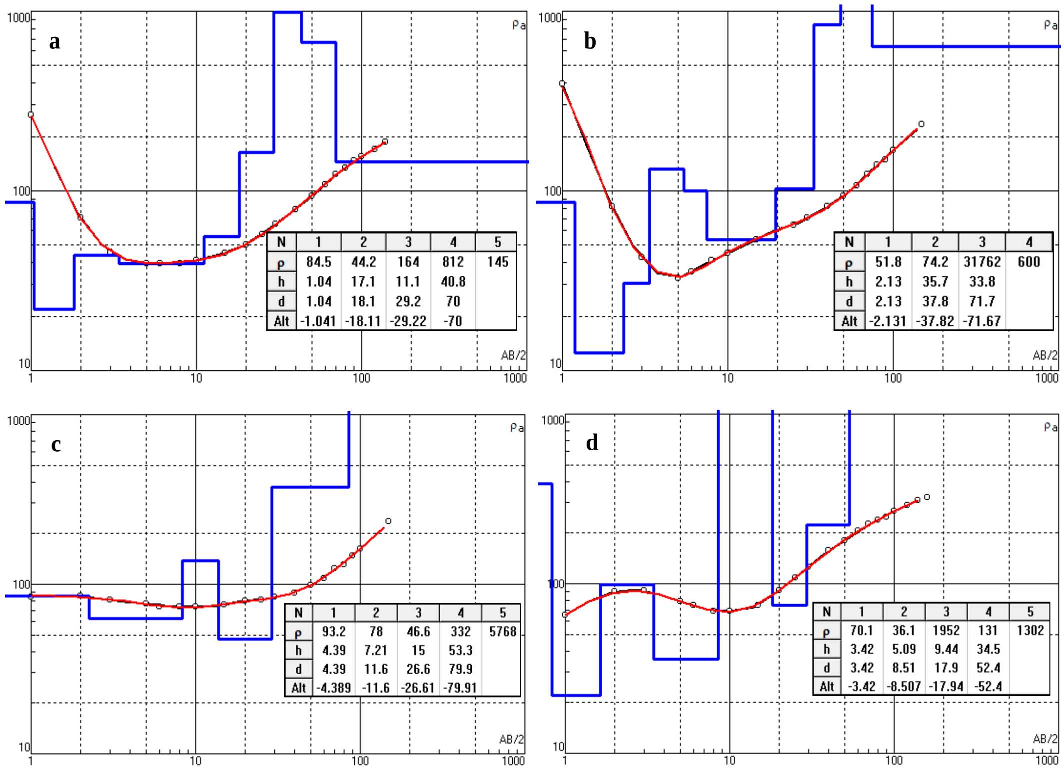

Figure 5: A typical VES curve type from the Study area; (a&b) H - Curve Type (VES 6&9) Main market (c&d) A - Curve Type (VES 14&12) Osana's Palace

4.2 Aquifer Resistivity and Depth

Aquifer apparent resistivity and depth across the study area have been determined from VES data and are presented in the form of contour maps (Figure 6). The minimum aquifer apparent resistivity is around 30 Ωm near FGGC while the maximum apparent resistivity is about 4077 Ωm near the main market and taxi park among others. The mean aquifer apparent resistivity in the study area is approximately 569.9 Ωm (Figure 6a). Depth to aquifers has been deduced from sounding results, indicating that the water-bearing zones are shallower in areas around the southern part (i.e., Osana's palace, GGSS etc.) with a depth of 30 m and much deeper in areas around central apart (i.e., Keana main market and motor park etc.) with a depth varying from 75 to 120 m. Whereas, areas around FGGC Keana have a depth greater than 120m which is exceptionally deep compared to other adjoining areas (Figure 6b).

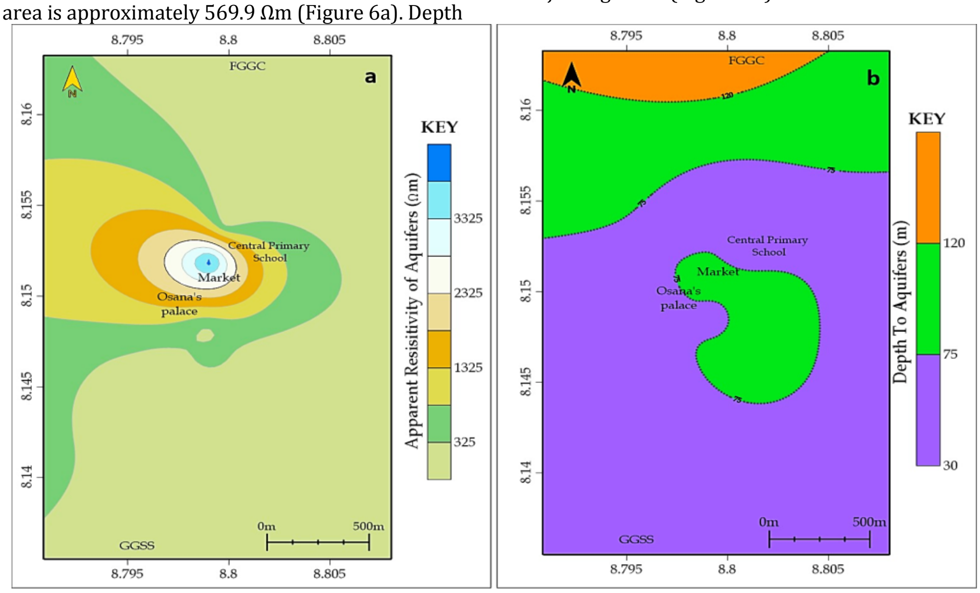

Figure 6: (a) A plot of Aquifer Apparent Resistivity in Ωm (b) A plot of Depth to aquifer layers of the Study area in meters.

4.3 Iso-Resistivity Model

Iso-Resistivity Model across the Study Area was calculated and presented in table 2. An iso-resistivity map is a qualitative interpretative tool which shows possible variations in resistivity at the given electrode spacing and does not give the true resistivities of a definite geo-electric layer (Uchenna et al., 2013). Contour maps of the iso-resistivity values at specific depth intervals of AB/2 equal to 10 m, 20 m, 40 m, 60 m, 80 m, 100 m, 140 m and 200 m were generated (Figure 7). The contour maps revealed a continuous difference of resistivity values with depth, suggesting a high resistive material at a greater depth of 200 m, with an average apparent resistivity of 231.07 Ωm. These were inferred as coarse grain sandstone, and a lower resistive material at a shallower depth of 10 – 20 m, also with an average apparent resistivity of 71.567 - 71.667 Ωm referred to as fine to medium grain sandstone. So, at an intermediate depth of 80 – 100 m, having an average apparent resistivity of 134.3 – 131.8 Ωm correspond to conductive materials inferred as medium grain sands, the water-bearing unit.

A similar trend is maintained in all the iso-resistivity plots from AB/2 equal to 10 m, 20 m, 40 m, 60 m, 80 m, 100 m, 140 m and 200 m, revealing very low resistivity values in the northern and southern part i.e., areas around FGGC Keana and GGSS Keana to a depth of over 200 m. However, from the above findings, it was deduced that the extreme northern section of the study area may likely appear to be unproductive of groundwater to a depth less than 150 m, this is because the area is suspected to be underlain by bands of shale of Keana Formation. (Figure 7).

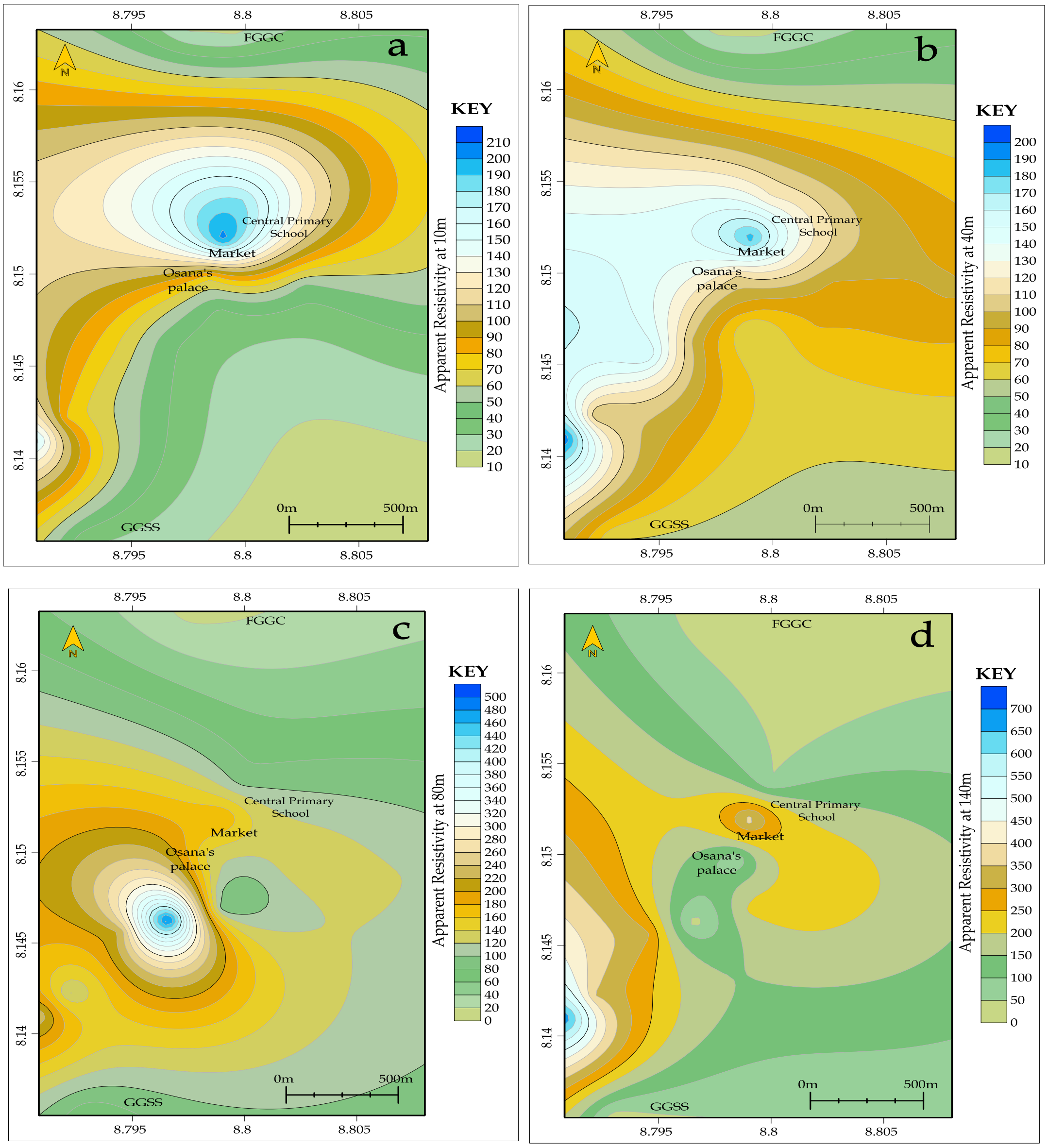

Figure 7: Iso-Resistivity Contour Map of the Study Area (a) AB/2=10m (b) AB/2=40m (c) AB/2=80m (d) AB/2=140m

4.4 Geo-Electric Models

Interpretations from VES carried out around the study area (Table 1) were used to generate geo-electric models or cross sections with three (3) major profiles which include; A-A', B-B', and C-C' were taken for interpretation . Four to six distinct geo-electric layers representative of the sub-surface lithology in the study area were noted. However, two of the cross-sections covering the main habitable areas are presented below and were used to infer the groundwater potentials of the study area (Figure 8).

Table 2: An Iso-resistivity value across the Study Area

VES NO	AB/2 (m)=10	AB/2 (m)=20	AB/2 (m)=40	AB/2 (m)=60	AB/2 (m)=80	AB/2 (m)=100	AB/2 (m)=140	AB/2 (m)=200
1	19	21	17	14	17	21	20	15
2	17	16	17	17	22	23	22	13
3	180	117	122	87	73.5	71	50	34
4	205	151	186.5	180	219.5	307	377	415
5	71	92	107.5	132	101.5	44.5	61	143
6	38	47	83	107	152	141	183	38
7	36.5	43	58.5	83	105	133	210	33
8	44	31	96	500	190.5	156	30	230
9	47	62	88	139	136.5	154	233	254
10	31	53	79	111	143	143	215	236
11	55	64	91.5	118	126.5	134.5	163	250
12	67.5	96	160.5	222	239.5	254	317	367
13	77	80	100	118	133.5	123	345	453
14	154	160	200	236	297	243	690	960
15	31.5	42	60	62	57.5	29	27	25

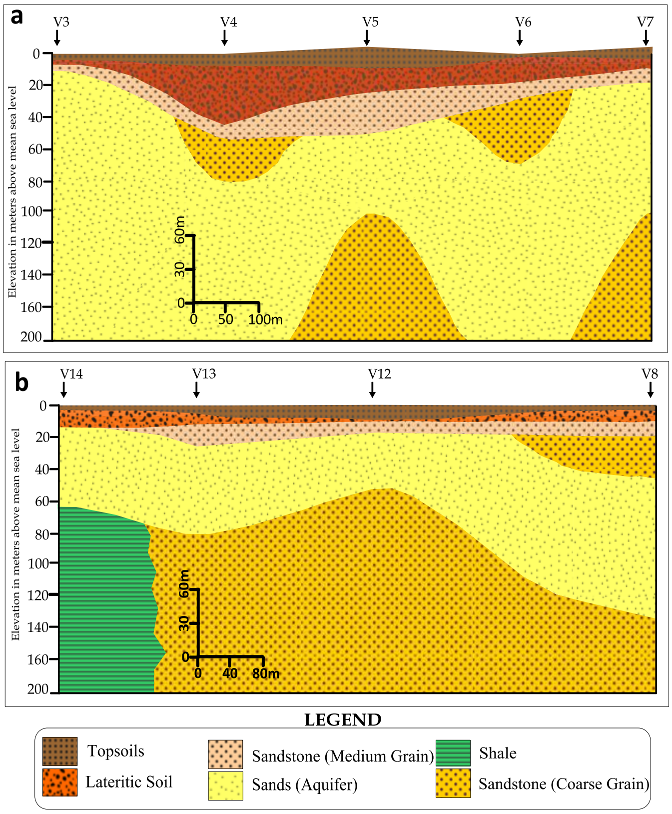

Figure 8: (a) Interpretative Cross-Section along B-BI Profile line (b) Interpretative Cross-Section along C-CI Profile line of the Study Area.

Profile B-B^{I} is 800 meters long and is oriented north to southward of the study area. Which cut across the opposite police station, former savanna bank, motor park, main market and taxi park areas. The section revealed Five to Six lithologic units with least conductive (coarse sandstone) layer forming the basal unit but also occur at some shallow depth in some areas, having resistivity values between 427.8 – 64336 Ωm; this is overlain by the sands (medium grain) unit with resistivity ranging from 60.05 – 4077 Ωm; this unit is also overlain by the sandstone (medium to fine grain) with resistivity ranging from 21.4 – 4071 Ωm; this is overlain by the lateritic unit with resistivity ranging from 38.36 – 210 Ωm; Overlying this layer is the Topsoil unit with resistivity ranging from 84.5 to 1063 Ωm (Figure 8a).

Profile C-C^{I} is 700 km long and trends southwest to northeastward of the study area cutting across Government Girls Secondary School Keana (GGSS), Obene primary school and close to Osana's palace. The section also revealed the occurrence of four to six geologic units with the sandstone (coarse grain) layer at the base, though missing at VES 14 with the emergence of a shale unit with a resistivity of 12.1Ωm, has resistivity values ranging from 985 to 5768 Ωm; this is overlain by the saturated sand unit with resistivity ranging from 72.3 to 485 Ωm; overlying this is another sandy unit, also missing at VES 14, has resistivity ranging from 46.6 to 1952 Ωm; the sandy unit is overlain a lateritic soil having resistivity ranging from 36.1 to 802 Ωm; overlying this, is the topsoil layer with resistivity ranging from 70.1 to 93.2 Ωm (Figure 8b).

5. Conclusions

In groundwater research, the electrical resistivity sounding technique is frequently used and has found critical applications all over the world. The geoelectric examination in Keana area showed the existence of subsurface geological formations that are conducive to groundwater storage. The findings reveal the presence of prospective aquifers, which could serve as viable groundwater supplies. Numerous groundwater potential zones exist, allowing for more efficient water resource management and distribution. So, this present study has helped map out zones for drilling productive boreholes in the study area. The VES analysis reveals that the Central part i.e., areas around VES 4 to 10 (central primary school, motor pack, main market etc.) and the Southern parts i.e., areas around VES 11 to 15 (which encompasses Osana's Palace, Obene Primary School, White House and GGSS Keana), of the study delineate aquiferous zones of the Keana area on an average depth of 100 m to 70 m as high to moderate yield is envisaged. Whereas the northern parts i.e., areas around VES 1 and 2 (FGGC), would have serious underground water problems. So, boreholes drilled in these areas that are shallower than 100 m may be unproductive. Yet, this recommendation does not supersede geophysical studies before drilling and the need to have a geologist at the site during drilling. It is therefore hoped that the results of this study will be invaluable to the planning of water supply schemes within the area. Additionally, the geoelectric analysis in Keana Town showed promising groundwater potential zones with appreciable depths and adequate water quantity for various applications. As a result, this contributes to a better understanding of aquifer properties and the long-term sustainability of water resources.

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Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Abdullahi Aliyu Itari, Iliyasu, Abdullahi Yerima, Umar, Nuhu Degree and Abdullahi, Saidu respectively. The first draft of the manuscript was written by Umar, Nuhu Degree and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Competing Interest

The authors declare that they have no competing interests.

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