IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 6, Issue 6 Ver. II (Nov. – Dec. 2018), PP 23-32
www.iosrjournals.org

Geology and Groundwater Potentials of a Basement-Sedimentary Boundary of Masuri Area of Bauchi State, North-East Nigeria

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Abstract: *The failure rate recorded in most groundwater projects has informed the general acceptance of geophysical survey as a prerequisite to any successful water well project***.** *The Vertical electrical sounding (VES) technique is extensively gaining wider applications in environmental, groundwater and engineering geophysical investigations. Geological studies of the Masuri area and its environs indicated biotite granite, granite-gneiss and rocks of the Keri-Keri Formation as the major rock types. A total number of 14 VES locations designated for the hydrogeological studies have indicated the predominance of consolidated formations with primary porosity but lacking in permeability. The interpretation of the VES has indicated 3 to 4 layer cases as top soils, sandstone, claystones and crystallinebasement. The layers with low resistivities correspond to the claystones. The study area is generally underdeveloped in terms of groundwater resources as acute water shortage has been witnessed in many places as evidenced from five (5) dry wells found in the area.*

Keywords: *Geology, Keri-Keri Formation, Masuri, Vertical Electrical Sounding, Iso-resistivity*

Date of Submission: 07-12-2018 Date of acceptance: 22-12-2018

I. Introduction

Groundwater is, no doubt, a hidden; replenishable resource whose occurrence and distribution greatly varies according to the local as well as regional geology, hydrogeological settings and to a certain extent the nature of human activities on the land such as mining, construction and manufacturing. Urbanization, industrialization and population explosion are the main factors that compel human beings to look beyond surface water and explore the groundwater resources for domestic and industrial uses (Dan Hassan, 1991).

The failure rate recorded in most groundwater projects has informed the general acceptance of geophysical survey as a compulsory prerequisite to any successful water well project. The electrical resistivity method employing the Vertical Electrical Sounding (VES) technique is extensively gaining wider applications in environmental, groundwater and engineering investigations. This is due to the fact that its field operation is easy, the equipment are portable with greater depth of penetration and can be interpreted using computer software (Dan Hassan, 1991).

The present work is aimed at providing a detailed geologic information as well as the groundwater potentials of the area around Masuri. The area is located within a sedimentary/ basement boundary in Alkaleri local Government (Alkaleri sheet 150N.E.) which lies between latitudes 10^0 15’ 00” & 10^0 18’ 11.52” N and longitudes 10^0 15’ 36.45” & 10^0 18’ 55.17” E (Fig.1). It covers a total land mass of about 36 square kilometers and is accessible mainly through footpaths and one major road (Bauchi-Gombe Federal Highway).

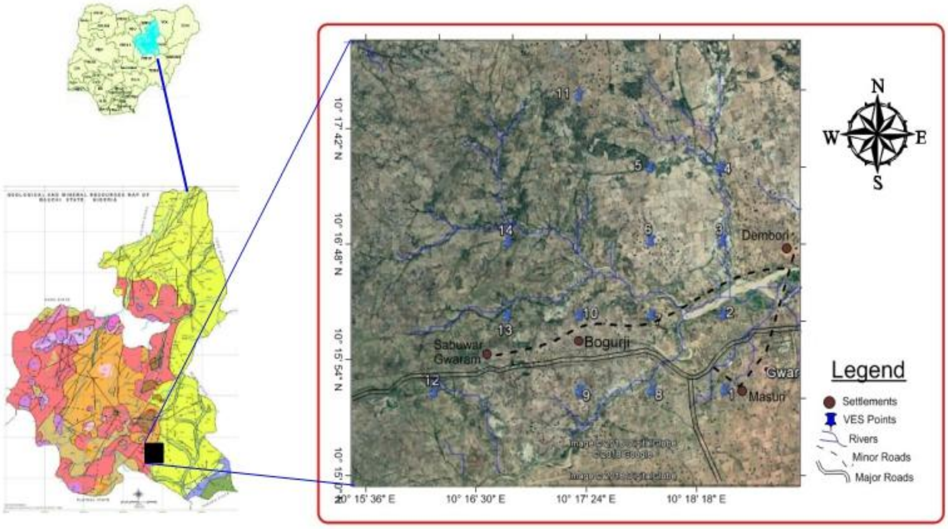

Fig. 1: A Satellite Image of the Study Area (Google Earth)

The area experiences two main seasons: rainy and dry seasons. The rainy season usually commences from May and ends in September with minimum rainfall of about 700mm per annum in the north to a maximum of about 1,300mm per annum in the south. The vegetation is typically Sudan Savannah type comprising widely dispersed trees (Ibrahim, 2010). The major drainage system of the area is controlled by the major river Masuri with streamlets, the drainage pattern is dendritic (Fig. 4) and influent in nature. The main soil type in the area is laterites, sandy and clay soils, with the lateritic soil restricted to the highlands and foot hill regions. The sandy soil is exposed along the course of the Masuri River. The clay loam is found in the low lying flat terrains which serve as the cultivated lands. The thickness of the soil zone varies from less than 1m to about 3.3m.

II. Study Area

2.1 Geology, Geomorphology and Hydrogeology of Masuri Area

The area under study is mainly underlain by crystalline rocks which belong to the Nigerian Basement Complex, thought to be mostly Precambrian in age and Tertiary sedimentary rocks.

Basement Complex

The rocks of the Basement Complex are the migmatites, migmatite-gneiss, quartzite complex and granite-gneiss. They form the oldest rock group and are presumably of Late Precambrian to Early Paleozoic age (Oyawoye, 1970). The older granite suites are presumably porphrytic biotite granite or biotite-hornblende granite.

Sedimentary Formation

Kerri-Kerri Formation

The Kerri-Kerri Formation represents a record of Early Tertiary sedimentation of clastic sediments in the Upper Benue Trough, Northeastern Nigeria. This formation is a Post-Santonian sequence deposited under continental environment represented by fluvial, deltaic, marginal lacustrine and transitional deposits (Dike, 1993).

It is essentially composed of coarse-grained sandstones, clayey grits, siltstones and claystones, with the claystones dominating the lithology in most places. Three distinct lithofacies have been recognized within the Kerri-Kerri formation (Adegoke, et al., 1986). These are the ferrogeneous sanstones, the clayey sandstones and the laterites.

The area of study has a highly undulating terrain with hills and ridges occupying the northern portion with maximum height of 478 m above Sea level and minimum height of 386 m above Sea level as reflected in the digital elevation model (Fig.2).

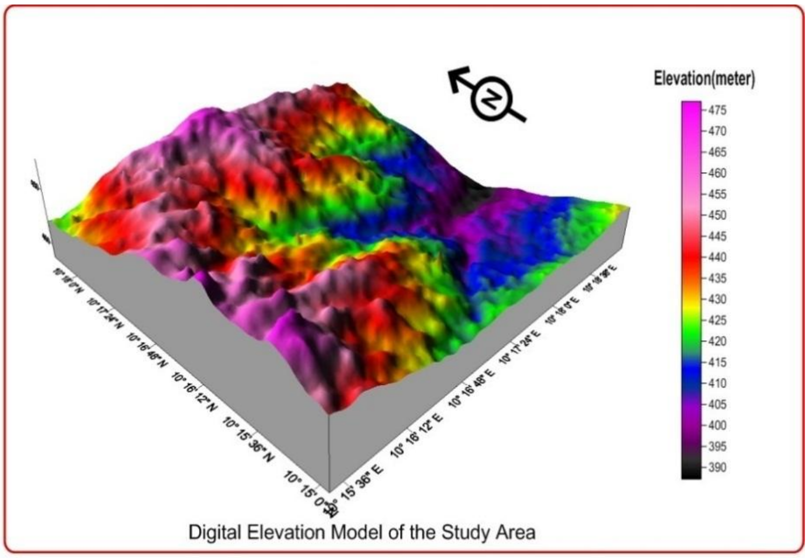

Fig. 2: Digital Elevation Model of the Study Area

The hydrogeology of the area is broadly divided into two in accordance with its geological settings; the Basement Complex and the Kerri-Kerri Formation. The weathered cover of the Basement Complex forms an aquifer with limited resources; hence, the water contained in this aquifer is subject to marked seasonal level fluctuation.

The fractured zone on the other hand, constitutes a richer aquifer with resources that tend to be constant on the rock formations. The greater the total thickness of the weathered and fractured zones forming the aquifer, the greater its water bearing capacity. Thus, the maximum groundwater resources in the Basement Complex are to be found along the main tectonic lines which constitute the preferential flow paths for the groundwater.

The Kerri-Kerri Formation is chiefly composed of permeable sandstones. Where sufficiently shallow, the permanent groundwater is the main source of water supply in most areas underlain by this Formation. Clay lenses in the Formation sometimes give rise to perched aquifers which can be of great importance locally. Water depth contours in this Formation on well correlation show the groundwater ridges are present below a number of streams. This factor may be important in locating some supplies such as the case of Darazo in the State.

The general trend of the major rivers in the area is from North to south and west to east. The important rock units in the area are Granite-gneiss and the rocks of the Keri-Keri Formation (sandstones and claystones). The area been part of the upper Benue trough; is structurally disturbed and influences the geology and the drainage pattern to a large extent (Benkhelil, 1989).

III. Methodology and Survey Design

The method of mapping along profiles from one outcrop to another taking note of river channels that revealed sub – surface lithology was used in a systematic manner in the field in order to understand the geology of the area. Climbing of hills, structural measurements were taken using compass clinometer, while Samples of fresh rocks units were taken at each location with coordinates labelled using GPS and pencil.

For the resistivity studies, the electrical method was employed. The application of electrical methods is entirely dependent upon the electrical conductivity of the subsurface strata under survey, which is largely governed by the grain size distribution and water within thestrata (Khan et al., 2018). The resistivity method can furnish information on sub-surface stratigraphy which might be unattainable by other geophysical methods.

The electrical investigation of the study area involves the characterization of the resistivities of the various geologic units using Vertical Electrical Sounding (VES) Method. A total of 14 vertical electrical soundings (VES) were carried out adopting the Schlumberger electrode configuration using ABEM Terrameter SAS300B obtained from the Bauchi State Water Board. The current electrodes (AB) were placed 250m apart to obtain information up to a depth of approximately one third of the distance between the electrode separations (Dahlin, 2000) i.e. AB/2 = 125m. The data obtained from the field was processed and modelled using Offix software, for interactive semi-automated interpretation with a view to determine the number of geoelectric layers that make up the area.

Fig. 3: Geophysical Data Acquisition in Progress at Location 12

Presence of water in voids, cracks, or fractures even in minor amounts eases the path for current passage and makes the geological formations relatively conductive. The locations of the VES points are given below (Table 1 and Fig.4).

Table 1: Location of Vertical Electrical Sounding (VES) Points

S/N	LOCATIONS	S/N	LOCATIONS
1	Masuri	8	Masuri
2	Masuri	9	Masuri
3	Dembori	10	Bogurji
4	Dembori	11	Sabuwar Gwaram
5	Dembori	12	Sabuwar Gwaram
6	Bogurji	13	Sabuwar Gwaram
7	Bogurji	14	Sabuwar Gwaram

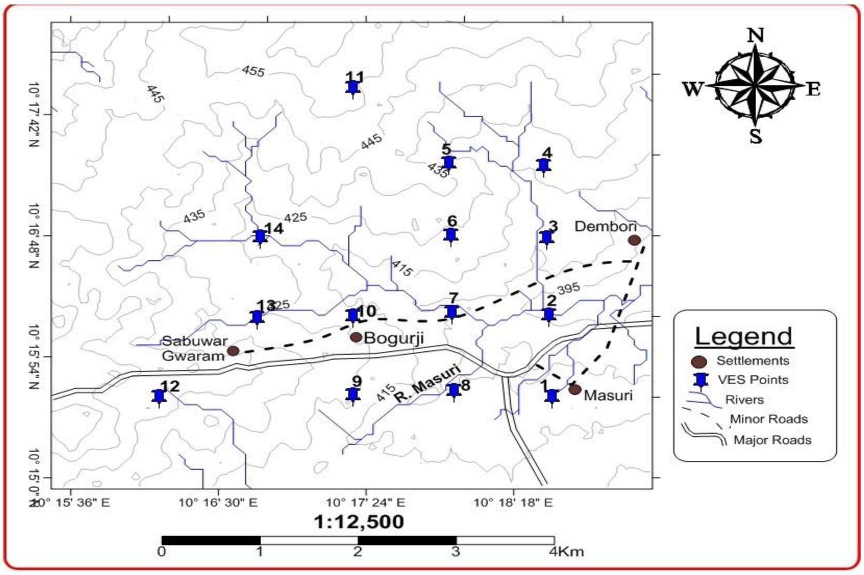

Fig. 4: Topograhic Map of the Area around Masuri Showing the Locations of VES Points

IV.RESULTS AND Discussion

This section presents the results of the geologic field work which comprise the detailed geology of the study area and the refined vertical electrical sounding (VES) data.

4.1 Geology of the Study Area

The geology of the area is divided into two: the Basement Complex and the Kerri-Kerri Formation.

Basement Complex

This is the oldest rock unit within the area. It occupies about 35% of the area by volume (Fig.5). Within this area, two major basement rock types are:

a. The biotite-gneiss and
b. The granite-gneiss

These are part of the Nigerian Migmatite Gneiss Complex (MGC), which are considered basement complex sensu stricto (Rahaman, 1988; Dada, 2006) with ages ranging from Pan-African (600ma) to Eburnean (2000ma). The biotite-gneiss is characterized by strong parallel banding of felsic and mafic minerals (Fig.6), and it is the dominant rock in this portion. The granite-gneiss however, is found in few places generally trending in the NE-SW directions.

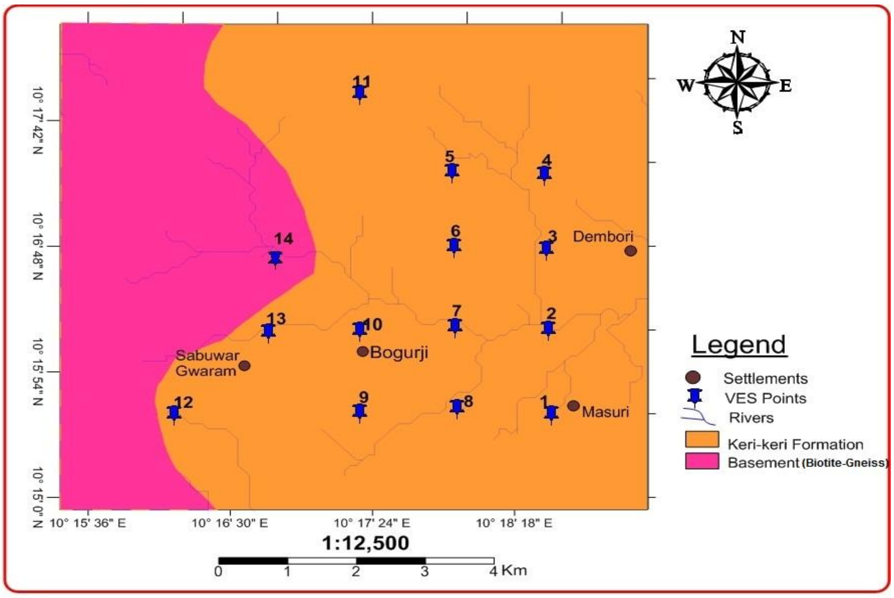

Fig.5: Geologic Map of the Study Area Showing the VES Stations

Fig. 6: Biotite-Gneiss Displaying Strong Parallel Banding of Mafic and Felsic Minerals

Unconformity

This is a buried erosional or non-depositional surface separating two rock masses or strata of different ages, indicating a break in sediment deposition. A non-conformity is a type of unconformity that exists between sedimentary rocks and metamorphic or igneous rocks when the sedimentary rock was deposited on the older pre-existing metamorphic or igneous rock.

The Kerri-Kerri Formation non-conformably overlies the Precambrian Basement rocks. This non-conformity is exposed within the study area at River Masuri (Fig.7), a tributary of River Gongola. The surface is undulating and pebbly indicating a new cycle of sediments deposition.

Fig. 7: Sedimentary/Basement Contact (non-conformity) along Masuri River

Kerri-Kerri Formation

Among the various rock units in the Upper Benue Trough, only the Early Tertiary Kerri-Kerri Formation is outcropping in the study area. This is the youngest rock unit within the area, occupying about 65% of the area by volume (Fig.5). Two litho-facies of the Kerri-Kerri Formation were identified. They are the kaolinitic sandstone facies and the lateritic facies, from the three litho-facies reported by Adegoke (1986), Dike (1993) and Maigari et al. (2005).

The Kerri-Kerri Formation is Paleocene in age, based on paleontological data (Adegoke, 1978) and is composed of sandstones and claystones. The thickness of the Formation varies from few meters to about 320m (Dike, 1993). Stratigraphic and structural studies on the Kerri-Kerri Formation show its structural deposition as that of a slightly asymmetrical graben characterized by a system of normal faults (Adegoke et al., 1986).

Kaolinitic Sandstone Facies

The kaolinitic sandstone facies characterized the northeastern parts of the study area especially in places like Dembori (Figs.8 and 9). The red and purple colouration indicates time of oxidation which occurs during period of low lake level (Adegoke et al., 1985). Also, the clays are probably allogenic clays derived from weathered feldspars while the silt content of this facies was deposited from the coarsest fraction of suspended load. In some areas, oxidized plane favour the laminations in the kaolin, these laminations suggest diastems or extended period of exposure prior to deposition of superjacent beds.

Fig. 8: The Kaolinitic Sandstone Facies of Kerri-Kerri Formation Outcropping at Dembori

Fig. 9: Active Mining of Kaolin Deposit at Dembori

Lateritic Sandstone Facies

The lateritic facies occupy places to the south-northwestern parts of the study area (Fig.10). The lateritic nature of this facies is due to intensive and prolonged chemical weathering, and iron oxide probably Heamatite is a common authigenic cementing agent (Adegoke et al., 1985). Also found in the area is the Basal Kerri-Kerri, which is highly indurated and gravelly as found in Masuri (Fig.11).

Fig.10: The Lateritic Facies of Kerri-Kerri Formation Outcropping along Bauchi-Gombe Federal Highway

Fig.11: Trough Cross-Bedded Sandstone along Masuri River

4.2 Interpretation of the VES Data

There are mainly two forms of interpretation: Qualitative and Quantitative interpretations. The qualitative interpretation is usually a preliminary work that involves explanations of anomaly based on the observations of the plotted curves. It is noted that most of the sounding curves in the area reflect much variation in the curve type. The interpretation of the resistivity curve indicates that, there are three to four layer situations with the first layer represented either by the top soil or lateritic horizon. The second layer is represented mostly by weathered to highly weathered rock, the third layer by partially weathered to fractured rock and the fourth layer by partially fractured or massive hard rocks.

Conversely, quantitative interpretation entails the use of compatible software which gives comprehensive and vital information about the subsurface in terms of layer resistivity, thickness and depth. The resistivity data obtained from VES Studies is applied to prepare isoresistivity maps for 1st, 2nd 3rdand 4thlayers of the whole area.

First layer: This layer is composed of sand mixed with varying content of clay and lateritic material. Its thickness varies from 0.4 to 3.3 m. The resistivity value of this layer varies from 197.5 to 5182.6ohm- m, it has been noticed that VES locations 10 and 13 have exceptionally high resistivity values within the range of 2263ohm- m and 5183ohm- m. This layer is relatively a dry layer and groundwater in this zone occurs in very limited quantities. From the study of the isoresistivity map of the 1st layer (Fig.12), it is found that the top layer is usually lateritic soil with sand mixed with varying contents of clay with resistivity ranging from< 200 ohm- m to > 5000 ohm-m.

About 70% of the area comprises of laterite with resistivity greater than 200 ohm-m. Resistivity value ranging from 200 to 706 ohm-m is located at Masuri and Dembori, while resistivity value ranging from 2260 to 5180 ohm-m is located at Bogurji and Sabuwar Gwaram etc.

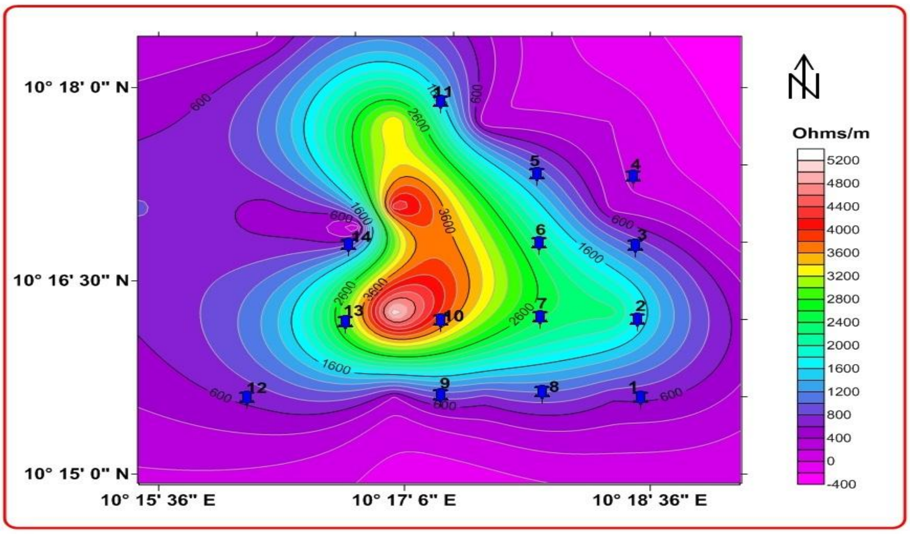

Fig. 12: Isoresistivity Map of First Layer

Second layer: This layer comprises of mainly sandy claystone, clayey sandstone and indurated sandstone. The thickness of this layer varies from 2.8 to 17.9 m. The resistivity of this layer varies from 36.2 to 761 ohms- m. Groundwater occurrence in this layer is very good. The isoresistivity map of the second layer (Fig.13) indicates that the resistivity value ranges <40 ohm- m to >200 ohm- m. Resistivity values of >200 ohm-m are located at Bogurji and Sabuwar Gwaram whereas values within 35 to 199 ohm-m are located at Masuri and Dembori.

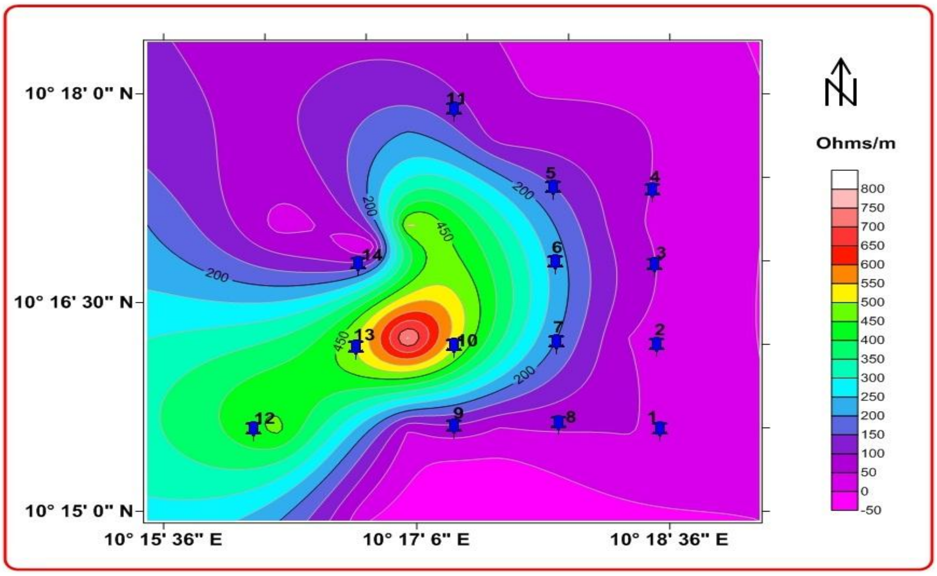

Fig. 13: Isoresistivity Map of Second Layer

Third layer: It represents hard and nonporous rocks in three layer cases (claystones and indurated sandstones) and highly weathered and fractured basement rocks in four layer cases. The thickness ranges from 6.8 m to 36.4m. The resistivity value of this layer ranges from12.2 ohm- m to very high (2471 ohm- m). Groundwater in fractured and weathered zones occurs in large quantities and can be considered as potential aquifers. The isoresistivity map of the third layer (Fig.14) indicates that the resistivity value ranges <13 ohm- m to >2000 ohm- m. Resistivity values of >1500 ohm- m are located at Masuri (VES 8) and Sabuwar gwaram (VES 11) due to presence of basement rocks, whereas values within 12 to 829 ohm- m are located at Masuri and Dembori.

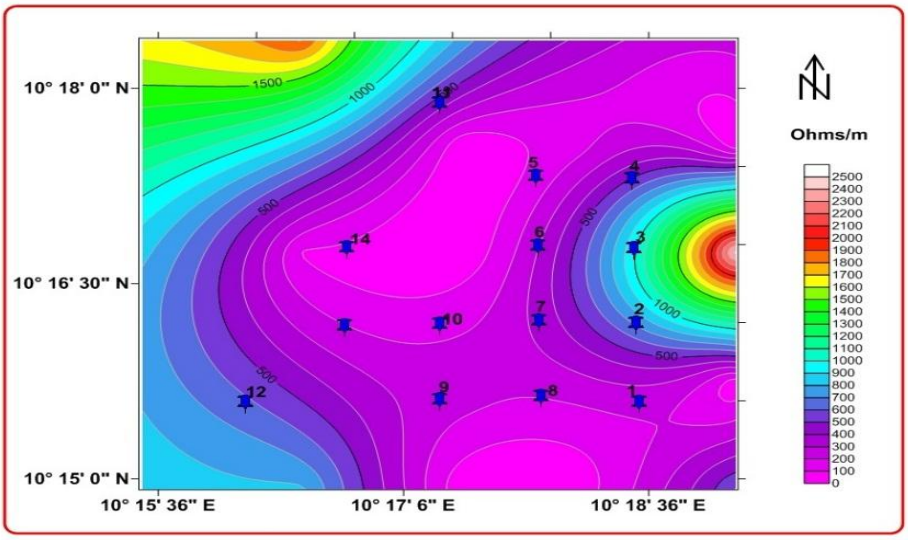

Fig. 14: Isoresistivity Map of Third Layer

Fourth layer: It represents partly fractured rocks and weathered to partly weathered basement rocks. The thickness of this layer varies from 36.5m to infinity. This layer extends indefinitely below the fourth layer and has very high resistivity values. The resistivity varies from 49.2 to 2290.6 ohm-m. Groundwater occurs only in fractured and weathered zones in limited quantities.

Groundwater occurrence is very good in these areas due to presence of laterite, highly weathered granite and sometimes clay, sandy loam and sandy clay. The isoresistivity map of the fourth layer (Fig. 15) indicates a large variation in resistivity values from less than 50ohm-m to more than 2000 ohm- m indicating presence of quite varied rock types such as weathered basement, fractured basement, Sandy claystones and indurated sandstones.

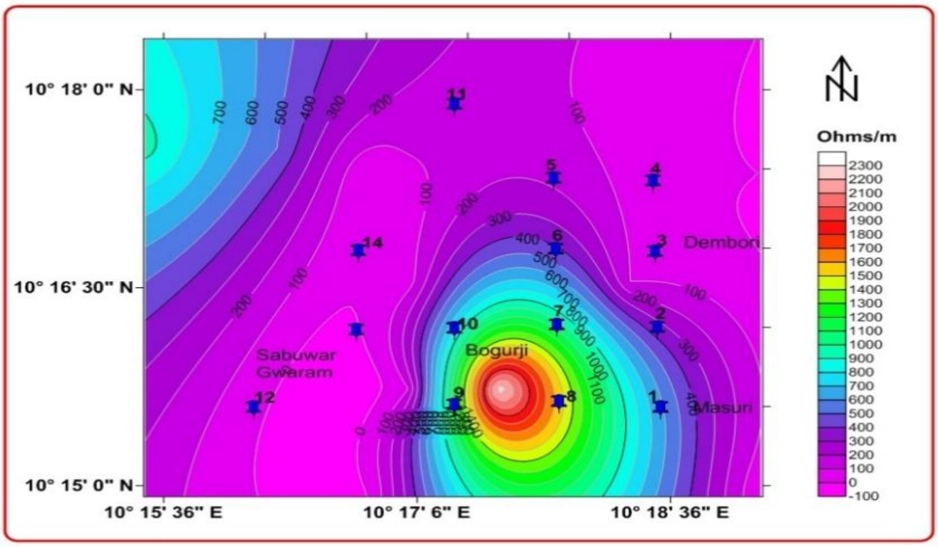

Fig. 15: Isoresistivity Map of Fourth Layer

IV. Conclusion

Geological mapping and Vertical Electrical Sounding (VES) conducted in the study area revealed the major rock types as biotite-gneiss, granite-gneiss and the Kerri-Kerri Formation. The biotite-gneiss is the dominant rock in the basement portion of the area, with the granite-gneiss found only in few places generally trending NE-SW. Two litho-facies of the Kerri-Kerri Formation have been mapped within the study area. They are the kaolinitic sandstone facies, and the lateritic facies. This conforms to the works of Adegoke et al. (1986); Dike (1993) and Maigari et al. (2005).

From the 14 sounding stations, three to four geoelectric layers have been identified as **top soils (1,97.5-5,182.6**Ωm**), sandstones (81.5-815.1**Ωm), **claystones (12.2-112.1**Ωm) and **the basement (828.9-2471.1**Ωm). The layers with low resistivities correspond to the claystones, which are porous but impermeable. Hence, the

groundwater condition of the entire area is poor to moderate and consequently, most places within the study area remain undeveloped, people suffer either due to lack of water or due to over-exploitation.
Based on the study conducted in the area, seismic method is recommended within the study area as the depths to water bearing zones seem to be extensive.

Acknowledgement

We are very grateful to Bauchi State Water Board for providing the equipment used in the exercise.

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