Determination of the Groundwater Potential of Parts of Makurdi Sheet 251 SW, North Central Nigeria, Using Electrical Resistivity Method

[1]Suleiman, T.M., [1]Idris-Nda A., [2]Sidi, A.A., [2]Aisha, M., [2]Hamidu, A., [3]Uti, I.M., and [4]Halima, H.

[1.]Department of Geology, Federal University of Technology, Minna, Nigeria
[2.]Department of Geology, Ibrahim Badamasi Babangida University, Lapai, Nigeria
[3.]Department of Soil Science and Land Resources Management, Federal University Wukari
[4.]Department of Mineral and Petroleum Resources Engineering, Kaduna Polytechnic
Corresponding email: sul.musa@futminna.edu.ng

Abstract

An integrated geological and geophysical studies were carried out to investigate the groundwater potential in part of Makurdi, North Central Nigeria. The schlumberger array was used for the geophysical investigation with a maximum AB/2 of 100m. A total of 20 Vertical Electrical Sounding (VES) stations were established. The model curve types obtained from the resistivity plots include Q, A and H curves. The study area constitutes three to four major lithologic units comprising the topsoil (laterite, clay or loose sand) and the subsequent layers comprising of either sandstone, clayey sandstone, clay or sandy clay. The best of these units as regards to groundwater potential is the uniform sandstone unit owing to its effective porosity and permeability. Isoresistivity maps at depths of 20, 30 and 50m respectively were generated and revealed that a dominant part of the study area has a very good groundwater potential at shallow depths of about 20 – 30m; while at a depth of 50m, only the North-Eastern and South-Eastern parts of the study area have a good groundwater potential. A groundwater potential map was generated at the end of the study dividing the study area into high, moderate and low groundwater potential zones denoted as A, B and C respectively on the map.

1.0 INTRODUCTION

The natural dispensation of water on the earth determines to a large extent the source of water that is of most benefit to man. The ocean/sea accounts for almost about ninety-seven percent (97%) of the global water distribution, glacier accounts for two percent (2%), groundwater accounts for less than one percent (0.67%) while the remaining 0.39% goes to surface water and other sources (Gleick 1993). From the above information; it draws to limelight the importance of groundwater as a means of supply of freshwater owing to its relatively high abundance, less proneness to contamination and natural filtration associated with its process of storage. Groundwater is a cryptical nature's treasure. Its exploitation has continued to remain a crucial issue due to its mostly unalloyed nature and relative abundance. Though there are other sources of water which includes streams, rivers, ponds, just to mention a few; none is as hygienic as groundwater. This is due to the excellent natural microbiological quality and generally adequate chemical quality groundwater possess for most uses resulting from its natural filtration process (Macdonald *et al*., 2003). Surface water is frequently found to be grossly degraded in quality because of its exposure to physical, biological or chemical contaminants (Edet, 2004). Groundwater on its own has less of a degree of contamination when compared with surface water and this has contributed to an increase in the number of boreholes drilled by the government, non-governmental organizations and individuals in Nigeria.

The availability and quality of groundwater in Makurdi, the capital town of Benue State, North Central Nigeria, are determined from a number of composite factors such as porosity and permeability. The Public Water Works which supplied water to all parts of the town has become dysfunctional and moribund. Most residents of the town have adjusted to providing their own domestic supplies by use of shallow hand dug wells (approximately 10 m deep) which are often poorly completed and seasonal in nature. The Makurdi Sandstone which is the main aquifer that supplies water into wells for abstraction is frequently indurated to the extent that well failure is always recorded when it is encountered using manual digging as is the case with all shallow boreholes. The wells are neither cased nor are they properly capped after completion. The immediate surroundings of the wells are inadequately sequestered from unsanitary conditions. Since there was no professional prospecting for the location of water bearing sediments, some of the boreholes have either failed entirely or partially because of uncoordinated drillings. When the rate at which a well is discharge is greater than the rate at which it is recharge, then the well may fail (Davison *et al.,* 1997). The nature of the aquifer is a function of subsurface geological composition that play an important role in determining the circulation of water from the surface (infiltration) to subsurface water through recharge processes (Bashir *et al.,* 2014).

Geophysical site investigations for groundwater exploration are scanty and inadequate in the study area and the hydrogeology is not well developed. The present study is therefore aimed at evaluating the groundwater condition and the nature of the subsurface layers, which will constitute the baseline information about the hydrogeology of the area. The result of the evaluation would be used to characterize the study area into hydrogeological zones based on the aquifer potential to serve as a guide in the development of productive hand dug wells and boreholes.

2.0 STUDY AREA

The study area is located in the North-western flank of Makurdi Local Government Area in Benue State which is the capital of the state. The study area lies between latitudes $07^0$42'25"N and $07^0$45'00"N and longitudes $8^0$30'00"E and $08^0$32'30"E covering a landmass of about 16.25km^2. The topography of the study area is generally low-lying (70-250m) with dominance of undulating plains and occasional elevations of between 400m to 600m above sea level.

Makurdi lies within the Guinea savannah vegetation zone with a few patches of forests. The annual rainfall ranges between 1,500 to 2,000 mm with its peak rainfall in the month of July. Temperatures in March and April are about 38 and 48°C, respectively, while in December/January, the temperature is 27°C (Benue State Water Supply and Sanitation Agency, 2008). Makurdi belongs to the Makurdi Formation which overlies the Albian Shale. It consists of thick current bedded coarse grained deposits. The Makurdi sandstone has a thickness of about 900 m (Offodile, 1976). The southern part of the Benue valley is generally gently undulating and punctuated by a few low hills. But toward the northeast, the relief is exaggerated by hills like the Lammuder and Ligri hills, which rise up to 600 m above sea level. The drainage consists of rivers which meander into the River Benue from the north and south directions.

Geologically, the Benue valley consists of a linear stretch of sedimentary basin running from about the present confluence of the Niger and the Benue rivers to the north east, and is bounded roughly by the Basement Complex areas in the north and south of the River Benue. The elongated trough-like basin is continuous with the coastal basin, and in fact, has been correctly described as the longest arm of the Nigerian coastal basin (Offodile, 2002).

Makurdi has a population density of over 380 persons per km^2 (Nigeria Data Portal, 2006). The study area is accessible by major roads, railways and footpaths.

Table 1: Summary of stratigraphic succession in the Lower Benue Valley (Okurumeh and Oteze, 1996).

Formation	Age	Lithology	Hydrologic Significance
Alluvium	Recent	Coarse grain, poorly consolidated to semi consolidated sand	Good Aquifer
Nsukka	Campano-Maastrichtian	Shales with alternating succession of clays, siltstone and lenses of coal and fine-medium grained sandstone	Aquiclude
Ajali	Campano-Maastrichtian	Sandstones, poorly cemented, fine-medium grained, white colored	Good aquifer
Mamu	Campano-Maastrichtian	Shales, carbonaceous, alternating with sandstones and coal seams	Aquiclude
Nkporo shale	Upper Cenomanian	Shale, calcareous sandstones and limestone	Isolated aquifers but generally an aquiclude
Agwu shale	Lower Cenomanian	Shale, calcareous sandstones and limestone	Isolated aquifers but generally an aquiclude
Eze-Aku/Makurdi Formation	Turonian - Cenomanian	Shales, Siltstone and cross bedded sandstone and limestone	Poor aquifer in sandstone units, but an aquiclude in shaly portion
Asu River Group	Albian	Marine shale, calcareous shales, sandstones, limestones and contact metamorphosed shales	Aquiclude

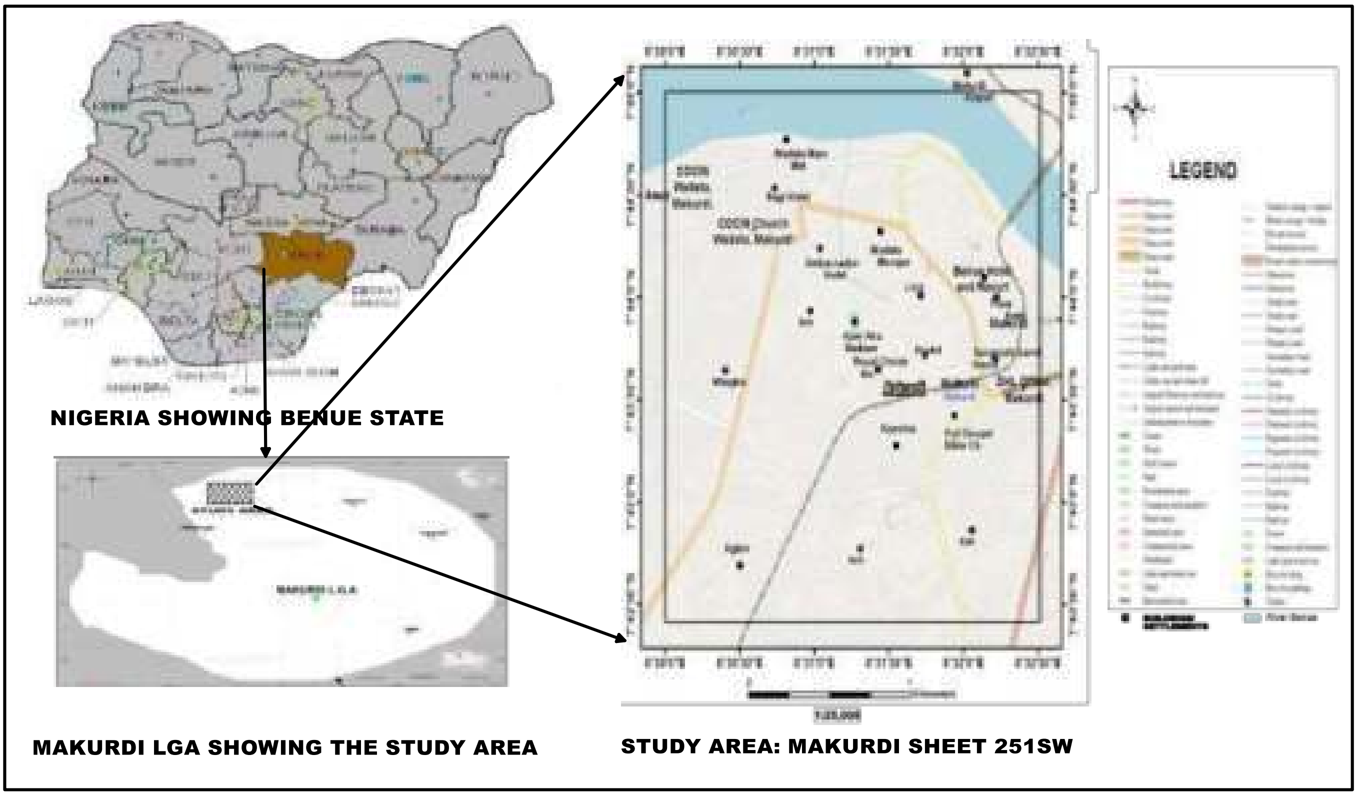

Figure 1: Location of the study area

3.0 METHODOLOGY

The geological mapping of the area was first carried out on a map of scale 1:25,000 prior to the geophysical investigation. The geophysical investigation method adopted for the research was the electrical resistivity method using the Schlumberger array. Different types of geological, geotechnical and environmental problems have been studied using surface electrical resistivity methods (Obiora *et al.,* 2015). The resistivity survey in the study area was completed with twenty Schlumberger electrical sounding (VES) (Figure 2). Rectified resistivity meter was used with maximum current electrodes spacing (AB/2) of 100.0 m, and (MN/2) of 15.0 m. The resistances of the subsurface were measured and recorded against the appropriate potential and current electrodes separation. The depth of penetration is proportional to the separation between the electrodes in homogeneous ground, and varying the electrodes separation provides information about the stratification of the ground (Dahlin, 2001). This method can be used in groundwater to determine depth, thickness and boundary of an aquifer (Zohdy, 1969; Obiora *et al.,* 2015). The Schlumberger electrode configuration was performed using the vertical electrical sounding field procedure to assess the electrical resistivity of the subsurface and the thickness of the aquifer. The apparent resistivity (ρ_a) was determined using

$$\rho_a = \pi . \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] . R_a$$

Where, AB is the distance between the two current electrodes, MN is the distance between the potential electrodes, and R_a is the apparent electrical resistance measured from the equipment. The equation can be simplified to $\rho_a = K.R_a$

Where, K is the geometric factor given by

$$\pi . \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right]$$

Using the conventional partial curve matching technique with two-layer master curves in conjunction with auxiliary point diagrams (Orellana and Mooney, 1966), the initial estimates of VES data was achieved. From this, estimates of layer resistivities and thicknesses were obtained which served as starting points for computer-assisted interpretation. The conventional curves and auxiliary point diagrams (theoretical curves) used in the interpretation helped in obtaining a good fit between the observed field curves and the theoretical curves during total and partial matching. The computer software program WinRESIST was used and the data sets obtained from the manual interpretation stage were keyed as inputs into the computer modeling software (WinRESIST) to generate data for the geoelectric profiles (Figures 4 and 5).

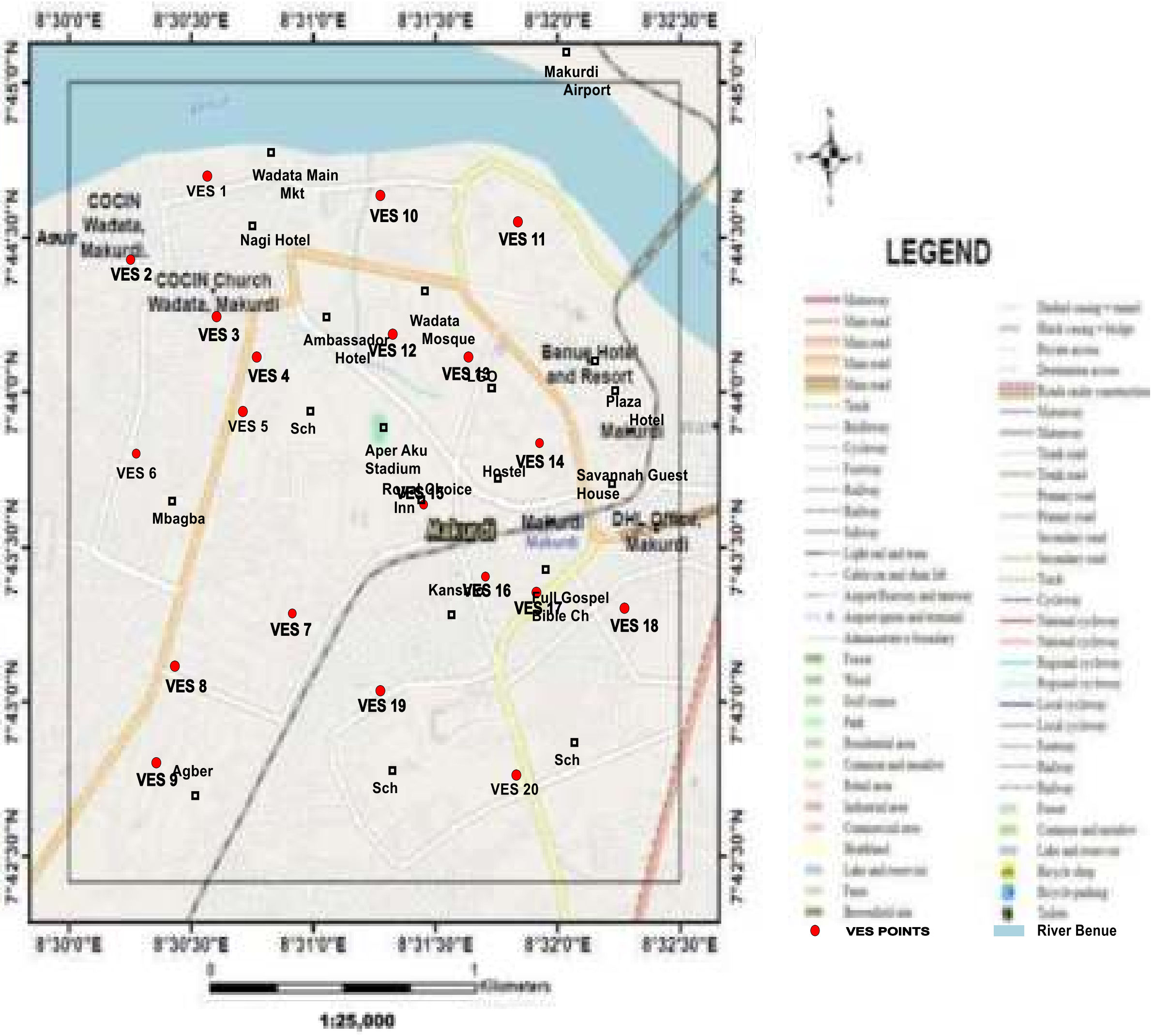

Figure 2: Location of VES points in the study area

4.0 RESULTS AND DISCUSSION

4.1 GEOLOGY

The study area falls within the sedimentary terrain of Nigeria and is composed almost entirely of sandstone formation on the surface; popularly known in most literatures as the Makurdi sandstone/Formation (Figure 3). It is indurated and where exposed appeared to be extremely weathered. Lots of structures such as iron concretions, mottling, lineation, dipping beds, laminations, bioturbation, fractures, graded bedding and ripple marks were observed on most of the low lying exposures (Plates 1-10). Texturally, the sandstone ranges from fine to coarse grain.

Plate I (A-F): A: Mottling of colours as seen in some exposures, **B:** Iron concretions as seen in some exposures, **C:** lineation as seen in some exposures, **D:** Dipping beds, **E:** Thin laminations, **F:** Bioturbation

Plate II (G-J): G: Fractured blocks as a result of physical weathering, **H:** Graded bedding as seen in the base of one of the outcrop, **I:** Ripple marks as seen in some exposures (paleocurrent indicator), **J:** Eroded surface (gully erosion)

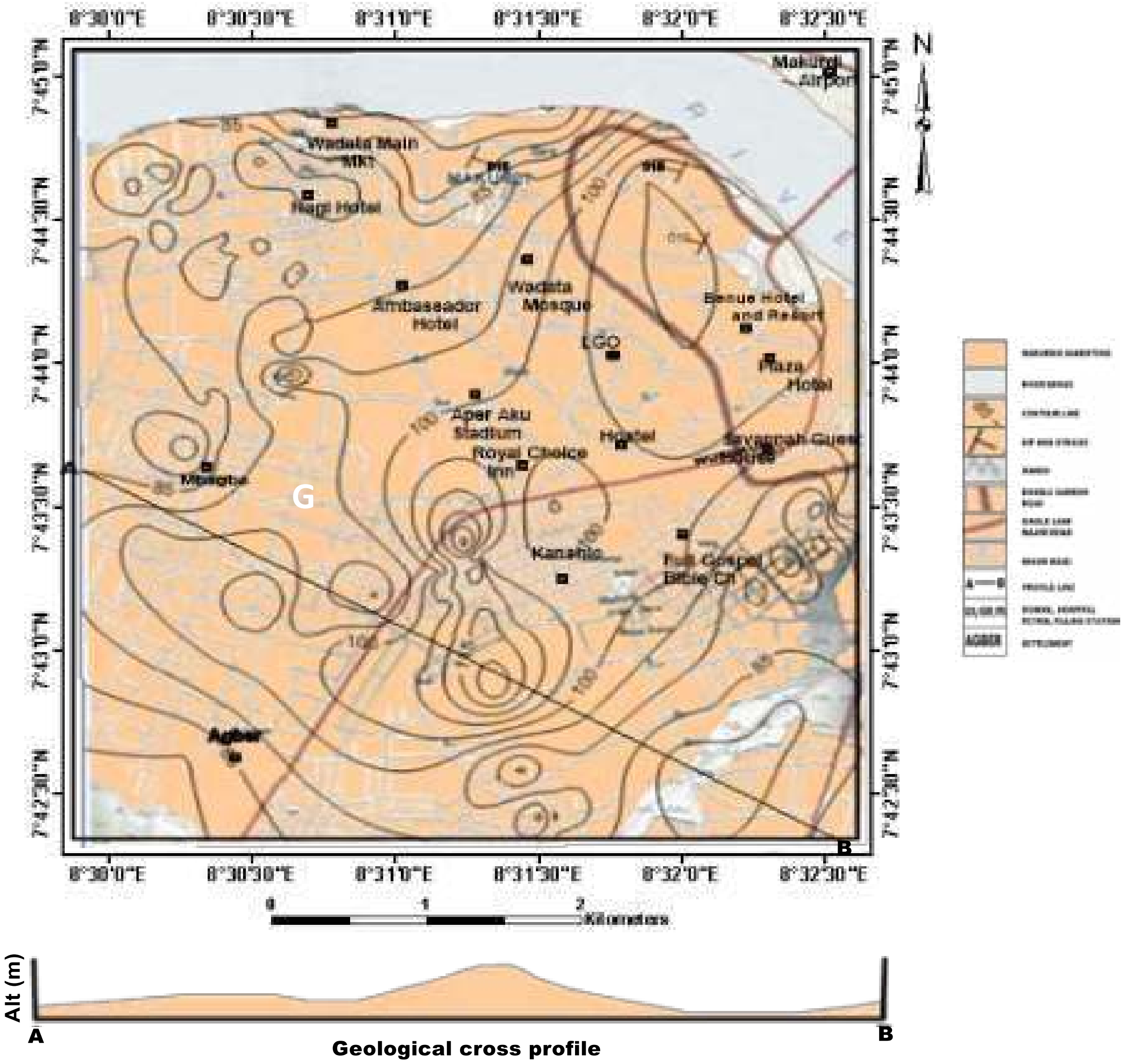

Figure 3: Geological map and cross profile of the study area

4.2 Applied Geophysics

The apparent resistivity curves obtained from the various VES points show three and four layers' earth models. The model curves are characterized by A, H and Q curve types. The layers comprise of the top soil which is either lateritic, sandy clay or loosed sand and the subsequent layers comprising of sandstone, clayey sandstone, clay or sandy clay.

4.2.1 Quantitative interpretation of geophysical investigation

Table 2a: Summary of quantitative interpretation of VES 1 to 10

LAYER	RESISTIVITY ρ (Ωm)/ THICKNESS T (m)/ DEPTH D(m)									
	POINTS OF GEOPHYSICAL INVESTIGATION									
	VES 1	VES 2	VES 3	VES 4	VES 5	VES 6	VES 7	VES 8	VES 9	VES 10
VES POINTS										
Layer 1 ρ1/T1/D1	174/1.8/1.8	94.4/2.3/2.3	361.4/0.8/0.8	122.9/0.6/0.6	175.9/1.1/1.1	31.4/12.7/12.7	88.6/5/5	42.6/1.1/1.1	594.4/2.8/2.8	241.7/0.5/0.5
Layer 2 ρ2/T2/D2	317.4/3.3/5.1	29.7/∞	10.6/6.3/7.1	9.8/9.5/10.1	27.7/1.7/2.8	75.5/∞	43.2/∞	10/3.1/4.1	304/12.3/15.1	80.6/25.4/25.9
Layer 3 ρ3/T3/D3	24.2/∞		32/1.3/∞	31.2/2.8/12.9	70.8/∞			81.1/∞	15.9/∞	49.5/∞
Layer 4 ρ4/T4/D5				29.9/∞						
CURVE TYPE	Q	Q	H	H	H	A	Q	H	Q	Q

Table 2b: Summary of quantitative interpretation of VES 11 to 20

LAYERS	RESISTIVITY ρ (Ωm)/ THICKNESS T (m)/ DEPTH D(m)									
	POINTS OF GEOPHYSICAL INVESTIGATION									
	VES 11	VES 12	VES 13	VES 14	VES 15	VES 16	VES 17	VES 18	VES 19	VES 20
VES POINTS										
Layer 1 ρ1/T1/D1	130/0.9/0.9	124.9/1.8/1.8	83.2/6.2/6.2	273.6/4.4/4.4	502/3.5/3.5	56/0.7/0.7	365/2/2	554/0.4/0.4	363.7/1.4/1.4	74.9/3/3
Layer 2 ρ2/T2/D2	41.4/∞	27.7/∞	48.5/∞	34.1/9.8/14.2	59/11.1/14.7	19.7/∞	47/∞	140.5/8.3/8.7	36.6/∞	17.2/9.1/12.1
Layer 3 ρ3/T3/D3				209.4/∞	1157/∞			91.2/∞		102.1/∞
Layer 4 ρ4/T4/D5										
CURVE TYPE	Q	Q	Q	H	H	H	Q	Q	Q	H

The geo-electric sections (Figures 4 and 5) were generated from the geo-electric parameter derived from the iteration of the model curves (Tables 2a and 2b) and the iso-resistivity maps (Figures 8, 9 and 10). From the geo-electric profiles/sections, a groundwater potential map was generated showing areas with similar litho-stratification and hence similar groundwater potential (Figure 11) which would in turn make exploration for groundwater easier and faster.

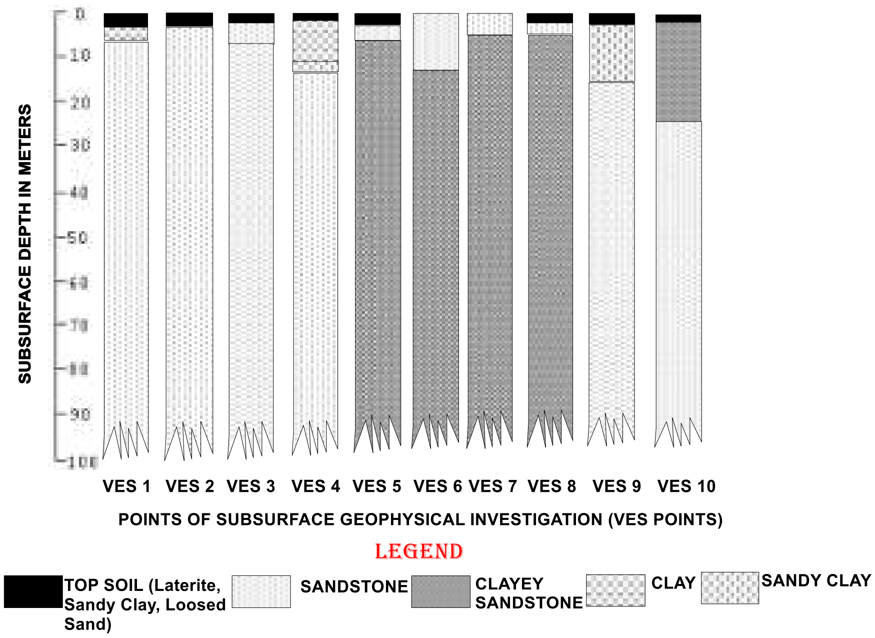

Figure 4: Geoelectric profiles for VES locations 1-10

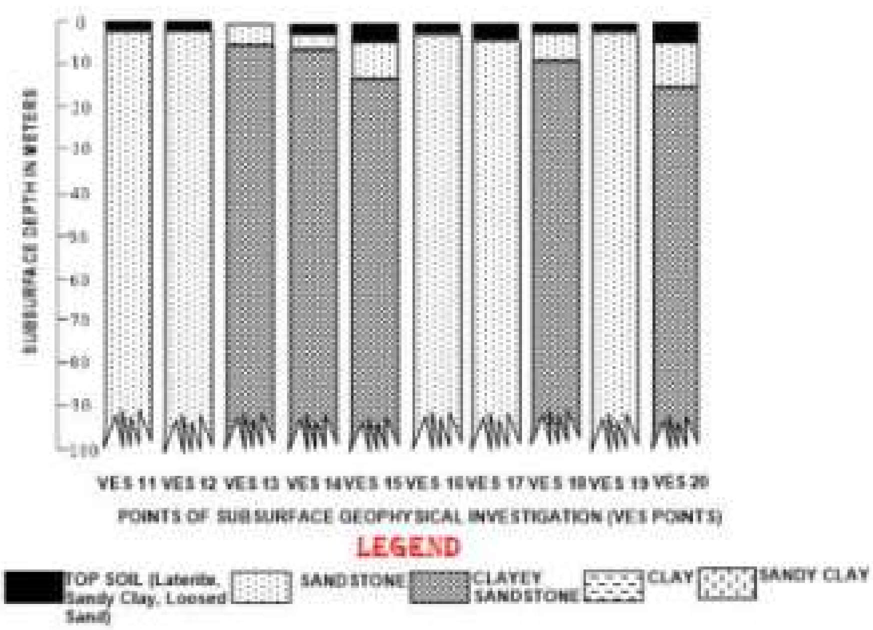

Figure 5: Geoelectric profiles for VES locations 11-20

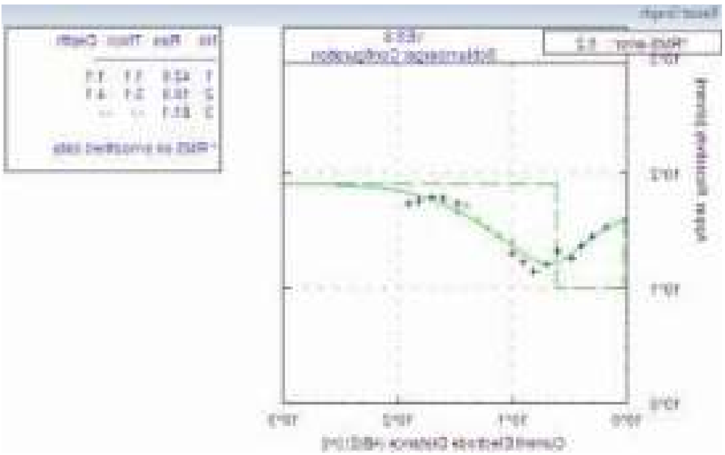

Figure 6: VES 8 Geo-Electric curve

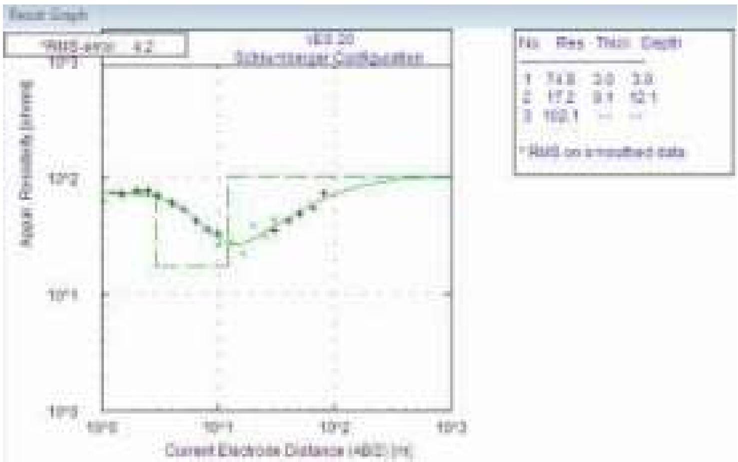

Figure 7: VES 20 Geo-Electric curve

4.2.2 Borehole Data of an Existing Productive Borehole in Makurdi

LOCATION OF BOREHOLE: HIGH LEVEL	**L.G.A: MAKURDI**
DATE OF DRILLING: 31-03-2017	ARRIVAL TIME: 7:00AM
DATE OF COMPLETION OF DRILLING: 01-04-2017	DESK HEIGHT: 1.1m
TOTAL DRILLING: 50M	COMPRESSOR HRS: 12HRS
TOTAL DEPTH CASED: 50M	RIG HRS: 8HRS
NO. OF BLANKS USED: 8	SWL: 6M
NO. OF SCREENS USED: 5	PREL. YIELD: 68L/Min
CO-ORDINATES AND ELEVATION OF BOREHOLE POINT: 743509N, 83215.9E and Elevation: 79m	

Table 3: Borehole log of an existing productive borehole in Makurdi

DATE	DEPTH (M)	TIME INTERVAL	LITHOLOGY/DESCRIPTION	REMARKS
31/03/2017	0 - 1	7:10 – 7:15AM	Dark brown loosed top soil	Dry
31/03/2017	1 - 4	7:15 – 7:50AM	Brownish sandy clay	Dry
31/03/2017	4 - 6	7:50 – 8:25AM	Light brown sandstone	Moist
31/03/2017	6 – 9	8:25 – 9:10AM	Greyish fine-grained sandstone	Moist
31/03/2017	9 – 14	9:10 – 9:50AM	Light brown clayey sand	Moist
31/03/2017	14 – 16	9:50 – 10:55AM	Brown Medium grained sandstone	Wet
31/03/2017	16 – 18	10:55 – 12:00PM	Brown Coarse grained sandstone	Water strike
31/03/2017	18 – 21	12:00 – 1:20PM	Brown fine grained sandstone	More water flow
31/03/2017	21 – 29	1:20 – 3:40PM	Greyish brown coarse grained sandstone	Increase in water flow
01/04/2017	29 – 33	8:00 – 9:30AM	Greyish brown coarse grained sandstone	Increase in water flow
01/04/2017	33 – 39	9:30 – 11:15AM	Greyish brown fine-grained sandstone	Steady water flow
01/04/2017	39 – 46	11:15 – 1:00PM	Greyish brown coarse grained sandstone	Increase in water flow
01/04/2017	45 – 50	1:00 – 2:30PM	Greyish brown fine-grained sandstone	Steady water flow

4.2.3 Isoresistivity

The iso-resistivity maps (Figures 8, 9 and 10) revealed that the area with the highest potential is the North-eastern and South-eastern portion of the study area. This assessment was based on the standard apparent resistivity readings (50 - 120□m) for potential aquifers within the study area (Makurdi) as obtained from previous works in the study area (Table 4).

Table 4: Range of apparent resistivity values for different sediments within the Makurdi environment (Dominic, 2016)

Apparent Resistivity Value (□M)	Anticipated Formation
<20	Shale
21-49	Sandy shale
50-120	Sandy formation
121-300	Sandy clay formation
301-600	Clayey formation
>600	Fresh Basement or lateritic formation

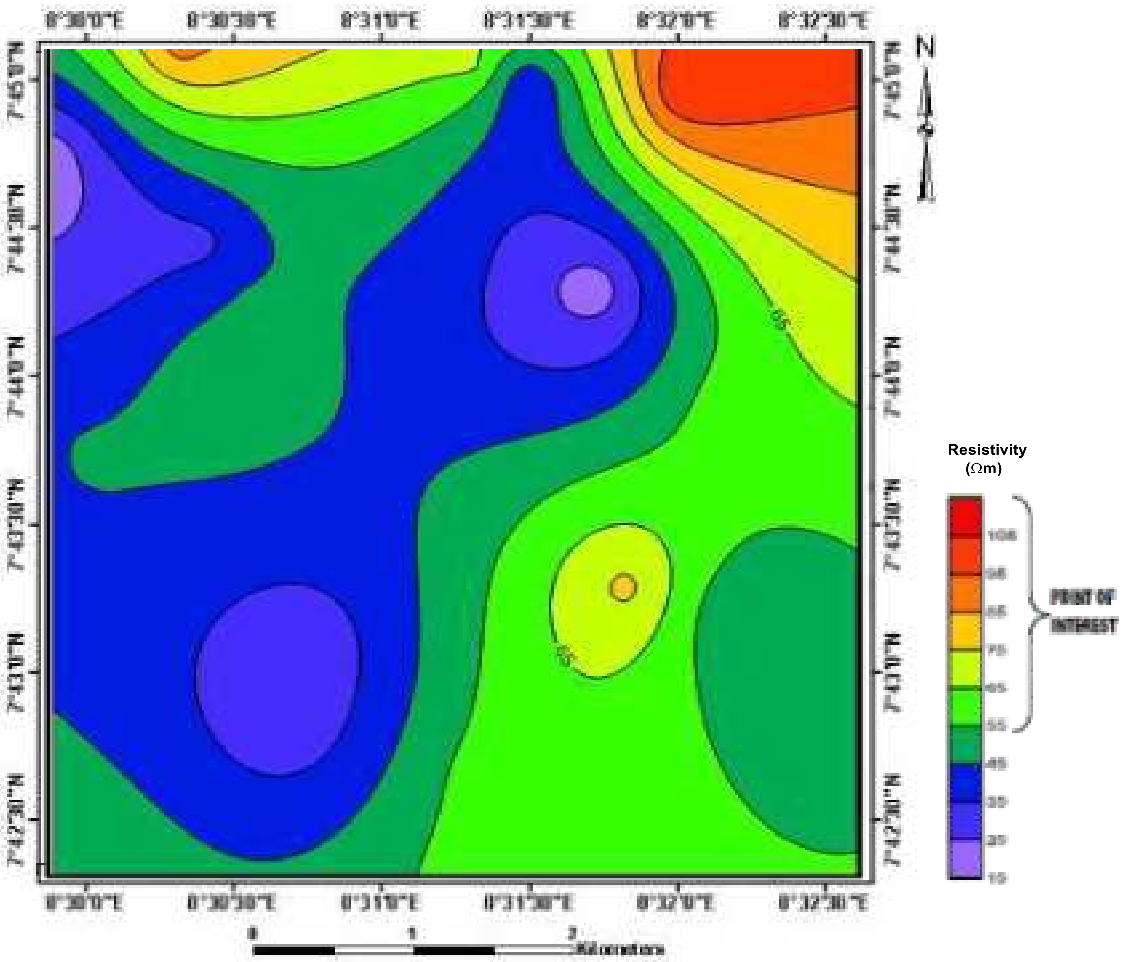

Figure 8: Isoresistivity contour at a depth of 20m

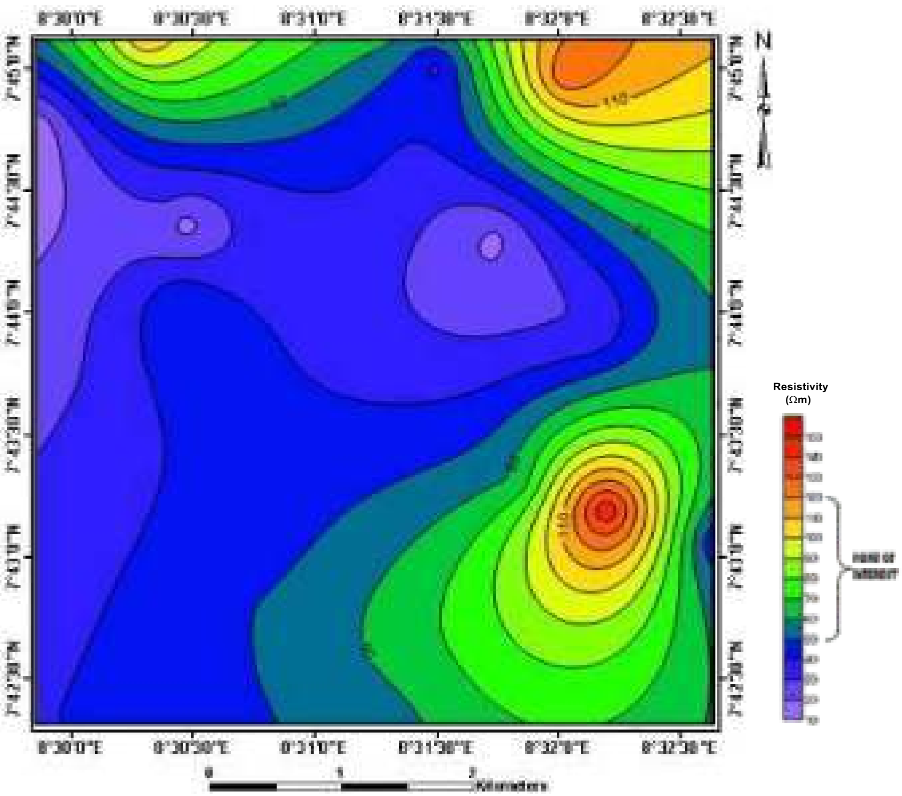

Figure 9: Iso-resistivity contour at a depth of 30m

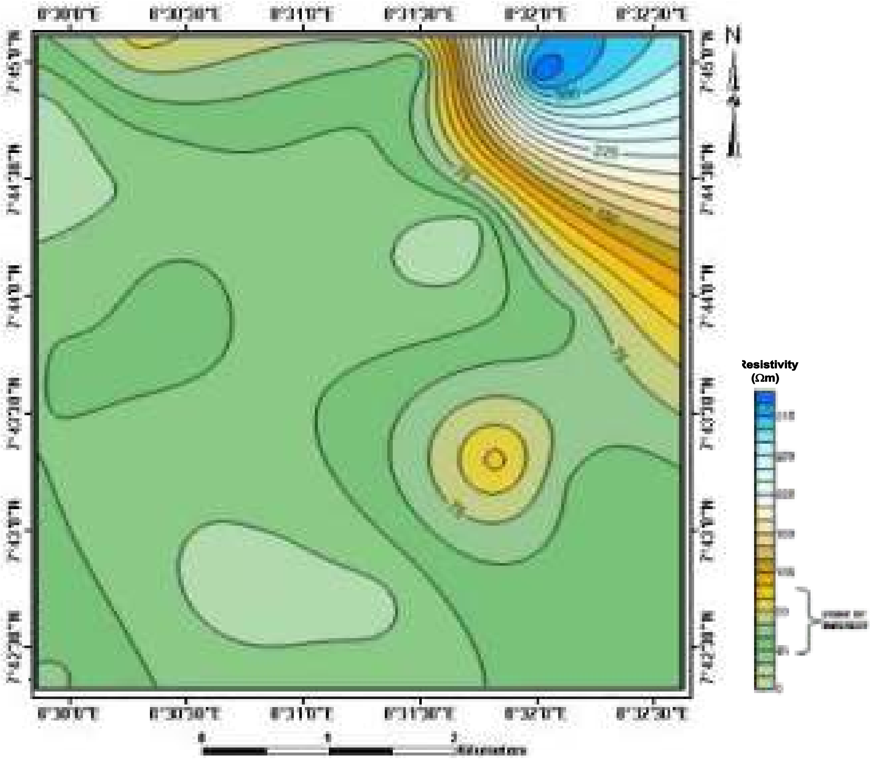

Figure 10: Iso-resistivity contour at a depth of 50

4.3.3 Groundwater potential of the study area

Unlike the basement environment where we are interested in fractures or saturated thick overburden, in the sedimentary environment, we are interested in the most porous and permeable formation or fractured indurated formation which in this case is the sandstone formation. In other to generate the groundwater potential map, we merged together the information from the geo-electric profiles and that of the iso-resistivity maps concentrating on areas with apparent resistivity readings that correlate with the range of apparent resistivity values for sandstone as shown in Table 4.

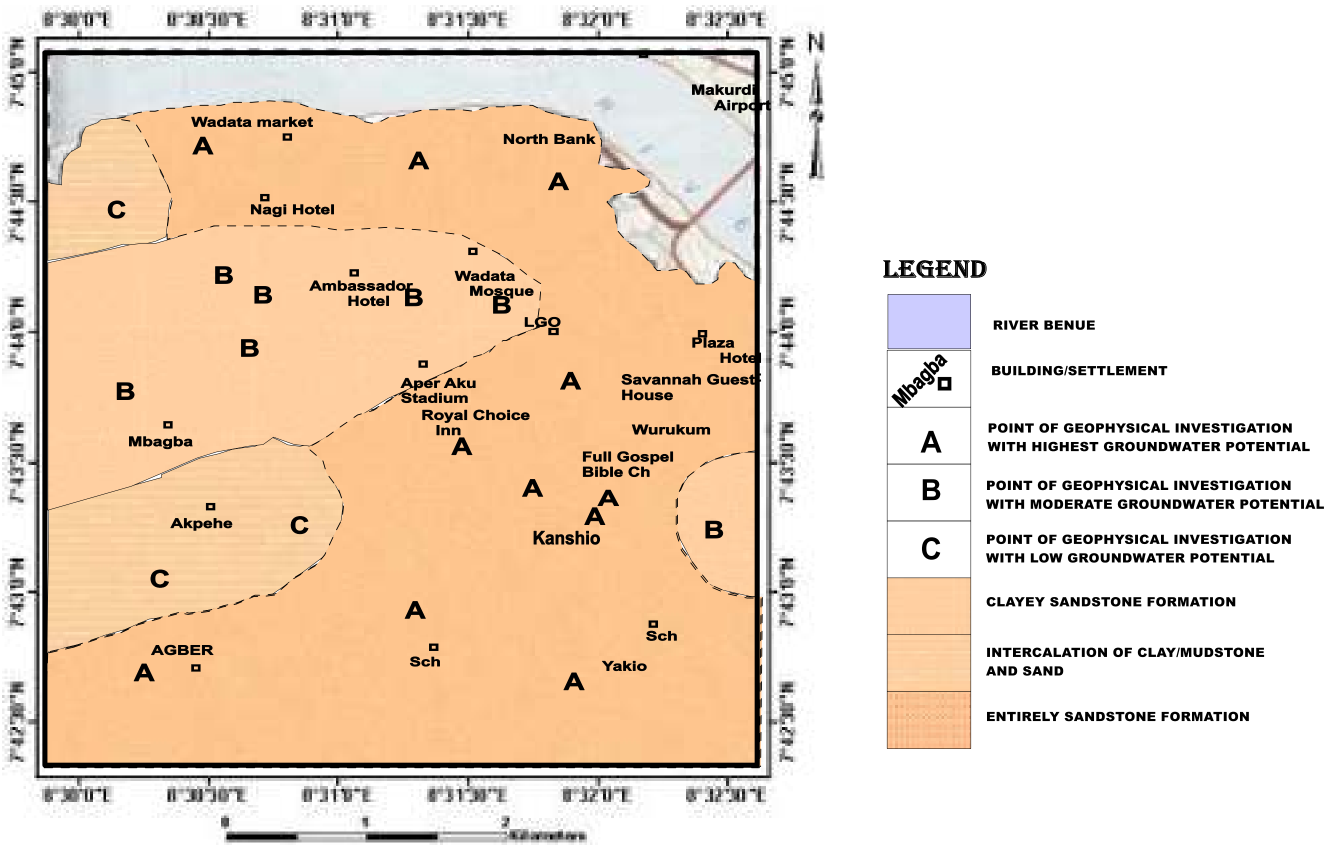

Figure 11: Groundwater potential map of the study area

5.0 CONCLUSION

The study area is entirely sedimentary and is dominantly sandstone with varying amounts of silt and clay. The sandstone is indurated though has undergone a relative amount of weathering as seen in some exposures. The texture ranges from fine to coarse grain. A geological and lithostratigraphic map was produced in other to have an insight on both the surface and subsurface geology. The geophysical investigation revealed that the study area comprises about three to four subsurface stratification comprising the top soil (laterite, clay or loosed sand) and the subsequent layers comprising of sandstone, clayey sandstone, clay or sandy clay. The thickness of these various layers varies with location. Information from the iso-resistivity maps and the geo-electric profiles was used to generate a groundwater potential map which aided in dividing the study area into high, moderate and low groundwater potential areas. The groundwater potential map revealed that a dominant part of the study area has a very good groundwater potential at shallow depths of about 20m – 30m while at a depth of 50m, only the North-eastern and South-eastern parts of the study area have a good groundwater potential.

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