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GEOPHYSICAL CHARACTERIZATION OF AQUIFER SYSTEMS USING VERTICAL ELECTRICAL SOUNDING METHOD IN DEMSA, NORTHEAST NIGERIA

Saleh Mustapha Babagana [*1], Satendra Sharma [2]

[*1, 2] Department of Physics, Yobe State University Damaturu, P.M.B 1144, Damaturu, Nigeria

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ABSTRACT

Electrical resistivity method using vertical electrical sounding (VES) technique and Schlumberger array was employed with the aim of delineating limits and types of aquifer system(s), and stratigraphic composition of the Demsa area, a confluence of Benue River in Northeast Nigeria. The result revealed that the hydrogeology of the area may be controlled by fractures (secondary porosity) developed in sedimentary units. Two aquifers, namely the upper alluvial aquifer and the confined deeper aquifer systems exist in the study area. The two aquifers occur at depths of 20.5 – 41 m, and 43.8 – 78.9 m respectively, and are separated by a thin layer of poorly permeable clays and silts, ranged between 1.1 – 5.3 m in thickness. The lateral extent of the aquifer systems extend almost evenly across the area. The aquifers' thickness tends to decrease with increase in distance of VES station from the Benue River which suggested that the aquifer systems are probably recharged by direct escapement of the Benue River.

1. INTRODUCTION

Data scarcity on groundwater resources in developing countries affects proper management of the resources in terms of its suitability and sustainability for domestic and agricultural activities. Groundwater is becoming a reliable alternative to surface water system in Nigeria, hence understanding the concept of developing and managing the resources is an issue to reckon with. Demsa (the area of the present study) is one of such areas where data on groundwater and by extension hydrogeology is still limited with little or no scholarly records, despite significant portion of its inhabitants relying on groundwater supply for domestic and irrigation activities. The aim of the present study was to apply electrical resistivity method – vertical electrical sounding (VES) technique - to delineate limits and types of aquifer system(s), and stratigraphy composition of the Demsa area. It was also to fill in the vacuum of scarce data on groundwater and hydrogeology in developing countries. Electrical resistivity method, specifically the vertical electrical sounding method has proved effective in the field of groundwater and hydrogeology exploration.

Electrical resistivity was carried out in the present study to investigate type and limits of aquifer systems, and stratigraphy composition of the study area with a view to bridge the gap of limited data on groundwater and hydrogeology in developing countries as Nigeria. A total of thirty four (34) VES points, covering about 9.57×10^5 Square Kilometer, were recorded and data acquired were processed using computer software (IX1D v3 Interpex) to investigate resistivity variation for characterization of stratigraphy composition and forms aquifer system(s) in and around the study area.

Various geophysical techniques have been employed in groundwater exploration to map out suitable points for sustainable boreholes development, and one of such techniques commonly used is the electrical resistivity method (Olawuyi and Abolarin, 2013). Electrical resistivity method basically reflects variation in groundwater resistivity. The electrical resistivity contracts existing between subsurface lithology are often adequate to delineate stratigraphy composition and characterization of aquiferous and non-aquiferous layers (Ginaya and Yagoob, 2017). Of all near surface geophysical methods, the electrical resistivity method has been widely applied for groundwater exploration (Joseph Olakunle Coker, 2012).

2. STUDY AREA

The present study area lies between $9^0.15$N to $9^0.60$N, and $11^0.70$E to $12^0.30$E which covers an area of about 9.57×10^5 Square Kilometer. Demsa is a catchment area of Benue River with a number of waterways across. The study area covers a total of seventeen (17) VES Stations wherein, thirty four (34) VES points were recorded. Kpasam, Bali and Bille are VES stations to the southwest, Bange, Dilli, Borrong and Mbula to the northeast, just by the Benue River. Other stations are Dowaya, Farai, New Demsa, Old Demsa, and Yelwa. Kokumso, Ngbolung, Dong, Lawaru and Bakin Dewi are VES stations along waterways. Fig. 1; shows a reference map of the study area indicating VES points at VES stations, waterways, and the Benue River. The map was design in QGIS software, using global positioning system (GPS) data obtained at the field.

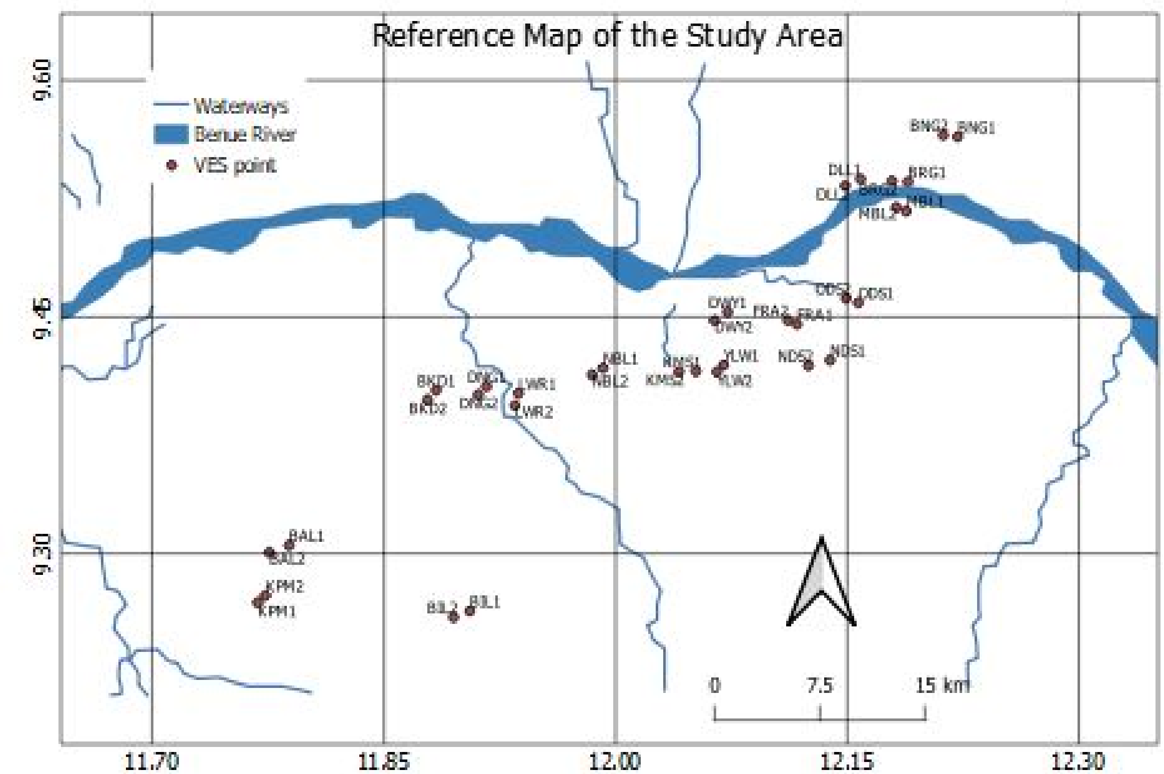

Figure 1: Reference map of the study area showing positions of VES points

2.1. GEOLOGICAL CONSIDERATION

Demsa, the study area, lies on Cretaceous sedimentary unit of the Yola Arm of Upper Benue Trough, the Bima Sandstone. The Bima Sandstone at the study area indicates the base of sedimentary succession in the Upper Benue Trough, and is sub-divided from base to top into three sandstone members of Lower Aptian/Albian Bima, Middle Albian Bima sandstone and Late Albian/Cenomanian Upper Bima Sandstone (Obiefuna, 2010). At the surface, the geologic units are composed of fine-medium grained sandstone to the north and south, and coarse grained sandstone to the northeast (Obiefuna, 2010). The stratigraphic composition of the Bima Sandstone consists mostly of alternating layers of poorly to moderately consolidated fine to coarse grained sandstone, clay-shale, siltstone and mudstone with average thickness in excess of 250 meters as seen from their outcrops in the field (Obiefuna, 2010). The Bima Sandstone of the study area alternates between light brown to reddish brown in colour and is highly cemented in most places of the area.

3. MATERIALS AND METHODS

Thirty-four (34) vertical electrical sounding were measured using Schlumberger array with AB/2 (current electrode spacing) varying from 2 to 200 m, and MN (potential electrode spacing) varying between 1 and 40 m. A total seventeen (17) VES Stations were carefully identified to appropriately cover the study area, with two (2) VES points measured in each of the VES stations. Using the Schlumberger array method, the MN spacings were kept in fixed positions while varying the AB/2 spacings. This was to allow for deeper penetrations of D.C signals for maximum coverage of stratigraphic composition of the study area. D.C current signals were injected into subsurface using resistivity meter, the ABEM SAS1000 gadget. The corresponding apparent resistivity of the subsurface strata were subsequently recorded and processed using computer software, the IX1D v3 Interpex to deduce lithology of the area in terms of resistivity, thickness, and number of layers. Another computer software, the Surfer 13, was used to processed contour maps of aquifers (water bearing layers), and 3D maps of the layers' thickness using XYZ data format. Kriging Gridding method was adopted in the XYZ data gridding with minimum contour 70 to 100, and maximum contour of 380 to 400 in second and fourth layers respectively. In both the layers, X-direction spacing was 4.6×10^{-3} with 100 nombers of nodes. The Z-transformation was linear. The thirty-four (34) VES points were KPM1, KPM2, BAL1, BAL2, BIL1, BIL2, DNG1, DNG2, BKD1, BKD2, LWR1, LWR2, NBL1, NBL2, KMS1, KMS2, and YLW1, YLW2 at Kpasam, Bali, Bille, Dong, Bakin-Dewi, Lawaru, Ngbolung Kokumso, and Yelwa VES stations respectively. Others were DWY1, DWY2, FRA1, FRA2, NDS1, NDS2, ODS1, ODS2, MBL1, MBL2, BRG1, BRG2, DLL1, DLL2, and BNG1, BNG2, at Dowaya, Farai, New-Demsa, Old-Demsa, Mbula, Borrong, Dilli, and Bange VES stations respectively.

Many studies have established the effectiveness of electrical resistivity sounding method in mapping and delineating groundwater potentials (Hubbard and Rubin, 2000; Maliva et al., 2015; Slater, 2007; Lachaal et al., 2012; Falgàs et al., 2011; Maliva et al., 2009; Singha et al., 2008; Lesmes and Friedman, 2005). The geophysical method is generally regarded fit for groundwater exploration (Cardiff et al., 2013; Bowling et al., 2006; O and A, 2018; Meyerhoff et al., 2014).

4. RESULTS AND DISCUSSION

The result from the geophysical survey is presented in Table 1, displaying such parameters as location of the VES points, resistivity and thickness of layers. Geophysical analysis of the result revealed four (4) geoelectric layers in most places of the study area. These layers are mostly sandy-soil, sandy-clay and sands, sandstones, clays, silts and gravels. The topmost layer has resistivity variation ranged between 176.54 Ωm at VES point DNG1 of Dong station, and 233.14 Ωm at VES MBL1 of Mbula station. The layer is mostly sandy (clay or soil). The thickness of the topmost layer ranged between 3.6 – 10.1 m. The second layer revealed a resistivity variation ranging from 77.48 Ωm at VES point MBL2 in Mbula VES station, to about 381.61 Ωm at VES point BAL1 of Bali station. This resistivity variation suggest that the layer is water bearing, and by extension, existence of aquifer. Thickness of the second layer varies between 20.5 – 41 m. The second layer is mostly sand and/or sandstone. The third layer is a thin layer of thickness ranged between 1.1 – 5.3 m, with resistivity variation ranged between 14.13 Ωm and about 668.35 Ωm. The fourth layer revealed a resistivity variation ranging from 100.01 Ωm at VES YLW1 of the Yelwa station, to about 441.26 Ωm at VES FRA1 in Farai station. The resistivity of this layer also suggests a layer of water bearing, hence the deep aquifer. The thickness of the fourth layer ranged between 43.8 – 78.9 m. The fifth layer is a layer of high resistivity ranging between 1180.03 Ωm at VES KPM1 of the Kpasam station to about 2222.81 Ωm at VES BNG2 of the Bange station. The contour maps in Fig. 2 and 3 revealed the almost even distribution of resistivities of the two aquifer systems across the study area, while Fig 4 and 5 show 3D maps revealing the thickness variation of the water bearing layers, which suggest the likelihood of the aquifer systems getting recharged by direct escapement of the Benue River.

Table 1: The values of vertical electrical sounding (VES) parameters with locations are given in the table. The resistivity (ρ) and thickness (h) of layers are also given in (Ωm) and (m) units, respectively. The source of information is based on the field survey done by the researchers

VES Point	Location	Longitude	Latitude	Layer	ρ(Ωm)	h(m)	Lithology description
KPM1	Kpasam	11.76850	9.26891	1	196.31	7.2	Sandy-clays
				2	88.72	22.6	Sand
				3	18.61	5.3	Clay
				4	103.25	43.8	Shale
				5	1180.03	-	Sand/gravel
KPM2	Kpasam	11.77333	9.27327	1	211.30	3.6	Sandy-soil
				2	97.61	26.0	Sand
				3	24.11	4.3	Clay
				4	123.40	-	Shale
				-	-	-	-
BAL1	Bali	11.78854	9.30523	1	200.01	5.5	Sandy-soil
				2	381.61	38.9	Silt
				3	31.20	4.8	Clay
				4	113.47	-	Shale
				-	-	-	-
BAL2	Bali	11.77598	9.30064	1	177.96	8.6	Sandy-soil
				2	112.58	33.0	Sand
				3	311.04	3.7	Silt
				4	131.02	-	Shale
				-	-	-	-
BIL1	Bille	11.90579	9.26359	1	218.11	7.5	Sandy-soil
				2	110.25	25.7	Sand
				3	16.23	5.3	Clay
				4	121.47	-	Shale
				-	-	-	-
BIL2	Bille	11.89519	9.25956	1	185.36	8.8	Sandy-soil
				2	101.33	39.8	Sand
				3	418.14	2.1	Silt
				4	124.78	-	Shale
				-	-	-	-
DNG1	Dong	11.91649	9.40592	1	176.54	7.6	Sandy-clay
				2	114.02	21.0	Sand
				3	15.12	1.8	Clay
				4	113.50	-	Sand
				-	-	-	-
DNG2	Dong	11.91129	9.40072	1	199.65	6.6	Sand-clay
				2	100.04	27.0	Sand
				3	386.21	1.7	Silt
				4	122.54	-	Shale

				-	-	-	-
BKD1	Bakin Dewi	11.88387	9.40344	1	201.47	4.9	Sandy-soil
				2	110.25	30.8	Sand
				3	15.63	3.8	Clay
				4	118.64	-	Shale
				-	-	-	-
BKD2	Bakin Dewi	11.87831	9.39741	1	222.17	10.1	Sandy-soil
				2	100.36	36.4	Sandstone
				3	18.88	3.1	Clay
				4	122.34	68.7	Shale
				5	-	-	-
LWR1	Lawaru	11.93706	9.40155	1	211.01	6.4	Sandy-clay
				2	98.74	24.4	Sandstone
				3	551.22	1.3	Silt
				4	133.54	-	Shale
				-	-	-	-
LWR2	Lawaru	11.93481	9.39386	1	218.00	7.1	Sandy-clay
				2	128.94	22.3	Sandstone
				3	20.14	2.4	Clay
				4	133.25	-	Shale
				-	-	-	-
NBL1	Ngbolung	11.99184	9.41756	1	188.66	9.6	Sandy-soil
				2	113.51	21.4	Sandstone
				3	14.25	-	Clay
				-	-	-	-
				-	-	-	-
NBL2	Ngbolung	11.98498	9.41331	1	220.01	7.5	Sandy-clay
				2	114.77	20.5	Sandstone
				3	468.55	1.6	Silt
				4	123.01	-	Sandstone
				-	-	-	-
KMS1	Kokumso	12.05229	9.41549	1	199.66	5.8	Sandy-clay
				2	112.27	30.5	Sandstone
				3	16.34	3.3	Clay
				4	120.05	-	Sandstone
				-	-	-	-
KMS2	Kokumso	12.04118	9.41537	1	199.63	7.9	Sandy-soil
				2	111.25	35.7	Sandstone
				3	21.53	1.4	Clay
				4	113.25	-	Sandstone
				-	-	-	-
YLW1	Yelwa	12.06990	9.41951	1	223.01	6.6	Sand-clay
				2	87.69	30.1	Sandstone
				3	18.55	1.2	Clay
				4	100.01	-	Sandstone
				-	-	-	-
YLW2	Yelwa	12.06553	9.41514	1	228.33	8.1	Sandy-soil
				2	110.05	36.1	Sandstone
				3	511.20	1.1	Silt
				4	120.54	-	Sandstone

				-	-	-	-
DWY1	Dowaya	12.07251	9.45308	1	187.44	6.3	Sandy-soil
				2	114.22	38.6	Sand
				3	14.13	3.1	Clay
				4	121.10	-	Sandstone
				-	-	-	-
DWY2	Dowaya	12.06405	9.44770	1	210.10	9.1	Sandy-clay
				2	108.41	37.5	Sandstone
				3	16.77	2.3	Clay
				-	-	-	-
				-	-	-	-
FRA1	Farai	12.11760	9.44534	1	200.14	7.2	Sandy-soil
				2	109.64	36.9	Sandstone
				3	15.55	2.1	Clay
				4	441.26	-	Shale
				-	-	-	-
FRA2	Farai	12.11169	9.44782	1	186.55	8.1	Sandy-clay
				2	115.46	39.8	Sand
				3	18.40	2.1	Clay
				4	116.18	-	Sandstone
				-	-	-	-
NDS1	New Demsa	12.13877	9.42261	1	211.41	7.9	Sandy-soil
				2	117.10	34.6	Sandstone
				3	17.45	3.4	Clay
				4	121.88	-	Sandstone
				-	-	-	-
NDS2	New Demsa	12.12502	9.41909	1	188.97	9.2	Sandy-soil
				2	108.55	36.8	Sand
				3	16.76	3.5	Clay
				4	113.61	-	Shale
				-	-	-	-
ODS1	Old Demsa	12.15709	9.45903	1	196.21	6.8	Sandy-clay
				2	107.24	37.9	Sand
				3	461.28	1.9	Silt
				4	123.50	-	Sandstone
				-	-	-	-
ODS2	Old Demsa	12.14922	9.46185	1	214.36	9.9	Sandy-soil
				2	110.54	38.8	Sandstone
				3	18.54	1.5	Clay
				4	122.35	-	Shale
				-	-	-	-
MBL1	Mbula	12.18834	9.51707	1	233.14	8.4	Sand-soil
				2	77.48	41.0	Sand
				3	16.64	4.1	Clay
				4	133.84	-	Shale
				-	-	-	-
MBL2	Mbula	12.18188	9.51942	1	221.34	5.5	Sandy-soil
				2	114.22	40.3	Sand
				3	17.88	3.1	Clay
				4	128.69	78.9	Sandstone

				5	1186.21	-	Sand/gravel
BRG1	Borrong	12.18940	9.53563	1	187.45	7.8	Sandy-clay
				2	112.39	39.7	Sandstone
				3	668.35	1.7	Silt
				4	133.54	69.7	Shale
				5	2216.44	-	Sand/gravel
BRG2	Borrong	12.17918	9.53622	1	200.11	8.1	Sandy-soil
				2	101.43	40.2	Sandstone
				3	15.48	1.8	Clay
				4	138.95	-	Shale
				-	-	-	-
DLL1	Dilli	12.15862	9.53739	1	176.58	8.3	Sandy-clay
				2	108.64	40.5	Sand
				3	19.68	2.3	Clay
				4	126.84	-	Shale
				-	-	-	-
DLL2	Dilli	12.14863	9.53304	1	210.05	7.6	Sandy-soil
				2	110.44	39.7	Sandstone
				3	18.84	1.8	Clay
				4	130.02	-	Shale
				-	-	-	-
BNG1	Bange	12.22147	9.56418	1	188.65	8.6	Sandy-clay
				2	109.91	39.0	Sandstone
				3	533.15	3.0	Silt
				4	133.24	-	Shale
				-	-	-	-
BNG2	Bange	12.21208	9.56523	1	196.21	7.1	Sandy-clay
				2	114.25	40.1	Sand
				3	16.33	1.4	Clay
				4	124.50	71.3	Shale
				5	2222.81	-	Sand/gravel

*ρ = Resistivity of layer, h = thickness of layer. Source: Field survey

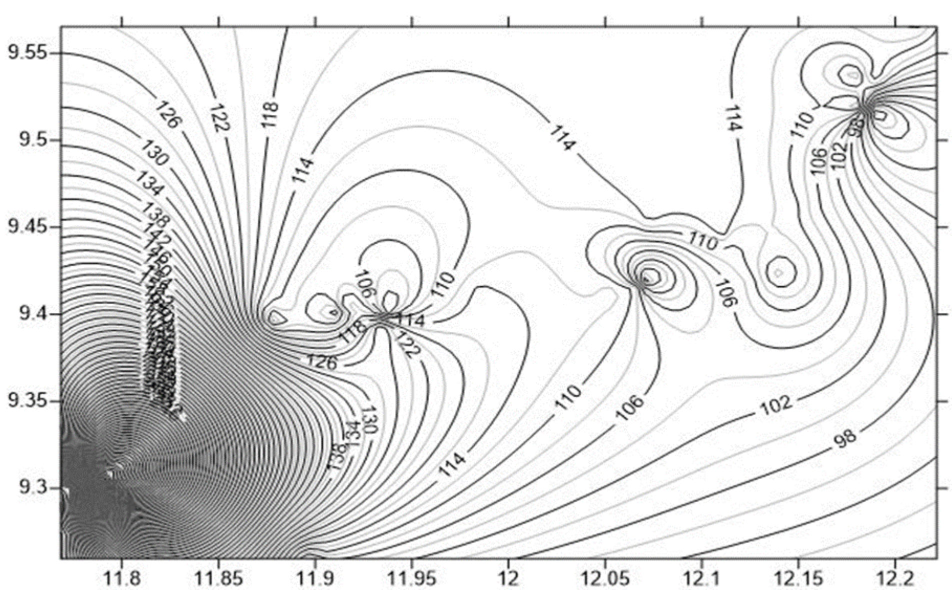

Figure 2: Contour map of resistivity of distribution across the Upper Alluvial Aquifer

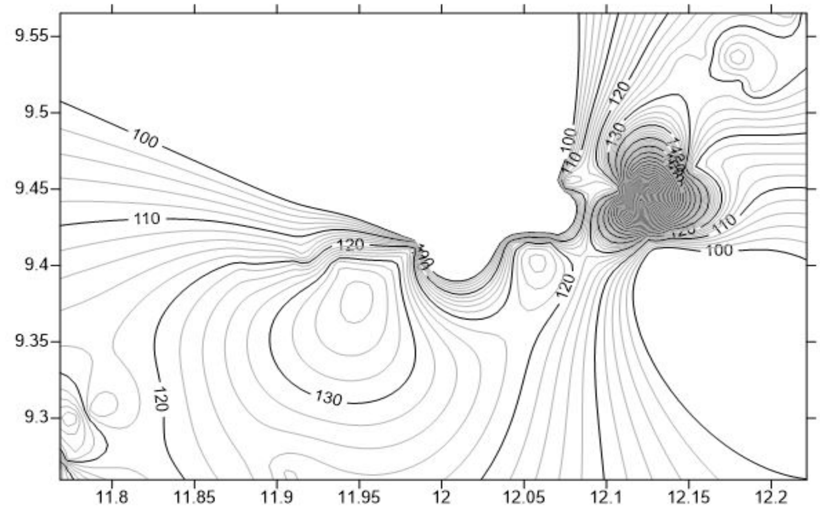

Figure 3: Contour map of resistivity variation across the Deep Aquifer

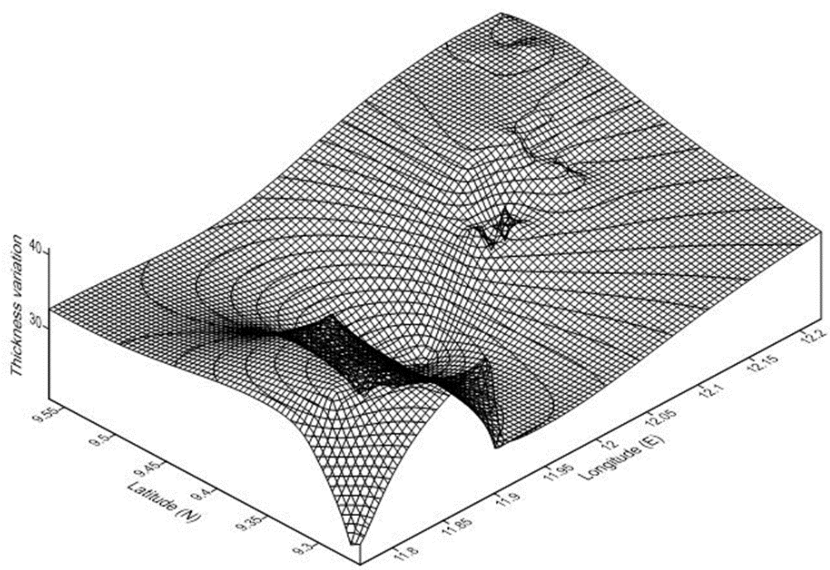

Figure 4: A 3-D representation of thickness variation across the Upper Alluvial Aquifer

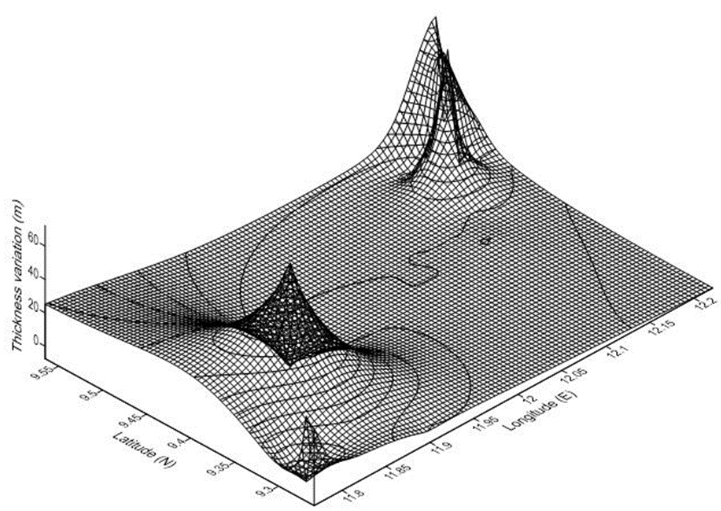

Figure 5: A 3-D representation of thickness variation across the Deep Aquifer

5. CONCLUSION

From the foregoing results and discussion, the authors of the present study thus concluded that;

1) The hydrogeology of the study area may be controlled by fractures (secondary porosity) developed in sedimentary units.
2) Two aquifers, namely the upper alluvial aquifer and the confined deeper aquifer systems exist in the study area.
3) The two aquifers occur at depths of 20.5 – 41 m, and 43.8 – 78.9 m respectively, and are separated by a thin layer of poorly permeable clays and silts, ranged between 1.1 – 5.3 m of thickness.
4) The lateral extent of the aquifer systems extend almost evenly across the area. The aquifers' thickness tends to decrease with increase in distance of VES station from the Benue River. This suggested that the aquifer systems are probably recharged by direct escapement of the Benue River.

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CONFLICT OF INTEREST

The author have declared that no competing interests exist.

AUTHORS' CONTRIBUTIONS

SMB conducted the research, collected the data, analyzed it and drafted the manuscript. SS supervised the research and manuscript.

AUTHOR'S INFORMATION

SMB (M.Sc.) is an Assistant Lecturer in the Department of Physics, Yobe State University Damaturu, Nigeria.
SS (M.Sc., Ph.D.) is a Professor in the Department of Physics, and Dean, Faculty of Science, Yobe State University Damaturu, Nigeria.

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