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Investigation of Groundwater Potential in New Jerusalem Area of Damaturu, Yobe State Nigeria, Using Electrical Resistivity Method.

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Abstract

The increasing trend in borehole failures and the general decline in groundwater levels and borehole yields due to climate change mostly in semi-arid regions such as Damaturu in Yobe State, needs an urgent intervention in order to sustain the provision of quality drinking water to the populace. In this study, we investigated the groundwater potential of New Jerusalem in Damaturu, Yobe State, using electrical resistivity method. The results obtained showed that the study area is composed of five (5) geoelectric layers which include the Topsoil, Clay, Sand, Sandy-clay and Sand. The third and the fifth layers were the aquifers in the study area. The first aquifer is semi-confined and the second aquifer is confined. The results obtained from this study area correlated perfectly with existing borehole data from the study area. The results of this study indicated that the second aquifer which is located at an average depth of 147 m below the Earth surface in most parts of the study area is the best source of quality drinking water in the area. The average thickness of the first layer is 1.2m and its average resistivity is 183 Ωm. The second layer has an average resistivity of 50 Ωm and an average thickness of 8.32 m. The third layer has an average resistivity of 301 Ωm and an average thickness of 57.5 m and an average depth of 67 m. The fourth layer has an average thickness of 81 m with an average resistivity of 148.2 Ωm. The average resistivity of the fifth layer is 285.4 Ωm. The thickness of the aquifer in the study area shows that the study area has good groundwater potential. Based on the findings of this study, we therefore recommend that boreholes for quality drinking water in the study area should be drilled to a depth of 140 m and above into the second aquifer.

Key words: Groundwater, Damaturu, electrical resistivity, confine aquifer, borehole.

INTRODUCTION

The growth in the population of the people in most cities and towns in Nigeria and the associated expansion in industrial activities have placed enormous pressure on the available water resources. Damaturu is located in the semi-arid region of Nigeria where there is scarcity of rivers and streams. The people in Damaturu and its environs depend heavily on groundwater for their domestic and industrial water supply. The demand for quality drinking water is increasing and its availability is strongly affected by climate change. Research reports have shown that groundwater table and rechargeability are declining due to climate variability (Chartzoulakis *et al*., 2001; Tsagarakis *et al*., 2001; Agada and Yakubu, 2022). In a semi-arid region area such as Damaturu where precipitation remains the main groundwater recharge, the fluctuation in the amount of annual precipitation in the area has

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affected both the groundwater water-table, quantity and quality (Agada and Yakubu, 2022). Extreme weather events such as droughts and heat wave which are prevalent in semi-arid regions are known to influence the lowering of water table. As a result of climate change, water availability is limited by climate variability (Agada and Yakubu, 2022). Due to climatic variability, the demand for irrigation water has become very high in semi-arid regions and the need to use groundwater for irrigation purposes has also become exceedingly necessary.

Ishaku *et al*. (2013) evaluated the groundwater potential in Bida Basin of North-Central Nigeria, and their results showed that the area is composed of topsoil, sand, clay, sandstones and sandy-clay layers. The groundwater bearing formation in the area has a thickness which varies from 35-50 m. The aquifer in the area is a sandstone which is the fourth layer. Agada *et al*. (2020) investigated groundwater potential in Gashua Northeast Nigeria. They observed that the area is made up of five (5) geologic layers which are: Topsoil, clay, sand, sandy-clay and sand. Amadi *et al.* (2013) evaluated the groundwater potential in some parts of Paiko, north-central Nigeria. The results of their study indicated that the area is composed of three geologic layers, which are: The topsoil, whose resistivity ranges from 0.9 m to 3.5 m. This topsoil is underlain by a weathered/fractured basement whose resistivity values ranges from 1.6 m to 29.0 m. The last geologic layer in their study area was the basement complex whose resistivity ranged from 900 to 2800 Ωm, extending to an infinite depth. Egwebe *et al.* (2004) investigated the aquifer potential at Ivbiaro, Ebesse in Edo State, using the geo-electrical direct current resistivity technique. The interpretation of their data yielded a depth of 96-147 m to the aquifer (sand) within the sand/shale sequence of the Mamu Formation. Amadi *et al.* (2011) evaluated the groundwater potential of Pompo Village in the neighborhood of Gidan-kwano Campus of Federal University of Technology, Minna, using electrical resistivity method. Five (5) out of the twelve (12) VES showed good groundwater potential in the study area. Electrical resistivity survey method has proven to be very effective for groundwater exploration (Obiora et al., 2017; Agada et al., 2020). Muhammed *et al*. (2008) delineated the aquiferous units in the central part of Minna by using electrical resistivity method, they were able to determine the depth to the groundwater and the thickness of the aquifer in their study area. Their results showed that the area was composed of four geological formations and the aquiferous unit have resistivity value of 120-900 Ωm and an average thickness of 25 m - 30 m. Agada and Yakubu, (2022) reported that some groundwater from Pompomari area of Damaturu is contaminated and could be responsible for the prevailing health complications associated with the consumption of contaminated water in the area.

The increasing demand of groundwater for domestic, agricultural and industrial purposes has made groundwater resources management a very important tool for sustainable development. Some boreholes in Damaturu have not been able to supply water throughout the year due to failures associated with improper sitting and reduction in groundwater table. Accessibility to quality drinking water in New Jerusalem area of Damaturu has been limited due to population growth and industrial expansion. In view of these constraints, there is a need for more groundwater exploration in New Jerusalem area of Damaturu Metropolis to supplement the available groundwater data at the Rural Water Supply and Sanitation Agency (RUWASA) Damaturu, Yobe State. The existing data could no longer provide reliable information as the number of borehole failure across the study area and other parts of Damaturu metropolis is increasing. The estimated 60 m drilling depth for boreholes in the New Jerusalem area of Damaturu is no longer sustainable due to the decline in groundwater table, low borehole yields and reports of water pollution related infections. In view of these prevailing conditions in the sudy area, this study is focused on evaluating the groundwater potential in New Jerusalem for efficient groundwater management in order to sustain adequate water supply to the metropolis. The results of this research will serve as a guide to groundwater exploration in the study area and Damaturu at large.

Study Area

The study area is New Jerusalem district of Damaturu. Damaturu, is situated on latitude 11° 39'N and longitude 11° 54'E (Figure 1). It is located in the Chad Basin and it has a semi-arid climate characterized by a long dry season and short rainy season. The duration for the rainfall last for about three to four months. The annual rainfall ranges from 500-1000mm and the rainy season is from June to September (Agada *et al.*, 2011). Damaturu has an estimated population of 69, 952 people in 2010 according to the National Population Census. Damaturu is located within the Chad Basin (Figure 2). The Chad basin extends to five countries in Africa, namely Chad, Nigeria, Cameroon. Central Africa Republic and Niger. The Chad Basin covers parts of Borno State, Yobe State, and Jigawa state (Agada *et al.*, 2020). In Nigeria, about ten percent of the Chad basin lies in the north-eastern part of Nigeria. The Chad formation is composed of inter-bedded sands, clays, silts and discontinuous sandy clay lenses which give aquifer characteristics ranging from unconfined, through semi-confined to confined types (Adegoke, 1985; Goni *et al.*, 2000; Bura *et al.*, 2018).

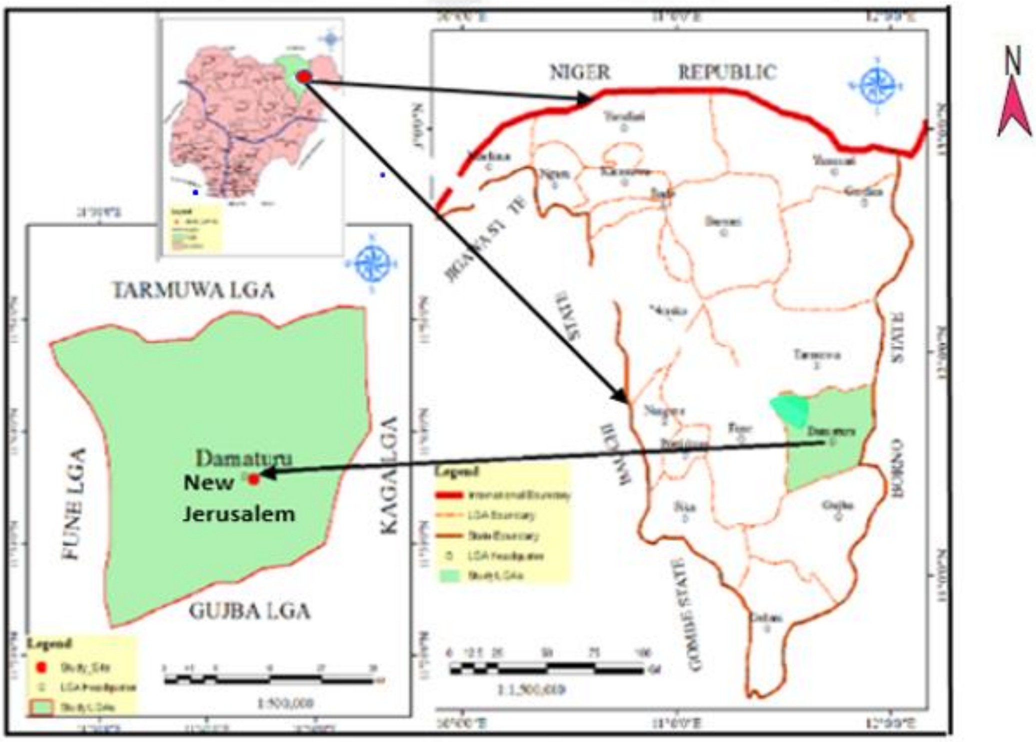


Figure 1: Map of Nigeria Showing New Jerusalem in Damaturu, Yobe State.

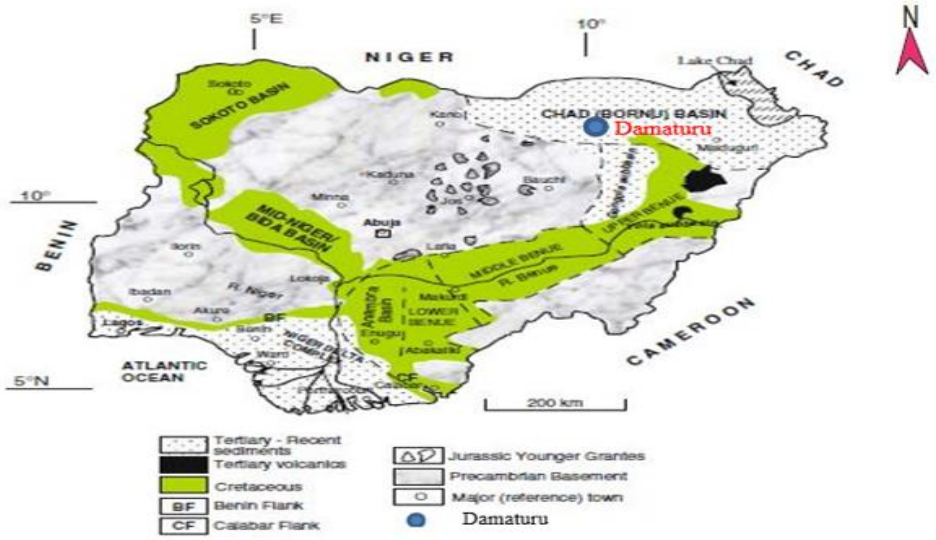


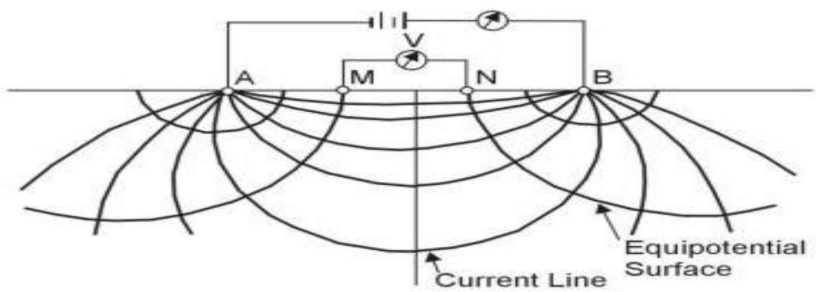
Figure 2: Geological Map of Nigeria showing the location of Damaturu in the Chad Basin (Obaje, 1999).

Materials

In this study, the geophysical survey was carried out using the following instruments: ABEM SAS1000 Digital Terrameter, Reels of electrical cables, Cable Jumpers, Steel electrodes, Personal Computer, Global Positioning System (GPS), Hammers, Measuring Tapes and 12V Battery which was used to power the ABEM SAS1000 Terrameter. Software such as OriginPro 2017 and WINRESIT version 1.0 were used to process the geophysical data.

Methodology

The study was carried out using electrical resistivity method and Schlumberger configuration (Figure 3) was adopted for the survey. The VES stations were carefully selected, considering the depth to the groundwater in the study area. The survey was extended to an existing borehole location for easy correlation of obtained results. Four electrodes in which two are for potential electrodes and the remaining two are current electrodes were laid collinearly. The electrodes were driven into the ground using hammer. The Schlumberger sounding techniques were adopted with current electrode spacing (AB/2) ranging from 1.5 to 450 m. Fifteen (15) Vertical Electrical Sounding (VES) were carried out in the study area with the intention of delineating the overburden thickness, aquifer thickness, and the lithology of the study area.



MN = Potential electrode spacing and AB = Current electrode spacing

Figure 3: Schlumberger configuration.

During the data acquisition process, emphasis was given to data resolution and depth of investigation. The acquired vertical electrical sounding (VES) data was presented in the form of tables and were processed using WINRESIST version 1.0. The results from the graph drawn by the processing software shows the thickness, depth and resistivity values of the various rock layers. In the graph, the apparent resistivity values were plotted against the current electrode spacing $\left(AB/_2\right)$ (m) and an iteration process was carried out until a good fit was obtained. OriginPro 2017 software was used to develop the geoelectric sections. The interpreted geophysical data were correlated with an existing borehole data from the study area.

RESULTS AND DISCUSSION

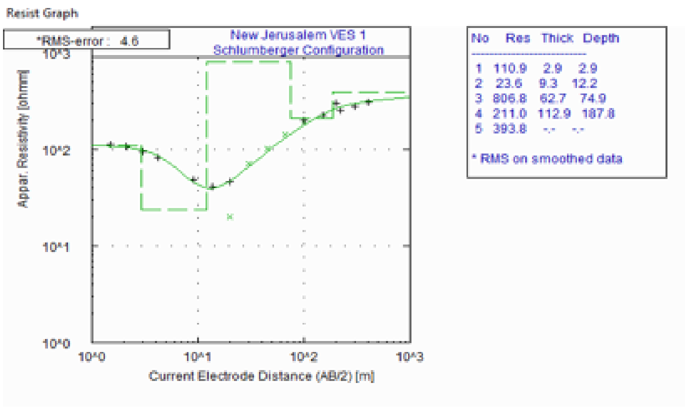
The electrical resistivity survey results showed that the study area is made up of five geoelectric layers in exception of the area around VES 2 which has four (4) geoelectric layers (Figure 5).The subsurface layers delineated are the topsoil, clay, sand, sandy-clay, and sand (Figure 5). The geoelectric layer sequence at VES 2 are: topsoil, clay, sandy clay and sand (Table 1). The study area is heterogeneous in nature, by its subsurface layer composition, and the thickness of the various geologic layers varies from one place to another in the study area (Figure 4). The thickness of the topsoil ranged from 0.7 to 2.9 m with an average value of 1.2 m (Table 1). The resistivity of the topsoil ranged from 110.9 Ωm to 349.5 Ωm. The topsoil has an average resistivity of 183 Ωm. It is underlain by a clay formation which is the second layer (Figure 5). The resistivity of the clay formation ranged from 23.6 Ωm to 75.4 Ωm. The thickness of the clay layer ranges from 4.2 to 12.6 m. It has an average thickness of 8.3 m. The clay formation aids the flooding of the study area due to its proximity to the earth surface and high water retentive capacity. The clay layer has little protection to offer the underlying aquifer because of its insufficient thickness (Figure 5). The third layer in most of study area is a sandy formation whose resistivity ranged from 126.4 Ωm to 806.8 Ωm (Table 1). The third layer in the vicinity of VES 2 is a sandy-clay formation (Figure 6). The third layer has an average resistivity of 301 Ωm. The thickness of the third layer ranged from 40 to 72.8 m. It has an average thickness of 57.5 m. The third layer is the first aquifer in most parts of the study area. It is a semi-confined aquifer and therefore it is susceptible to contamination. The fourth layer in VES 3 area is a thick clay formation overlying a sand formation, which is considered to be the second aquifer in the study area. In most parts of the study area the second aquifer is overlain by a thick sandy- clay formation (Figure 6).

Most of the boreholes in the study area were drilled to the third layer whose average depth is 67.0 m. Boreholes sited within this depth are prone to irregular water supply due to the fluctuating water table caused by drought and other extreme weather events. The fourth layer has resistivity values which ranged from 45.5 to 564 Ωm and has an average resistivity of 148.2 Ωm. The thickness of this layer ranged from 49.3 to 156.6 m with an average thickness of 81 m. In most parts of the study area, the fourth layer is a sandy-clay formation. The fifth layer is a sandy formation whose resistivity ranged from 31.2 to 594.5 Ωm. It has an average resistivity value of 285.4 Ωm. The fifth layer is the second aquifer in the study area which is confined by the overlying sandy-clay and clay formations. It has a very large thickness according to existing literatures but was not determined in this study. The results obtained from this study correlated well with an existing borehole log from the study area

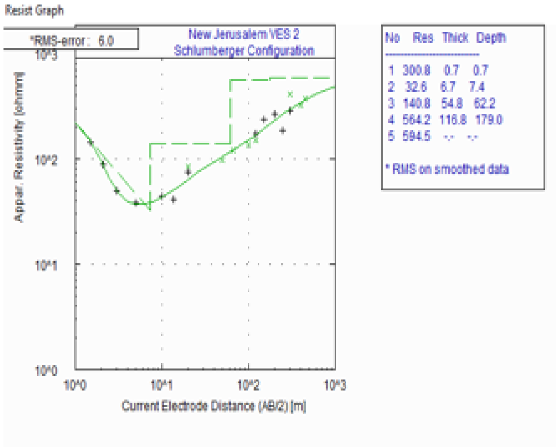
Table 1: Geoelectric and Lithologic Parameters of the Study Area.

VES No.	Coordinates		Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
	Latitude (°N)	Longitude (°E)					
VES 1	11.73437	11.96145	1	110.9	2.9	2.9	Topsoil
			2	23.6	9.3	12.2	Clay
			3	806.8	62.7	74.9	Sand
			4	211.0	112.9	187.8	Sandy clay
			5	393.8	----	----	Sand
VES 2	11.73460	11.96398	1	300.0	0.7	0.7	Topsoil
			2	32.6	6.7	7.4	Clay
			3	140.8	54.8	62.2	Sandy clay
			4	564.2	116.8	179.0	Sand
			5	594.5	----	---	Sand
VES 3	11.73390	11.96524	1	238.3	0.7	0.7	Topsoil
			2	45.2	7.1	7.8	Clay
			3	350.2	40.1	48.0	Sand
			4	45.5	156.6	204.5	Clay
			5	183.5	----	----	Sand
VES 4	11.73259	11.96164	1	349.5	0.8	0.8	Topsoil
			2	55.5	12.6	13.4	Clay
			3	380.7	41.9	55.4	Sand
			4	105.6	49.3	104.6	Sandy clay
			5	31.2	----	----	Clay
VES 5	11.73094	11.96103	1	114.1	0.9	0.9	Topsoil
			2	25.0	10.6	11.5	Clay
			3	126.4	46.0	57.5	Sand
			4	101.5	96.4	153.9	Sandy clay
			5	282.1	----	----	Sand
VES 6	11.72984	11.96470	1	125.6	0.9	0.9	Topsoil
			2	45.5	8.7	9.6	Clay
			3	300.2	50.6	60.2	Sand
			4	105.1	75.2	135.4	Sandy clay
			5	246.0	-----	----	Sand
VES 7	11.72951	11.96702	1	200.0	1.0	1.0	Topsoil
			2	65.7	7.1	8.1	Clay
			3	289.5	58.2	66.3	Sand
			4	117.3	81.8	148.1	Sandy clay
			5	243.6	------	----	Sand
VES 8	11.72797	11.96293	1	145.3	1.3	1.3	Topsoil
			2	62.1	6.2	7.5	Clay
			3	209.4	72.8	80.3	Sand
			4	125.8	69.5	149.8	Sandy clay
			5	340.0	-----	----	Sand
VES 9	11.72724	11.96751	1	120.2	0.7	0.7	Topsoil
			2	55.6	4.2	4.9	Clay
			3	314.3	58.4	63.3	Sand
			4	136.7	75.3	138.6	Sandy clay
			5	290.0	----	----	Sand

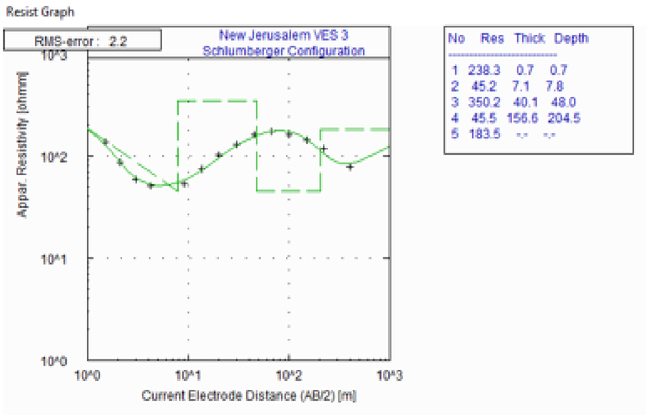
			1	300.3	1.7	1.7	Topsoil
VES 10	11.72585	11.96227	2	75.4	10.8	12.5	Clay
			3	195.0	70.1	82.6	Sand
			4	106.8	54.4	137.0	Sandy clay
			5	245.5	---	----	Sand
			1	150.9	1.3	1.3	Topsoil
VES 11	11.72587	11.96026	2	49.7	7.9	9.2	Clay
			3	180.5	67.8	77	Sand
			4	127.0	71.2	148.2	Sandy clay
			5	226.4	----	---	Sand
			1	176.2	1.7	1.7	Topsoil
VES 12	11.72962	11.96465	2	73.3	6.2	7.9	Clay
			3	432.5	53.2	61.1	Sand
			4	114.1	71.0	132.1	Sandy clay
			5	304.0	----	---	Sand
			1	146.1	1.2	1.2	Topsoil
VES 13	11.72991	11.96547	2	50.9	8.5	9.7	Clay
			3	240.0	62.0	71.7	Sand
			4	127.1	65.7	137.4	Sandy clay
			5	287.5	----	-----	Sand
			1	148.7	0.8	0.8	Topsoil
VES 14	11.72895	11.96826	2	71.2	8.6	9.4	Clay
			3	195.7	67.5	76.9	Sand
			4	134.5	56.1	133	Sandy clay
			5	211.0	----	-----	Sand
			1	120.4	1.4	1.4	Topsoil
VES 15	11.72630	11.96802	2	45.7	12.2	13.6	Clay
			3	354.0	51.7	65.3	Sand
			4	101.2	82.5	147.8	Sandy clay
			5	401.5	----	----	Sand



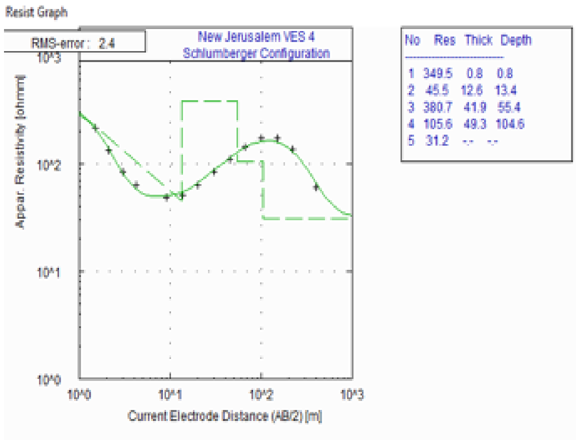
VES 1 Curve



VES 2 Curve



VES 3 Curve



VES 4 Curve

Figure 4: Typical VES Curves obtained from the study area.

The results of this study showed that boreholes drilled to the second aquifer between the depths of 140 to 200 m will be more productive in terms of yields and also have high sustainability compared to boreholes drilled to a depth of 60 m. The second aquifer is confined and it is considered to have high quality groundwater. In VES 15, the second aquifer is closer to the Earth surface than other parts of the study area. The sandy-clay layer in VES 15 is small compared to other parts of the study area (Figure 7).

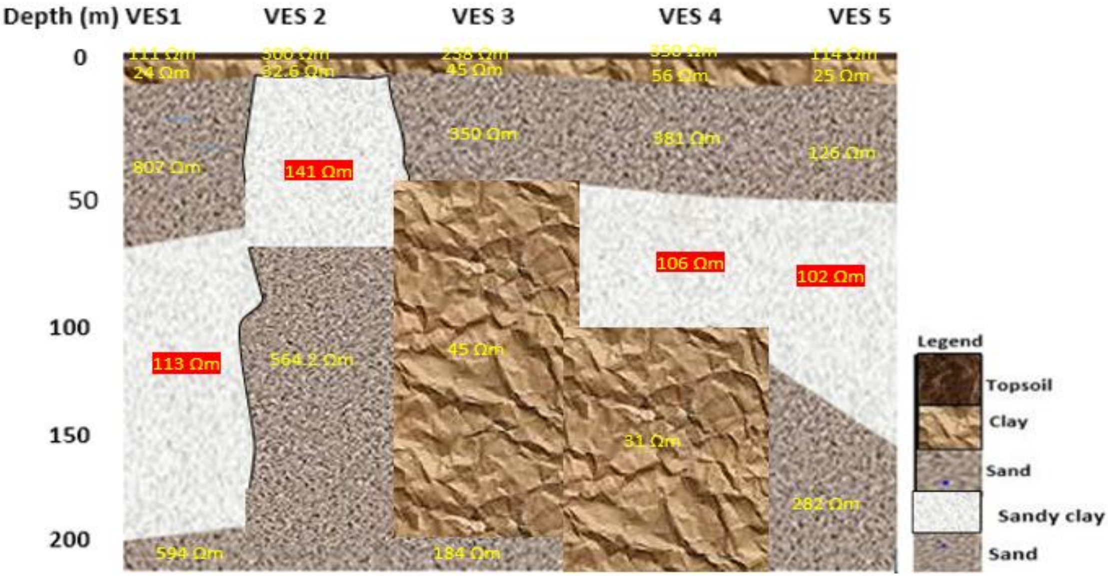


Figure 5: Geoelectric sections of VES 1-5 obtained from the study area.

The fifth layer at VES 4 station is a clay formation, and this part of the study area is not suitable for siting of boreholes except if the borehole will be drilled to a depth greater than 200 m below the ground surface.

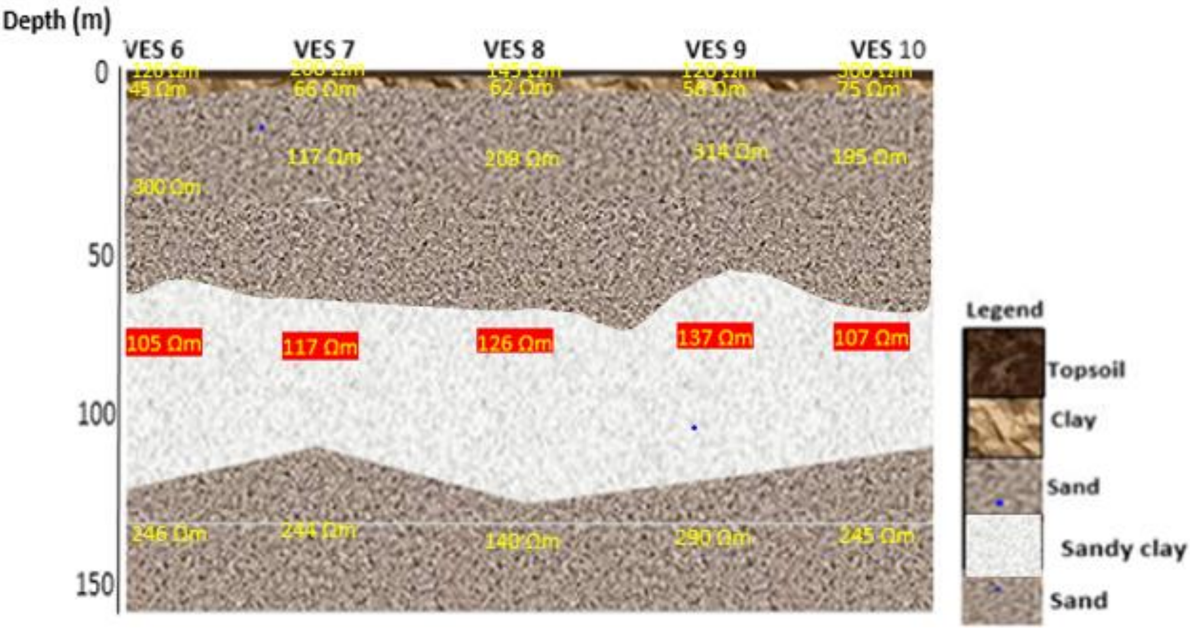


Figure 6: Geoelectric sections of VES 6-10 obtained from the study area.

The second aquifer is overlain by a thick sandy-clay formation which protects it from contamination.

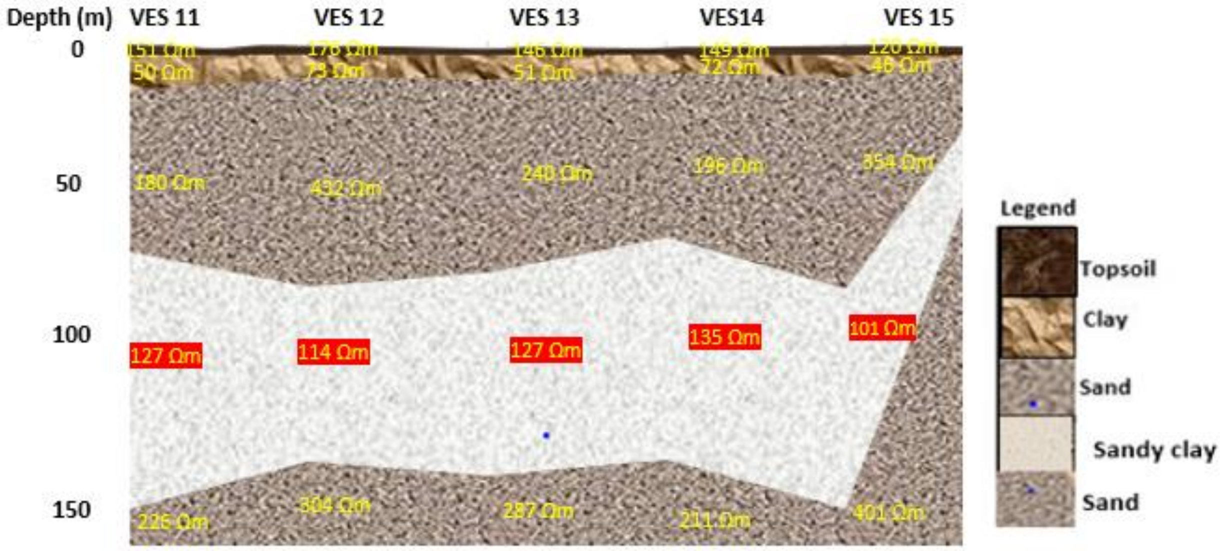


Figure 7: Geoelectric sections of VES 7-15 obtained from the study area.
In VES 15, the sandy- clay formation layer thickness is small compared to other parts of the study area. The second aquifer in the vicinity of VES 15 is susceptible to contamination due to its proximity to Earth surface.

The results obtained in this study showed that Damaturu is within the Chad Basin and the various geologic layers delineated in this study are similar with the results obtained by Agada *et al*. (2020) in Gashua area of Yobe State, because both places are within the Chad Basin. Although there are remarkable differences in the subsurface layer thicknesses and sequences in some areas. These differences could be attributed to the depositional activities which occurred during the formation of the Chad Basin. The results obtained from this study further demonstrated that Damaturu is at the fringe of the Chad Basin. A comparison of the thickness of the various subsurface layers obtained in this study with that which was obtained in Maiduguri by Alkali (1995) showed that the Chad Basin deeps towards the centre. The geoelectric sections (Figures 5, 6, and 7) showed that the study area is a typical sedimentary environment characterized by pronounced variations in subsurface layer thicknesses from one point to another within the study area. These variations are reflections of the energy of the depositional environment. The heterogeneity of the subsurface in the study area is also responsible for the varied depths to water table in the study area (Figure 5).

The results of this study showed that the second aquifer which is located at an average depth of 147 m below the earth surface in most parts of the study area is the best source of quality drinking water to the people of New Jerusalem and its environs in Damaturu, Yobe State, Nigeria. Due to the prevailing water related diseases such as cancer, renal failure and cholera in the study area, boreholes for quality water supply in the study area should be drilled to the second aquifer which is confined and protected from contamination. The drilling of the groundwater boreholes to the second aquifer will help to reduce or possibly eliminate health complications associated with the consumption of polluted water in Damaturu as reported by Agada and Yakubu (2022).

CONCLUSION

In this study we investigated the groundwater potential of New Jerusalem in Damaturu. The results of the study revealed that the area has two aquifers which are capable of providing groundwater to the people in the area. The first aquifer is semi-confined, and it is unsuitable for siting of boreholes for quality drinking water supply and therefore the second aquifer which is confined is recommended for groundwater abstraction for domestic consumption. Based on the findings of this study, it is advisable to drill boreholes for domestic water consumption to a depth of 140 m or above in the study area for sustainability and quality groundwater supply. The appreciable thickness of the aquifers in the study area clearly indicates that the area has good groundwater potential.

Conflict of interest
The authors declared that there are no competing interests.

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