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Full Length Research

Investigation of groundwater occurrence in Old BB Quarters, Wukari, North-East Nigeria using geo-electrical sounding and physiochemical methods

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ABSTRACT: The Vertical Electrical Sounding (VES) technique and physicochemical methods were employed to investigate groundwater occurrence within the sedimentary region of Old BB quarters, Wukari in Taraba State, Nigeria. The ABEM 300 SAS Terrameter was used to collect data from ten (10) locations, utilising the Schlumberger array configuration. Data collected was analysed using computer software (Interpex), which yielded an automatic interpretation of apparent resistivity. The VES result revealed a heterogeneous nature of the subsurface geological sequence. The geological sequence has mostly four to five geological layers. The layers inferred are top lateritic soil, clay, weathered sandstone and indurated sandstone. The resistivity value for top lateritic soil ranges from 97.655 to 623.41 Ωm with a thickness of 0.39 to 6.14 m. The second layer recorded resistivity values ranging from 20.436 to 509.11 Ωm with corresponding thicknesses of 2.14 to 27.40 m. The third layer, with resistivity values ranging from 1.03 to 18.73 Ωm and a thickness of 2.80 to 70.54 m, was interpreted as the weathered/fractured layer and consisted of intercalation of sandstone with clay. The layer was suggestive of the aquiferous zone. The resistivity values of the indurate sandstone ranged from 640.33 to 5994.00 Ωm. An iso-resistivity section was generated for AB/2 = 10 m, 60 m and 100 m, electro-stratigraphic section was produced while hydraulic conductivity and transmissivity values were derived from the resistivity data and represented as contoured maps. The maps reveal relatively low resistivity values, implying the presence of clayey materials and/or weathered sandstone. VES stations 4, 6, 9, and 10 were identified as potentially productive. Physicochemical parameters from hand-dug wells showed that temperature, TDS, and EC values exceeded WHO standards, while the anion concentrations were within the acceptable limits prescribed by NSDWQ and WHO. For borehole measurements, the physical parameters complied with recommended levels, although calcium and copper levels in boreholes 2, 3, 4, and 5 surpassed WHO safety limits. All other parameters complied with WHO standards. This has provided information on the depth to groundwater and the thickness of the aquifer unit in the study area.

Keywords: Anions, cations, geological sequence, groundwater, hydraulic conductivity, physical parameters, resistivity, transmissivity, vertical electric sounding.

INTRODUCTION

In recent times, the use of geophysical methods for exploring groundwater and evaluating its quality has significantly risen, thanks to advancements in computer software and various numerical modelling techniques. Vertical electrical sounding has gained popularity for groundwater exploration and subsurface characterisation because of the simplicity of the method (Nur and Ayuni, 2011; Alao and Abubakar, 2025). The goal of the geo-electrical survey method is to identify the surface effects that result from the passage of electrical current through the earth (Kure *et al*., 2017).

To effectively utilise geophysics for successful groundwater exploration, it is essential to have a solid understanding of the hydrogeological characteristics involved (Samuel *et al.,* 2020). Studies have indicated that geophysical techniques are among the most dependable and precise methods available for subsurface structural investigations and rock variation (Ayuni *et al.,* 2018; Mohammed *et al*., 2024).

Over the years, there has been a significant increase in the application of geophysics for mapping groundwater resources and assessing water quality. Vertical Electrical Soundings have become exceedingly popular in groundwater research due to the straightforward nature of the technique (Yusuf *et al*., 2020; Nur and Ayuni, 2011; Ayuni *et al*., 2017; Chavez Pacheco *et al*., 2023; Nyaberi, 2023).

Evaluating the available water supply necessitates a characterisation of the aquifer's extent and the hydraulic properties closely linked to its lithology (Onasachi *et al.,* 2016). According to Rolia and Sutjiningsih (2018), groundwater is defined as the water that fills saturated pathways, including naturally surfacing springs. It serves as a crucial water source, particularly in regions lacking drains, streams and sufficient rainfall, indicating the groundwater potential for communities.

In alluvial and sedimentary rocks, groundwater is present in the pore spaces between grains, while in hard rocks, it is primarily attributed to secondary porosity and permeability resulting from weathering, fracturing, jointing, and faulting processes (Chavez Pacheco *et al*., 2023; Lachassagne *et al*., 2021).

Physicochemical methods are crucial for investigating groundwater occurrence and quality. These methods analyse physical and chemical properties of water samples to understand their origin, movement, and potential contamination (Otieno *et al*., 2012). Key parameters include pH, conductivity, turbidity, temperature, total dissolved solids (TDS), and various ions and metals. These parameters help in identifying the source of groundwater, assessing its suitability for various uses, and detecting potential pollution (Dewangan *et al.,* 2023).

Hence, this research work is aimed at using the electrical resistivity method to investigate the hydro-geological condition and characterisation of the subsurface in the Old BB area of Wukari Local Government of Taraba State.

METHODOLODY

Study area

Old BB area of Wukari Local Government of Taraba State is located within latitude 7 °50'30''N to 7°52' 00''N and longitude $9^0$45'00''E to $9^0$47'00''E and covers an area of 20.5 km^2 (Figure 1). The climatic conditions of the study area (Old BB) fall within the rough warm tropical climate region, where the wet and dry seasons are prominent in the area. Geologically, the study area lies within the Middle Benue Trough. The Benue trough is a linear northeast-southwest trending basin, 800 km long and 90 km wide on average, in eastern Nigeria. It is considered to have originated as an aulacogen on the Precambrian shield as a result of the separation of the African and American plates in early Cretaceous times (Ogungbesan and Akargbobi, 2011).

Benue Trough is an elongated trough of subsidence. It forms an important part of a system of linear sedimentary basins which includes the Niger, Benue and Gongola rivers (Ofoegbu, 1985). The Benue Trough has a width of 130-150 km and trends northeasterly to attain an approximate length of 800 km. The trough is filled with Cretaceous rocks whose ages range from Middle Albian-Maastrichtian (Coccioni and Premoli Silva, 2015).

Methods

The investigation of groundwater occurrence in Old BB Quarters, Wukari, Northeast Nigeria, was conducted using a combination of geo-electrical and physicochemical methods. The geo-electrical component involved the use of Vertical Electrical Sounding (VES) based on the Schlumberger electrode configuration, which is effective for probing vertical variations in subsurface resistivity.

In the Schlumberger array, two current electrodes (A and B) are placed symmetrically at a wider spacing, while two potential electrodes (M and N) are positioned closer to the centre (Figure 2). The Full Schlumberger configuration was adopted in this study, where the AB spacing was progressively increased to obtain resistivity data at varying depths, and the MN spacing was adjusted only when necessary to maintain measurable voltage differences. The theoretical foundation is based on Ohm's Law, given as:

$$V = IR \qquad 1$$

The apparent resistivity (ρ_a) is calculated using equation 2:

$$\rho_a = K \times (\Delta V / I) \qquad 2$$

Where K is the geometric factor dependent on electrode spacing, ΔV is the potential difference, and I is the current injected.

These measurements were analysed to determine subsurface resistivity layers, which help infer Lithology and aquifer potential. Complementary physicochemical analysis of groundwater samples—covering parameters like pH, electrical conductivity (EC), and total dissolved solids (TDS)—provided insights into the quality and suitability of the groundwater for consumption.

Data acquisition and analysis

Ten (10) Schlumberger VES were carried out using ABEM

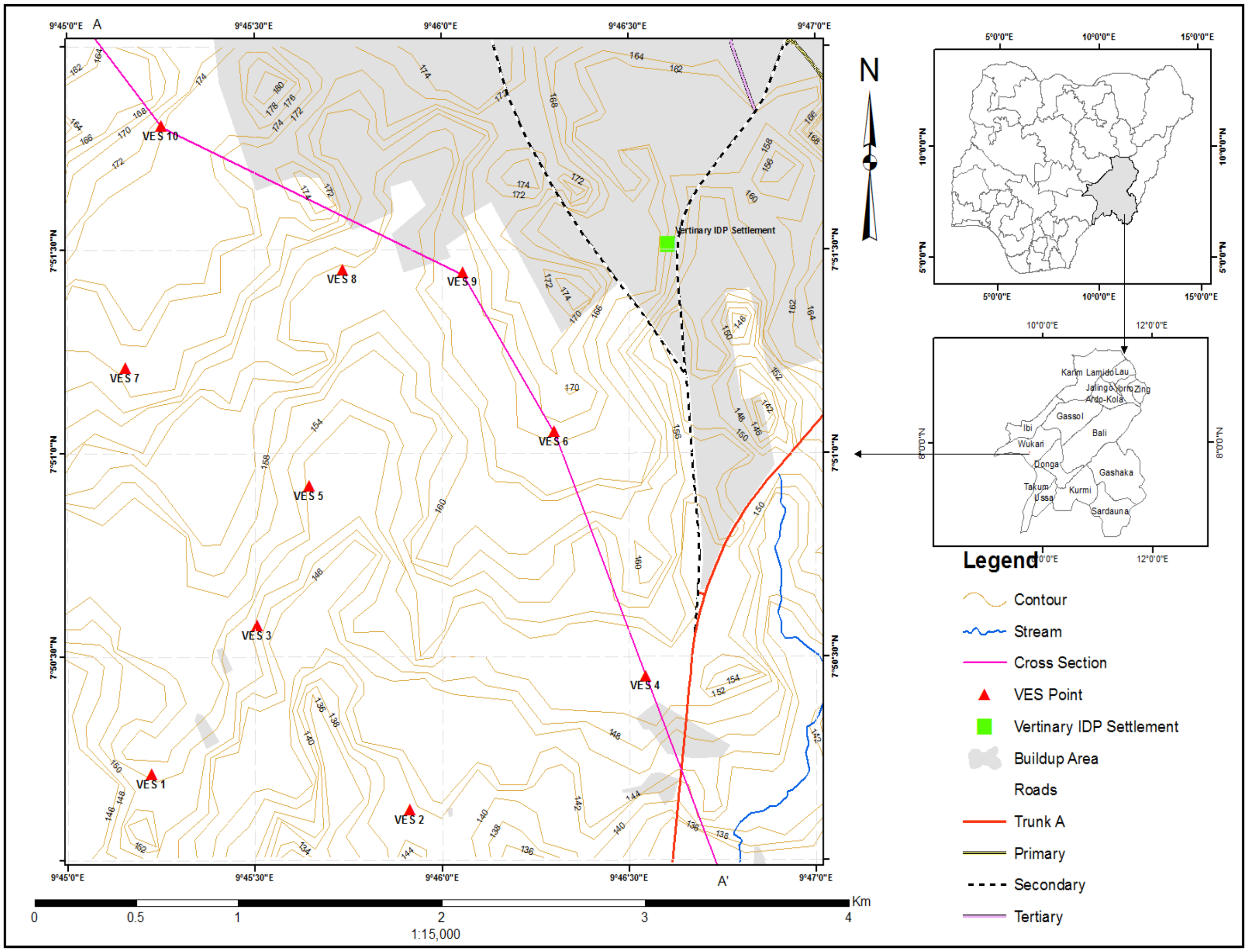

Figure 1. Topographic Map of the Study Area Showing VES Points.

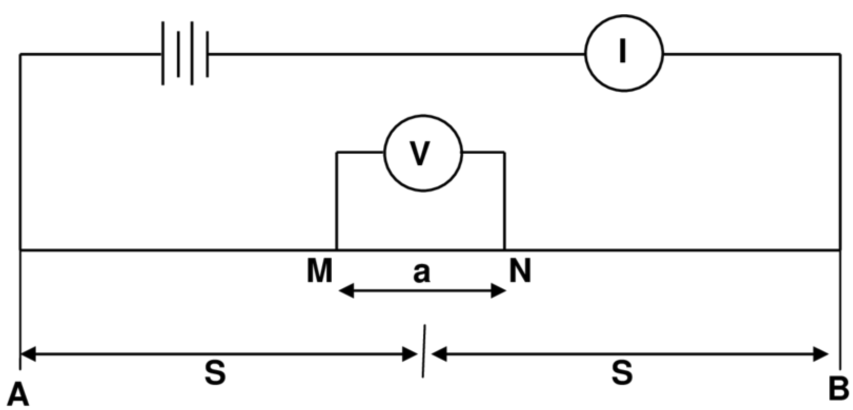

Figure 2. The Schlumberger electrode configuration.

SAS 300 Terrameter and a current of 12 volts universal direct/alternate current with a frequency of 5 Hz and while adopting a spread of AB/2 = 100 m.

The results of the geophysical data acquired from the field are presented using the apparent resistivity values obtained from various locations visited within the study area. The analytic method of interpretation was carried out using the partial curve matching method. The method

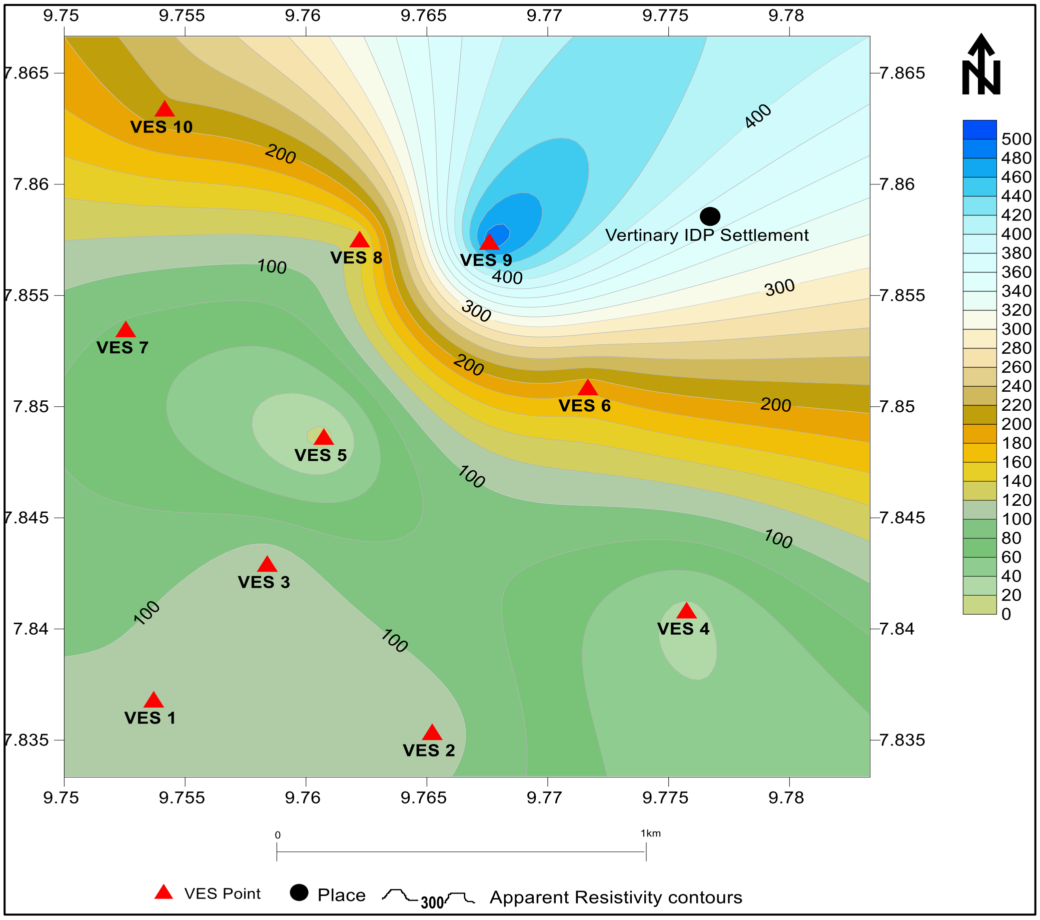

Figure 3. Iso-resistivity contour map for AB/2 = 10m (Contour interval = 20 Ωm).

utilises two two-layer model curves with their corresponding auxiliary curves. The curves are matched, and the layer resistivity and depths were determined. These were later used as starting models for a computer program (Interpex).

The shape of the VES curve (apparent resistivity plotted against electrode spacing) provides information about the subsurface. A curve that rises with increasing electrode spacing suggests that the resistivity is increasing with depth, while a curve that falls suggests the opposite.

By implication, both the features of each of the layers and their maximum depth of penetration would easily be ascertained by simply observing each of the VES curves. The reason is that the shape of a VES curve is indeed determined by the number of subsurface layers, their thicknesses, and the resistivity contrast between them. These factors influence how electrical current flows through the subsurface, which is then reflected in the shape of the apparent resistivity curve measured during a VES survey (Osemeikhia and Asokhia, 1982).

The obtained results are presented in Table 1, while Figures 2, 3, and 4 represent iso-resistivity maps for AB/2 = 10 m, 60 m and 100 m, respectively. Profile AA[1] was traced and presented in Figure 5.

RESULTS AND DISCUSSION

The Vertical Electrical Sounding modelling carried out at ten VES stations was used to derive the geo-electric section, which indicates the existence of mostly four geologic layers (Dauda and Ali, 2024). The curves obtained indicate type Q, QH, KH and KQ. This comprised topsoil/laterite, sandstone, clay and indurated sandstone. The topsoil/laterite consists of laterite intercalated with sandstone and has resistivity ranging from 97.655 - 623.41 Ωm, the thickness range from 0.39 -6.14 m, with a depth range from 0.39 - 6.14 m. The second layer is predominantly clay and clayey sand with resistivity ranging from 1.0265 to 28.08 Ωm and thickness that varies from 2.80 to 70.54 m, and a depth of 19.56 to 85.53m. While the third layer consists of Weathered Sandstone and silty materials with resistivity ranging from 19.02 to 509.11 Ωm, the thickness varies from 2.14 to 81.05 m, with depth varying from 2.53 to 82.73 m. The fourth layer consists of Indurated sandstone, with resistivity varying from 30.44 to 5994 Ωm; this is the layer with the highest resistivity; it has infinite thickness and infinite depth (Table 1). VES point 3 has five layers; the fourth layer of the point consists of clayey sand with a resistivity of 6.87 Ωm, a thickness of

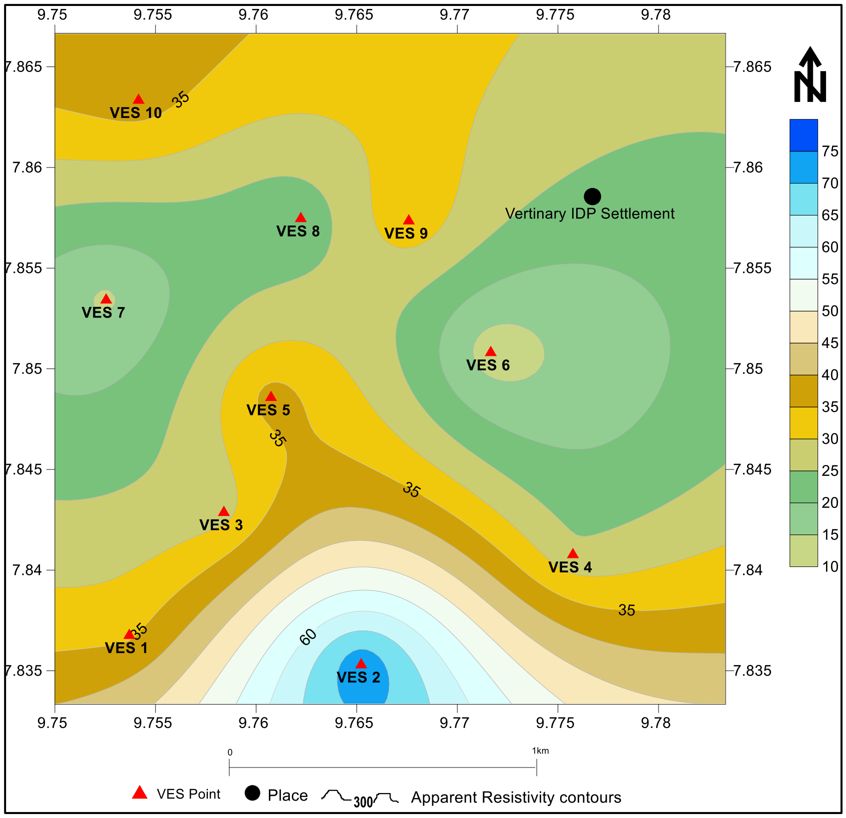

Figure 4. Iso-resistivity contour map for AB/2 = 60m (Contour interval = 5 Ωm).

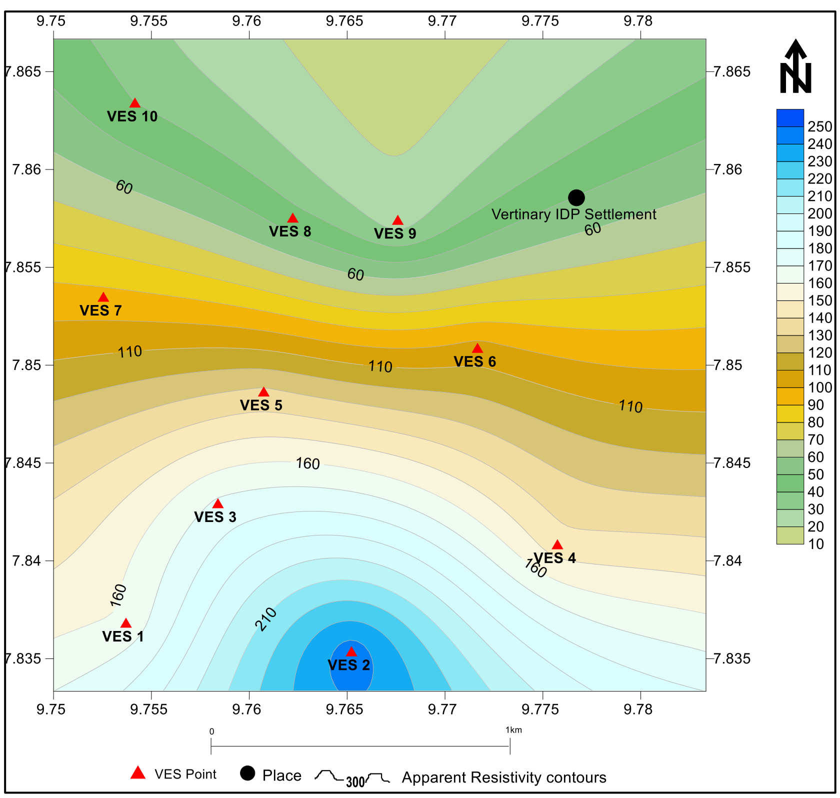

Figure 5. Iso-resistivity contour map for AB/2 = 100m (Contour interval = 10 Ωm).

Table1. Summary of result obtained from computer interpretation of 10 VES points.

Ves No	Coordinates	No. of layers	Thickness (M)	Depth (M)	Resistivity (Ωm)	Curve type	Lithology
1	N 07°50’33.2” E 009°46’18.4”	1	1.91	1.91	352.75	QH	Top lateritic soil
		2	6.13	8.04	138.89		Materials Weathered layer Clayey
		3	11.53	19.567	11.215		Clay Indurated sst
		4	-	-	3318.8		
2	N 07°50’38.4” E009°46’28.4”	1	1.68	1.68	417.94		Top lateritic soil
		2	81.05	82.73	159.77		Weathered sst
		3	2.80	85.53	1.0265		Clay
		4	-	-	1495.5		Fresh bedrock
3	N 07°51’10.6” E009°46’29.7”	1	0.39	0.39	554.37	QH	Topsoil/Laterite
		2	2.14	2.53	214.47		Sandstone
		3	29.75	32.28	28.08		Weathered sst
		4	21.71	54.00	6.87		Clay
		5	-	-	4386		Indurated Sst
4	N 07°51’14.2” E009°46’30.4”	1	4.71	4.71	623.41	QH	Top lateritic soil
		2	12.94	17.65	78.22		Silty materials
		3	15.04	32.70	7.88		Weathered layer
		4	-	-	3504		Fresh bedrock Indurated sst
5	N 07°51’20.1” E009°46’32.2”	1	4.20	4.20	244.99	KH	Top lateritic soil
		2	18.63	22.83	20.436		Clayey materials
		3	13.87	36.70	10.36		Clay Weathered layer
		4	-	-	4088.8		Fresh bedrock Indurated sst
6	N07°51’29.4” E009°46’36.3”	1	6.14	6.14	145.24	KH	Top lateritic soil
		2	27.40	33.54	19.02		Clay
		3	18.34	51.88	8.99		Weathered sst
		4	-	-	4484.1		Fresh bedrock Indurated sst
7	N07°51’33.1” E009°46’39.6”	1	2.77	2.77	360.39	KH	Top lateritic soil
		2	6.44	9.21	509.11		Sandstone/Silt
		3	20.2	29.41	22.34		Clay
		4	-	-	30.44		Weathered sst

Table 1. Contd.

Ves No	Coordinates	No. of layers	Thickness (M)	Depth (M)	Resistivity (Ωm)	Curve type	Lithology
8	N07°51'36.1" E009°46'41.1"	1	1.24	1.24	238.23	KQ	Top lateritic soil
		2	13.11	14.35	174.16		Silty materials
		3	15.29	29.62	6.47		Clay
		4	-	-	640.33		Fractured layer
9	N07°51'39.0" E009°44.0"	1	1.93	1.93	115.41	QH	Top lateritic soil
		2	25.86	27.79	138.13		Silty materials
		3	34.56	62.34	18.725		Highly weathered sst
		4	-	-	5994		Weathered layer Fresh bedrock Indurated sst
10	N07°51'41.2" E009°46'48.2"	1	1.81	1.81	97.66	KQ	Top lateritic soil
		2	5.27	7.08	180.32		Sandy clay
		3	70.54	77.62	12.331		Sandstone with clay intercalation
		4	-	-	1220.7		Indurated sst

21.71 m, and a depth of 54.00 m.

Iso-resistivity

Iso-resistivity maps show variation of apparent resistivity for different locations within a specific environment at a particular depth (Aizebeokhai *et al*., 2010). However, the variations may be a good indicator of areas of low or high resistivity, which may help to evaluate locations that have aquifers or not. For a better understanding of the subsurface groundwater occurrence, iso-resistivity maps were generated with the Surfer 12 software. After converting the coordinates for each VES point (latitude and longitude) to their decimal equivalent, the contouring of their resistivity values was done for AB/2 = 10 m, AB/2 = 60 m, and AB/2 = 100 m.

The data from the geo-electric sounding was used for the preparation of the iso-resistivity map of the area. Resistivity contour maps display the lateral variation in the surface geology of the area. The areas with low resistivity values indicate the occurrence of relatively good conductors, and the lowest resistivity value obtained was 12 Ωm, while those with high values indicate poor conductors and the highest resistivity value obtained was 496 Ωm.

Iso-resistivity of AB/2 = 10 M

The Iso-map for AB/2 = 10 m reveal the heterogeneity in the composition of the subsurface. It shows resistivity values ranging from 12 to 496 Ωm. The highest resistivity values were found along the North-eastern part of the study. High resistivity value can be seen at VES 9 and low values at VES 1, 2, 3, 4 and 7.

Iso-resistivity of AB/2 = 60 M

The iso-resistivity map of AB/2 = 60 m reveals the situation of the subsurface at a depth of 20 m, which is the depth of penetration. It has resistivity values ranging from 12 to 74 Ωm. The anomalous zones were seen at VES 2 southern part of the study.

Iso-resistivity of AB/2 = 100 M

The iso-resistivity map of AB/2 = 100 m reveals the situation of the subsurface at a depth of 33 m, which is the depth of penetration. It has resistivity values ranging from 24 to 246 Ωm.

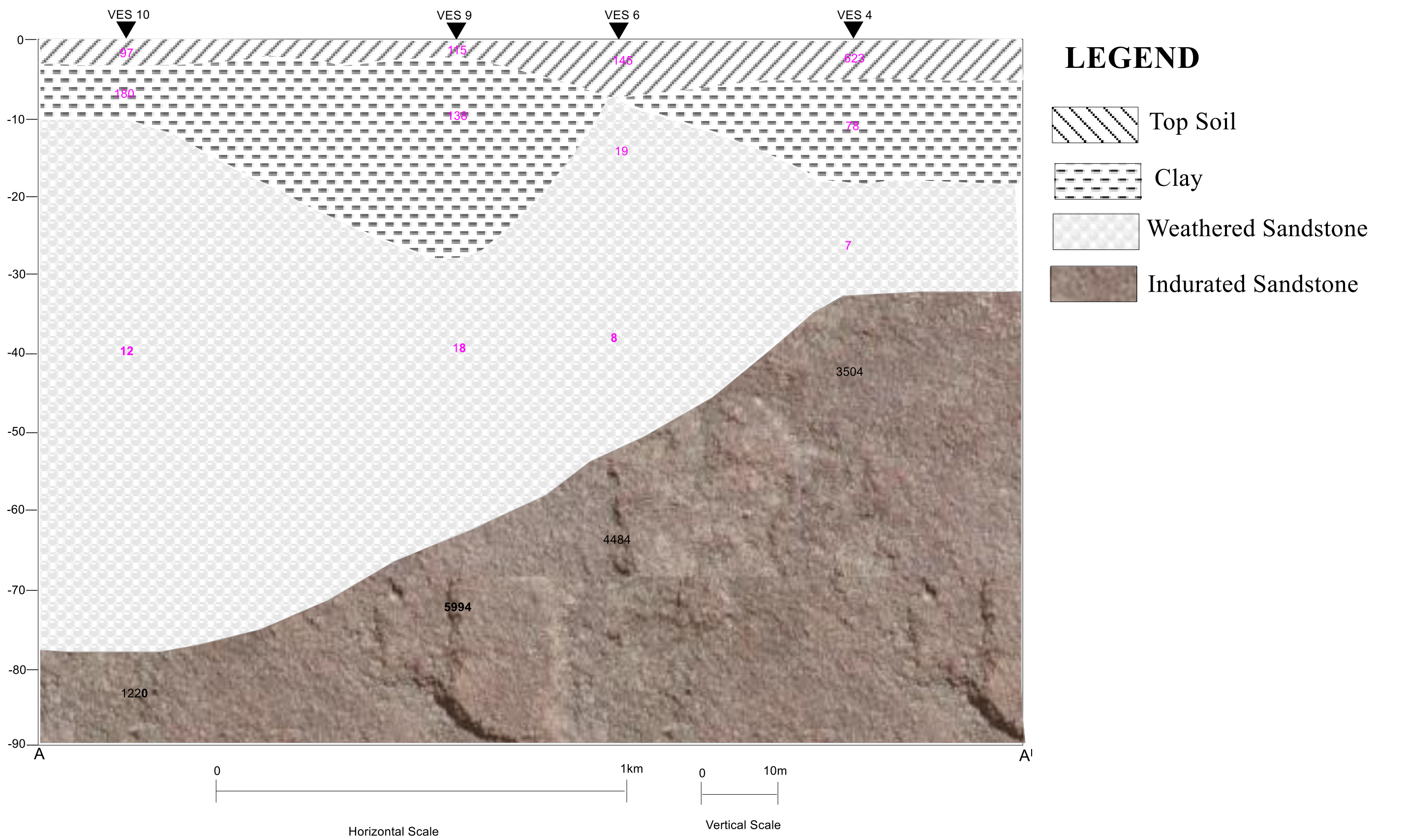

Figure 6. Geoelectro-stratigraphic section profile A-A'.

Geoelectro-stratigraphic section

A geoelectric section is a visual representation of subsurface layers showing variations in their electrical resistivity and depths along a specific profile (Ojo *et al.,* 2024). Geo-electro sections were taken along profile A-A' (comprises VES 10, VES 9, VES 6, and VES 4) as shown in Figure 6. The section revealed that there are three to four geologic layers beneath the subsurface of the study area. The geologic sequence beneath the study area is composed of topsoil, clay, weathered sandstone and highly indurated sandstone.

Aquifer parameters

Aquifer parameters like hydraulic conductivity and transmissivity were calculated from resistivity data and are important for groundwater development and evaluation (Oli *et al*., 2022). Hydraulic conductivity was calculated using equation 3.

$$K=386.4R_{rw}^{-0.93283} \text{ (m/day)} \qquad 3$$

Where R_{rw} is the aquifer resistivity, and K is the hydraulic conductivity.

The transmissivity values were calculated using equation 4 (Offodile, 1983).

$$T = Kb \text{ (m}^2\text{/day)} \qquad 4$$

Where T is Transmissivity (m^2/day), K is Hydraulic Conductivity (m/day), and b is Aquifer Thickness (m).

Generally, the higher the transmissivity value of an aquifer, the better its productivity prospects. Hydraulic conductivity is proportional to permeability. High permeability will be observed in the aquifer zone with high hydraulic conductivity, and also contaminants will be easily circulated (Kazakis *et al.,* 2016). The hydraulic conductivity was calculated from the electrical resistivity sounding data. The ten potential aquifer resistivities were contoured as shown in Figure 6. The hydraulic conductivity and transmissivity of the aquifer were determined using the equation above.

The maximum hydraulic conductivity value is observed at VES 3, 4, and 8 toward the northern, south-west and south-eastern portions of the study area, while the maximum transmissivity values were observed at VES 2 and 10 with values of 1200 and 2600 m^2/day (Figures 7 and 8), indicating a high groundwater potential zone. According to *(Gabriel et al. 1997),* the fractured aquifer has

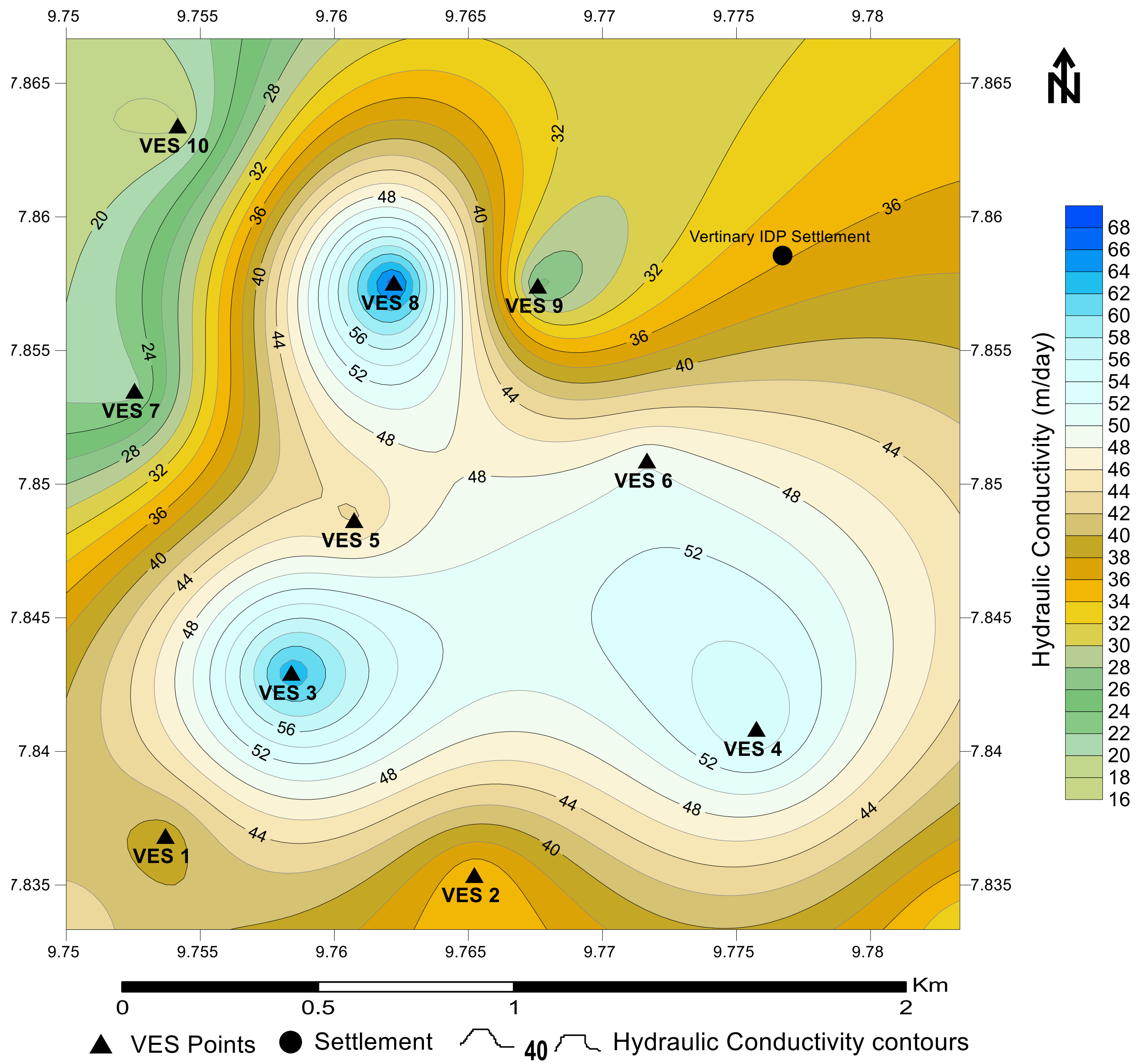

Figure 7. Hydraulic conductivity contour map (contour interval 2m/day).

low to moderate hydraulic conductivity and transmissivity values, which give rise to low and moderate yield.

Physiochemical analysis

Results from five selected hand-dug wells (Table 2) indicate that the temperature ranges from 27.2 to 30.2°. Total dissolved solids (TDS) values range from 194 – 620 mg/l relative to World Health Organisation (WHO) and Standard Organisation of Nigeria (SON) guidelines for potable water (Oloyede-Kosoko *et al*., 2015). HDW 2 has a TDS value of 620 mg/l, which is above the NSDWQ limit. Turbidity values range between 4.99 – 310 mg/l. HDW 1, 2, 4, and 5 have values above permissible WHO limits. Electrical conductivity (EC) has values that range from 390 – 833 mg/l and are within the permissible WHO limits.

Chemical parameters from the hand-dug wells (Table 2) show that $CaCO_3$ ranges from 36 – 73 mg/l, while Ca^{2+} ranges from 7 – 8.0 mg/l, Fe^{2+} has values from 0.12 – 0.86 mg/l, HDW 1 and 3 have values above the WHO and NSDWQ limits. Analysis for anions shows that CO_3 range from 40 – 100 mg/l, SO_4^{2-} 21.3 – 89.8 mg/l. Chlorine (Cl^-) has values from 10 – 70 mg/l, and Fluorine (Fl^-) values are 0.1 – 0.7 mg/l. Anion values fall within the permissible WHO and NSDWQ limits.

Physical parameters were also examined from five selected boreholes (Table 2) and indicate a temperature of

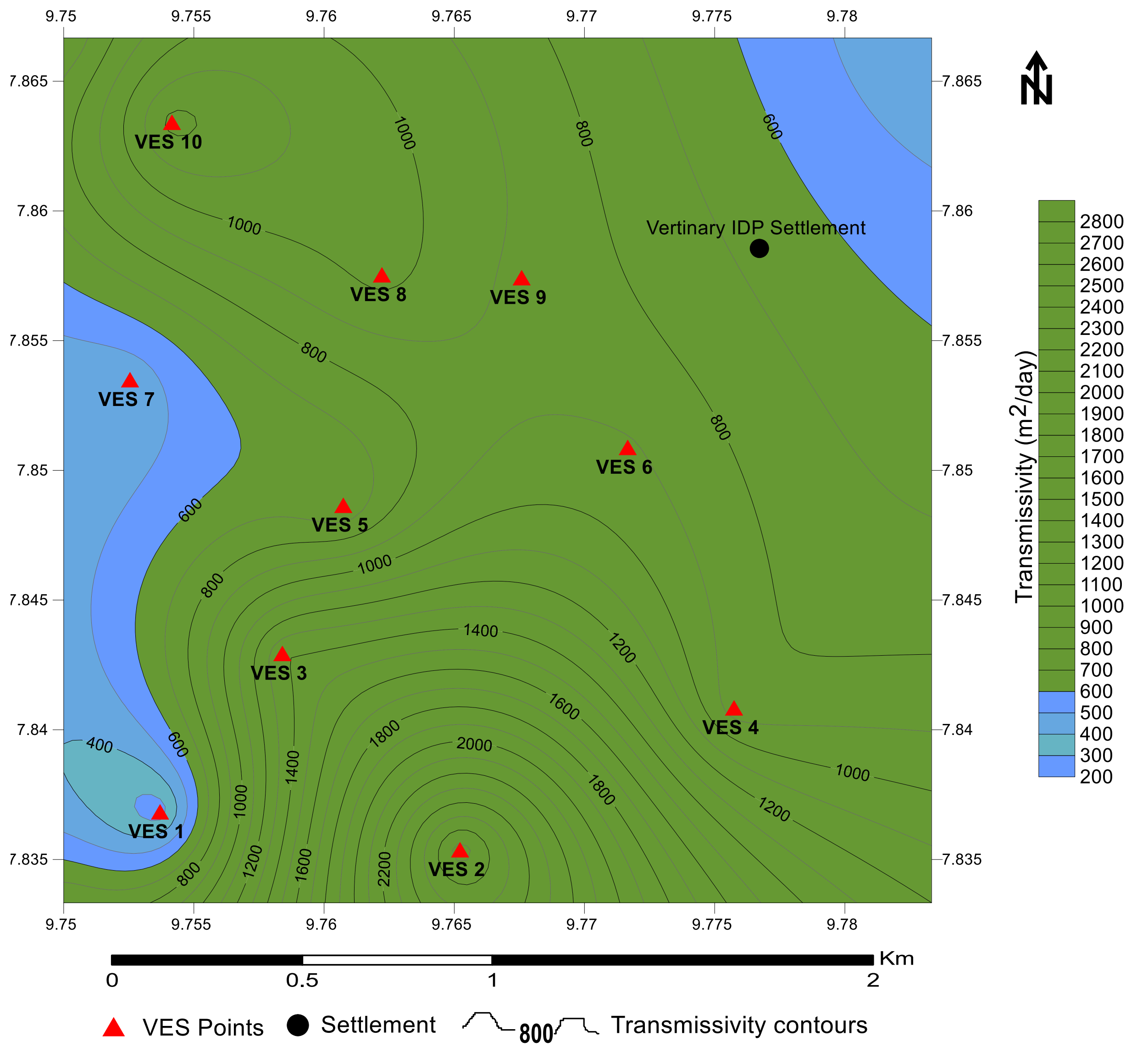

Figure 8. Aquifer transmissivity contour map (contour interval 100 m^2/day).

27. 7 – 28°C while total dissolved solid values range from 166 mg/l – 187 mg/l and falls within the WHO limit for drinking water. Turbidity values are from 0.62 – 111 mg/l, while electrical conductivity values are from 227 – 252 mg/l with a pH of 6.48 – 6.79.

Analysis for anions from the five boreholes (Table 2) indicates that CO_3 has values from 30 – 95 mg/l, while $SO^2{}_4$ ranges from 18.5 – 75.2 mg/l. Calcium (Ca^{2+}) has values from 1.37 – 2.69 mg/l and are above the WHO limits. Chlorine (Cl^-) and Fluorine (F^-) have values that range from 60 mg/l – 89 mg/l and 0.3 mg/l – 0.95 mg/l, respectively.

The elevated concentrations of certain parameters in the analysed water samples—such as TDS, turbidity, Fe^{2+}, and Ca^{2+}—can be attributed to both geogenic and anthropogenic sources. Geogenic factors include the natural weathering and dissolution of minerals from surrounding rocks and soils, which are likely responsible for high levels of iron, calcium, carbonate, and TDS. On the other hand, anthropogenic influences, such as poor sanitation practices, agricultural runoff, and surface contamination from nearby human activities, could explain the elevated turbidity and localised exceedances of certain chemical parameters, especially in hand-dug wells that are more vulnerable to surface infiltration.

Implications of geophysical, hydrochemical findings, and future direction

Vertical Electrical Sounding (VES) with Schlumberger array is applied within this research in the evaluation of the

Table 2. Result of physiochemical analysis obtained from five selected boreholes and five hand dug wells.

			Physical Parameters					Chemical Parameters									
								Cation(mg/L)					Anions(mg/l)				
S/N	Samples	T(°C)	TDS (mg/L)	Color	Turbidity	EC ($\mu S/cm$)	P^H	$CaCo_3$	Ca^{2+}	Na^+	No_3^+	Fe^{2+}	CO_3^-	SO_4^{2-}	Cu^{2+}	Cl^-	F^-
1	HDW1	27.9	494	79	310	717	6.72	36	2.0	50	0	0.86	100	21.3	0	10	0.71
2	HDW2	29.0	620	0	119	833	6.58	49	4.3	100	0	0.3	79	62.9	0	50	0.52
3	HDW3	27.2	194	4	4.99	390	6.33	50	7.0	58	0	0.66	70	15.7	0	35	0.35
4	HDW4	29.2	307	1	20.5	417	7.17	73	8.0	90	0	0.32	90	89.8	0	67	0.22
5	HDW5	30.2	454	17	128	618	6.80	29	1.7	80	0	0.12	40	21.3	0	70	0.1
6	BH1	28.1	178	24	111	238	6.65	20	2.6	59	0	0.11	60	53.4	0	89	0.7
7	BH2	27.8	166	1	1.04	227	6.79	35	9.0	30	0	0.45	30	75.2	2.69	70	0.3
8	BH3	28.0	184	1	0.83	247	6.48	48	5.0	120	0	0.01	60	23.6	1.37	88	0.92
9	BH4	27.7	187	0	0.62	252	6.79	89	3.8	40	0	0.01	95	18.5	2.1	60	0.95
10	BH5	28.1	173	0	1.1	234	6.66	32	5.3	80	0	1.0	75	67.8	1.9	68	0.76
11	NSDWQ	Ambient	500	15	5	1000	6.5-8.5	20-200	-	200	50	0.3	120	200	2.0	250	1.5
12	WHO	-	1000	15	5	1000	6.5-8.5	200	-	250	50	0.2	120-180	250	1.0	250	1.5

groundwater potentiality of Old BB Quarters, Wukari, Nigeria. Resistivity results from the study confirm the existence of permeable aquifer horizons in sandstone units, weathered, a critical parameter in groundwater viability. The aquiferous horizons (VES 4, 6, 9 and 10) found in this research have low resistivity readings (1.03 – 18.73 Ωm), showing high groundwater potential (water-holding capacity). In comparison with other research (Oseji et al., 2005; Samuel *et al*., 2020), this agrees with resistivity levels in productive aquifers as presented. In addition, transmissivity values of 2600 m²/day support effective pumping of groundwater (Kazakis *et al*., 2016). Optimum hydraulic conductivity is 1200 m²/day, corresponding to transmissivity of 2600 m²/day, which suggests high permeability according to noteworthy studies (Dogara et al, 2017; Omeiza and Dary, 2018; Alao and Abubakar, 2025). Physiochemical examination reveals borehole calcium over standards prescribed by WHO, while that of hand-dug well TDS exceeds the standard. The results reveal hydrogeological heterogeneity as well as the necessity for sustainable groundwater monitoring. That is, boreholes should be positioned in zones of high transmissivity with water treatment procedures to improve quality. However, the physicochemical factors indicate differences between hand-dug wells and boreholes. Although EC values of boreholes are within WHO (1000 µS/cm) and NSDWQ thresholds, hand-dug wells indicate high TDS (620 mg/l) above NSDWQ thresholds (500 mg/l). Hand-dug wells' turbidity violates the WHO's standard of 5 NTU, with a possibility of sediment intrusion. High calcium levels (>200 mg/l) in boreholes violate the WHO's permissible limits, with scaling and hardness risks in domestic use. This is supported by the previous studies (Onasachi *et al*., 2016; Omeiza *et al*., 2023; Alao *et al*., 2023), where fractured aquifers suffered mineral contamination. Contaminants align with patterns in fractured aquifers (Onasachi *et al*., 2016; Alao, 2025). The elevated heavy metal hand-dug wells pose risks to public health (WHO, 2021). Regular water treatment and aquifer monitoring are essential for public health (Samuel *et al*., 2020; Alao, 2023). For maximal use of groundwater, the high transmissivity areas need to be addressed with boreholes, and filtration systems need to be incorporated to meet high calcium levels. Regular water quality checks will align local water schemes with WHO norms. AI-driven hydrogeological modelling for aquifer delineation improvement can be pursued as a future study. Additionally, extending the application of VES surveys to large-scale sedimentary basins would improve regional groundwater mapping for sustainable use.

Conclusion

The study has demonstrated the usefulness of the

VES method in the exploration of groundwater in the sedimentary terrain carried out at ten (10) different stations in Old BB quarters of Wukari. The curve types obtained were QH, KH and K. The curves obtained exhibited mostly four geoelectric sections. It's noticed that the probable stations, as noted from the iso-resistivity maps and geo-electric section, suitable for sighting of boreholes, are VES 4, 6, 9 & 10, signifying permeability and storage. Maximum hydraulic conductivity and transmissivity values at VES 3, 4, 8 and 2, 3, respectively. Physiochemical analysis shows TDS values from hand-dug wells exceeding the WHO standard, while anions fall within the permissible NSDWO and WHO limits. Physical parameters from boreholes were observed to be within recommended limits, while calcium is above the safety limits of the WHO. This has provided information on the depth to groundwater and the thickness of the aquifer unit in the study area. This information is going to be relevant to the development of an effective water scheme for the area.

CONFLICT OF INTEREST

The author states that there is no conflict of interest.

REFERENCES

Aizebeokhai, A. P., Olayinka, A. I., & Singh, V. S. (2010). Application of 2D and 3D geoelectrical resistivity imaging for engineering site investigation in a crystalline basement terrain, southwestern Nigeria. *Environmental Earth Sciences, 61*, 1481-1492.

Alao, J. O. (2023). Impacts of open dumpsite leachates on soil and groundwater quality. *Groundwater for Sustainable Development*, *20*, 100877.

Alao, J. O. (2025). The evolving roles of geophysics in environmental assessment, monitoring, and management of landfill leachate contaminant plumes: An overview. *Case Studies in Chemical and Environmental Engineering*, *11*, 101124.

Alao, J. O., & Abubakar, F. (2025). Groundwater exploration, management strategies and sustainability: Geophysical approaches. *Geosystems and Geoenvironment 4*(3), 100395.

Alao, J. O., Dogara, M. D., Danlami, A., & Samson, E. E. (2019). Comparative assessment of half schlumberger configuration as an alternative method to the conventional schlumberger configuration at trade centre, mani-nissi village, Kaduna, Nigeria. *SSRG International Journal of Applied Physics, 6*(3), 51-56.

Alao, J. O., Yusuf, M. A., Nur, M. S., Nuruddeen, A. M., Ahmad, M. S., & Jaiyeoba, E. (2023). Delineation of aquifer promising zones and protective capacity for regional groundwater development and sustainability. *SN Applied Sciences*, *5*(5), 149.

Ayuni, N. K. Fagbenro, W. A., & Moshud, K. M. (2018). Hydro-geoelectrical Study of Zing and Environs, Taraba-State, Northeast Nigeria. *FUW Trends in Science and Technology Journal, 3*(2B), 884-857.

Ayuni, N. K. Onudibia, M. E. Fagbenro, W. A., & Ocheje, J. A. (2017). Geophysical survey report for water borehole at Tudun Wada Bazza, Michika, Adamawa-State, Northeast Nigeria. *International Journal of Geophysics and Geochemistry, 4*(6), 61-65.

Chavez Pacheco, M. D. P., Caysahuana Flores, J. A., Julian Salvador, D. J., & Mallma Capcha, T. (2023). Vertical electrical sounding method to detect groundwater and design of a tubular well for the Pampas District–Peru. *Civil Engineering and Architecture*, *11*(4), 1984-2006.

Coccioni, R., & Premoli Silva, I. (2015). Revised Upper Albian–Maastrichtian planktonic foraminiferal biostratigraphy and magnetostratigraphy of the classical Tethyan Gubbio section (Italy). *Newsletters on Stratigraphy*, *48*(1), 47-90.

Dauda, G., & Ali, A. M. (2024). Delineating leachate-groundwater interaction at Gyadi-Gyadi dumpsite, Kano, using natural electromagnetic (EM) field detector and Vertical Electrical Sounding (VES). *Geosystems and Geoenvironment, 3*(4), 100303.

Dewangan, S. K., Shrivastava, S., Kadri, M., Saruta, S., Yadav, S., & Minj, N. (2023). Temperature effect on electrical conductivity (EC) & total dissolved solids (TDS) of water: A review. *International Journal of Research and Analytical Reviews*, *10*(2), 514-520.

Dogara, M. D., Aboh, H. O., Alao, J. O., & Kogi, K. A. (2017). The Aquifer Overlying the Basement Complex in Some Parts of Dan-Hono, Kaduna, Nigeria. *Kada Journal of Physics*, *1*(2), 45-52.

Kazakis, N., Vargemezis, G., & Voudouris, K. S. (2016). Estimation of hydraulic parameters in a complex porous aquifer system using geoelectrical methods. *Science of the Total Environment*, *550*, 742-750.

Kure, N., Aboh, H. O., Jimoh, R., Alao, J. O., & Isaac, H. D. (2017). The delineation of the aquifer overlying the basement complex within Ahmadu Bello university (main campus) zaria. Department of physics, Kaduna state university, Kaduna, Nigeria. *British Journal of Applied Sciences*, *19*(1), 1-9.

Lachassagne, P., Dewandel, B., & Wyns, R. (2021). Hydrogeology of weathered crystalline/hard-rock aquifers—guidelines for the operational survey and management of their groundwater resources. *Hydrogeology Journal*, *29*(8), 2561-2594.

Mohammed, M. A., Szabó, N. P., Alao, J. O., & Szűcs, P. (2024). Geophysical characterization of groundwater aquifers in the Western Debrecen area, Hungary: insights from gravity, magnetotelluric, and electrical resistivity tomography. *Sustainable Water Resources Management*, *10*(2), 67.

Nur, A., & Ayuni, K. N. (2011). Hydro-geophysical study of Michika and environs, northeast Nigeria. *International Journal of the Physical Sciences*, *6*(34), 7816-7827.

Nyaberi, D. M. (2023). Application of vertical electrical sounding in mapping lateral and vertical changes in the subsurface lithologies: a case study of Olbanita, Menengai Area, Nakuru, Kenya. *Open Journal of Geology*, *13*(1), 23-50.

Ofoegbu, C. O. (1985). A review of the geology of the Benue Trough, Nigeria. *Journal of African Earth Sciences, 3*(3), 1-9.

Ogungbesan, G. O., & Akaegbobi, I. M. (2011). Petrography and Geochemistry of Turonian EzeakuSandstone Ridges, lower Benue Trough, Nigeria Implication for Provenance and Tectonic Settings. *Ife Journal of Science, 13*(2), 1-16.

Ojo, O. T., Chiaka, I. J., & Mark, A. I. (2024). Geophysical subsurface mapping using the electrical resistivity technique: A comprehensive study of the Petroleum Training Institute Main Campus in Effurun. *Indonesian Journal of Earth Sciences, 4*(1), A846-A846.

Oli, I. C., Opara, A. I., Okeke, O. C., Akaolisa, C. Z., Akakuru, O.

C., Osi-Okeke, I., & Udeh, H. M. (2022). Evaluation of aquifer hydraulic conductivity and transmissivity of Ezza/Ikwo area, Southeastern Nigeria, using pumping test and surficial resistivity techniques. Environmental Monitoring and Assessment, *194*, Article number 719.

Oloyede-Kosoko, S. O. A., Idowu, A. O., & Ayoni, O. O. (2015). Evaluation of water quality with World Health Organization and Nigeria Industrial Standards using geographic information system. *World Scientific News, 24*, 18-42.

Omeiza, A. J., Lawal, H. A., & Nur, M. (2023). Investigation of groundwater vulnerability to open dumpsites and its potential risk using electrical resistivity and water analysis. *Heliyon*, *8*, e09855:

Omeiza, J. A., & Dary, M. D. (2018). Aquifer vulnerability to surface contamination: a case of the new millennium city, Kaduna, Kaduna State Nigeria. *World Journal of Applied Physics*, *3*(1), 1-12.

Onasachi, J. M., Yakubu, H. M., Shaibu, M. M., & Gyang, D. S. (2016). Geophysical Investigation of Groundwater Potential in Basement Terrain, Okene, Central Nigeria. *International Journal of Emerging Trends in Science and Technology, 3*(7), 2348-9480.

Oseji, J. O., Atakpo, E. A., & Okolie, E. C. (2005). Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta state, Nigeria. *Journal of Applied Sciences & Environmental Management*, *9*, 157-160.

Osemeikhian, J. E., & Asokhia, M. B (1982). *Applied Geophysics for Engineering and Geologists.* Mc-Graw Hill. p.155.

Otieno, F. A. O., Olumuyiwa, I. O., & Ochieng, G. M. (2012). Groundwater: Characteristics, qualities, pollutions and treatments: An overview. *African Journal of Agricultural Research*, *4*(6), 162-170.

Rolia, E., & Sutjiningsih, D. (2018, June). Application of geoelectric method for groundwater exploration from surface (A literature study). In *AIP Conference Proceedings* (Vol. 1977, No. 1, p. 020018). AIP Publishing LLC.

Samuel, S. Nur, A. Ayuni, N. K., & Yusuf, S. (2020). Geo-electrical investigation for groundwater potential of Kaltungo and Environs, Northeast Nigeria. *Applied Journal of Physical Science, 2*(3), 55-67.

Yusuf, S. Ayuni, N. K. Ali, U., & Samuel, S. (2020). Geophysical investigation for groundwater potential using vertical electrical sounding at a West African Location. *International Research Journal of Advance Science, 1*(1), 9-15.