GEOPHYSICAL MAPPING AND GEOTECHNICAL CHARACTERIZATION OF WATER BEARING FORMATIONS OF RIMIN DOKO, ZARIA LOCAL GOVERNMENT AREA KADUNA STATE

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Abstract: In Nigeria the provision of water for consumption is usually deemed as one of the fundamental objectives of the Government. Zaria water distribution system is mainly characterized by old and poorly maintained infrastructure. The study examines the geophysical mapping and geotechnical characterization of water bearing formations of Rimin Doko, Zaria Local Government Area Kaduna State. The method used in this research work Vertical Electrical Sounding (VES) Schlumberger using ABEM Terameter SAS 1000 machine for studying electrical resistivity properties of site (soil) layer in the subsurface area of Kauran Sarki community. This is to assess the groundwater potential of some areas, searching for the existence of possible aquifers in the area also estimating the possible depth for borehole drilling. The Geohysical and Geotechnical investigations are restricted to some various points in the affected area of Rimin Doko based on results obtained at the points; VES1, VES2, VES3, VES4, VES5, VES6, VES7 & VES8 ineterpretion shown better Aquifers at VES4, VES5...VES8. considering Geotechnical investigation, the soil permeability for VES1, VES2...VES8 were found to be low due to the soil high specific gravity. The study found that drilling of boreholes at Late Emir Yamusa Primary school to area beyond on the south-eastern part of the study areas are preferable because of better potential aquifers are within the part. The study recommends that, in order to achieve best yield from the available aquifers screened casing should be properly provided and grouted.

Keywords: Aquifer, Borehole, Geophysical, Geotechnical, Vertical Electrical Sounding), Water.

1. INTRODUCTION

Water is an important and abundant mineral on the Earth. All living things require water for survival and growth. The Earth is having approximately 70% of water. Similar description of water as mineral resource was stated by Ayodeji, Abubakar and Samuel (2017).

Water remains a resource that is both invaluable and vital for all livings and their activities, at the same time water is increasingly being threatened as a result of growth in human population and demand for more water for domestic, agricultural and commercial purposes. The Author also added that, portable water is precious, live cannot be sustain without it at the same time human activities have great impact on water supplies quality and quantity (Chikagbum *et al.*, 2020).

In Nigeria and many African countries, the provision of water for consumption is usually deemed as one of the fundamental objectives of the Government. In Kaduna, specifically, many water provision initiatives have been put in places over the years, with some success recorded in some areas, water provision in the Kaduna cannot be write as a perfect success story. It was estimated that presently about 1805 boreholes constructed by the State Water Resources ministry, which covers all the 23 local government areas in state. In addition, an organization known as Rural Water Supply and Sanitation Agency

(RUWASSA) reported to have constructed four hundred numbers of boreholes in state. However, records have indicated that in the year 2011 only 20% of the total boreholes are functional while service coverage is estimated at 11% and 32% of the rural and urban population respectively (Afuwai *et al*., 2015).

African Development Fund (2011) reported that; the Federal Government of Nigeria improved its efforts in providing adequate and safe water supply services as a major instrument for eradicating poverty and improving social and economic development. Further added that; water supply development project will improve likewise public health and standard of living of communities like Zaria towns at the same time increase the economic investment which in turn enhances opportunities for jobs and improved livelihood of the residents of the community. Zaria town is experiencing wet and longer dry season.

Nwoke and Edori (2021) described groundwater (boreholes) as the major source of water available for domestic, industrial, agricultural irrigation and commercial consumptions.

University of Benin (2021) reported that boreholes are effective ways of exploring from the water bearing strata (aquifer) in the ground and pumping it to the surface level. Also, that, boreholes for extraction of water normally consists of a vertically drilled hole, a strong protective casing to prevent collapse of the soil walls as well as for filtering of water into the borehole space through the screen of the casing pipe, surface cover. Before drilling of borehole, a good site has to be located, where experience suggests the potentiality of reaching adequate quantity of good quality groundwater. During the drilling activities there are different stages which require careful attention in order to prevent the drilling work from failing. Besides the practical drilling skills also attention is required to be paid to important processes which are taking place beneath the ground level during and after the drilling activities.

The demand for drinking water is increasing since last thirty years due to increase in population growth of the world. The major sources of water to balance the demands include both surface waters and groundwater. Groundwater occurs beneath the surface of the earth via soil pores, fissures, fractures as well as weak geological zones (aquifers). The water is protected from bacterial contamination and evaporation. These merits make communities to heavily rely on groundwater for general purposes.

Nwobi et al., (2022) adopted the use of geophysical investigation using of vertical electrical sounding. The investigation aimed at assessing the groundwater potential of some areas, searching for the existence of possible aquifers in the area also estimating the possible depth for borehole drilling.

In Zaria there is increase in population and commercial development which caused increase in the uses of water and that; Zaria water distribution system is mainly characterized by old and poorly maintained infrastructure also of low coverage similar findings were reported by Muhammed et al., 2021; Yusuf 2012. The said problems cause low and epileptic pump water supply in Rimin Doko community. Majority of the residents depends on shallow wells, which dries every season mostly from the month of October to May, leaving the community with only option of accessing water that is very expensive water supply by water vendors. Most of the time women and children have to trek a long distance before getting a better water source. Meanwhile, trekking exposing themselves to attack from bad elements. Some of the residents engage in manual drilling of boreholes but unfortunately, they do not yield at all or the

yield is not sufficient enough for domestic consumption. Hence, investigative research focusing at the geotechnical and geophysical aspect of the landmass of the affected communities will serve as a turning point in the process of tackling the problem. Upon completion, it will enable the researchers to identify and advice on how to overcome this long lingering hardship among the residents of the affected communities in Zaria. Iduser et al., (2021) Muhammed et al., (2021) and Garba at el., (2013) have conducted research aiming at assessing the yield of boreholes in Zaria but till this time no researcher attempted to investigate and analyze the cause through geotechnical perspective. The research results will reveal the cause of insufficient water yield by the soil formations in the community and appropriate suggestions can be provided as well. Plate I is showing a typical of Non-functioning borehole in Rimin Doko community.



Plate I. Non-functional Borehole at Rimin Doko, Zaria.

2. METHODOLOGY

2.1 MATERIALS

The tools and equipment used for this research are;

i. GPS device for locating coordinates
ii. ABEM Terrameter SAS 1000 for electrical sounding for geophysical surveying
iii. IPI2win software
iv. Glass fibre tape for linear measurements
v. Hammer for pegging

2.2 THE STUDY AREA

The study area is a small community known as Rimin Doko Kauran Sarki, Zaria, which is located in Zaria metropolitan city which lies on latitude 11° 07" N and 12° 00" N and longitude 07° 44" E and 8° 00" E (see Plate II). Kauran Sarki area is predominantly considered as low yield site in terms of underground water exploration. The area is located in the North-Western part of Nigeria. Zaria is also one of the seven

original Seven Hausa - city (Hausa Bakwai). The area experiences two different seasons namely; the wet season and dry seasons which are caused by the movement of the Inter-Tropical Discontinuity under the forces of two major air masses namely the tropical continental and the tropical maritime. It has about 800 mm as mean annual rainfall in a wet season between the months of April and October. The temperature is high throughout the year, with the monthly mean rising from January (21°C) and attaining a higher in April (29°C). The study area is accessible and located at some few meters away from the Emirs palace in the South direction.



Plate II. View of Rimin Doko Kauran Sarki
Source: Field Work using ArcGIS Earth (2022)

2.3 METHOD

The method used in this research work Vertical Electrical Sounding (VES) Schlumberger method using ABEM Terrameter SAS 1000 machine for studying electrical resistivity properties of site (soil) layer in the subsurface area of Kauran Sarki community. The electrode spacing is been increase progressively, maintaining the center point of the electrode array fixed. Resistivity measurements in the field were carried out using ABEM SAS 1000 Terrameter. The full and half Schlumberger configuration array was adopted with half and full current electrodes spread (AB/2 between 1.00 and 40.0m and half potential electrode separation MN/2 between 0.5 and 2.5m). The apparent resistivity (ρ_a) was measured in twelve locations using Equation (1).

$$(\rho a) = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] R \quad \ldots \text{Equation 1}$$

The equation is further simplified into equation 2 as follows;

$$\rho a = K.R \quad \ldots \text{Equation 2}$$

Where the geometric factor is: $k = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right]$

AB and *MN* are representing the current and potential electrode separations respectively where *R* is the measured resistance. The process was carried out by measuring the resistance of the earth via the effect of

current sent into the ground through electrodes. The measured resistance (R) was multiplied by the geometric factor (*k*), determined by the electrode configuration (See Plate III) The investigation was carried out on the 21st November, 2022 and aimed at each VES site in; determining depth to bedrock, geophysically delineating the various lithological units that constitute the overburden (the regolith), determining the presence or absence of fractures in the bedrock in the area under study and select the most promising site for drilling the borehole.

The survey occupied Eight (8) Vertical Electrical Soundings employing the Hummel (Modified Schlumberger) array only.

The site coordinates were captured using the GPS device known as eTREX Legend Garmin while the processing of apparent resistivity data was done using a software known as IPI2win. This led to the obtaining of model representative curves.



Plate III. Conducting Vertical Electrical Sounding alongside Students Team at Kauran Sarki Zaria

3. RESULTS AND DISCUSSION

3.1 Geophysical Investigation

Vertical Electrical Sounding results were obtained at the beginning by matching the curves with standard master curves and their auxiliaries. These were improved by adopting Interpex 1-D Sounding Inversion methods and are presented in Figure 1 to 8 as field and digitized curves.

The results obtained of the vertical electrical sounding (VES) data shows basically four lithologic units; the top lateritic soil; silt / sandy clay; sandy weathered transition zone and poorly weathered or fresh basement with possible fractures. The first 2 units constitute the overburden while the last unit makes up the bedrock. Table 1 is showing the thickness of overburden while Figure 1 to Figure 8 are showing the resistivity (points of fracture) of the soil formations at the various depths of the selected points (VES1, VES2…VES8). Having deeper overburden thickness and points of fractures as indicated by Table 1 and Figure 1 to Figure 8 respectively, VES 4, 5, 6, 7

and 8 were found to be having better (potential) fractures (aquifer) in the bedrock due to the nature of the curve in the graph compared to VES 1, VES2 and VES3.

Table 1. Overburden thickness at various VES Points.

VES POINTS	OVERBURDEN THICKNESS
VES 1	8-10m
VES 2	6-8m
VES 3	6-8m
VES 4	10-15m
VES 5	6-10m
VES 6	6-10m
VES 7	10-15m
VES 8	6-10m

Source: VES Field Results (2022)

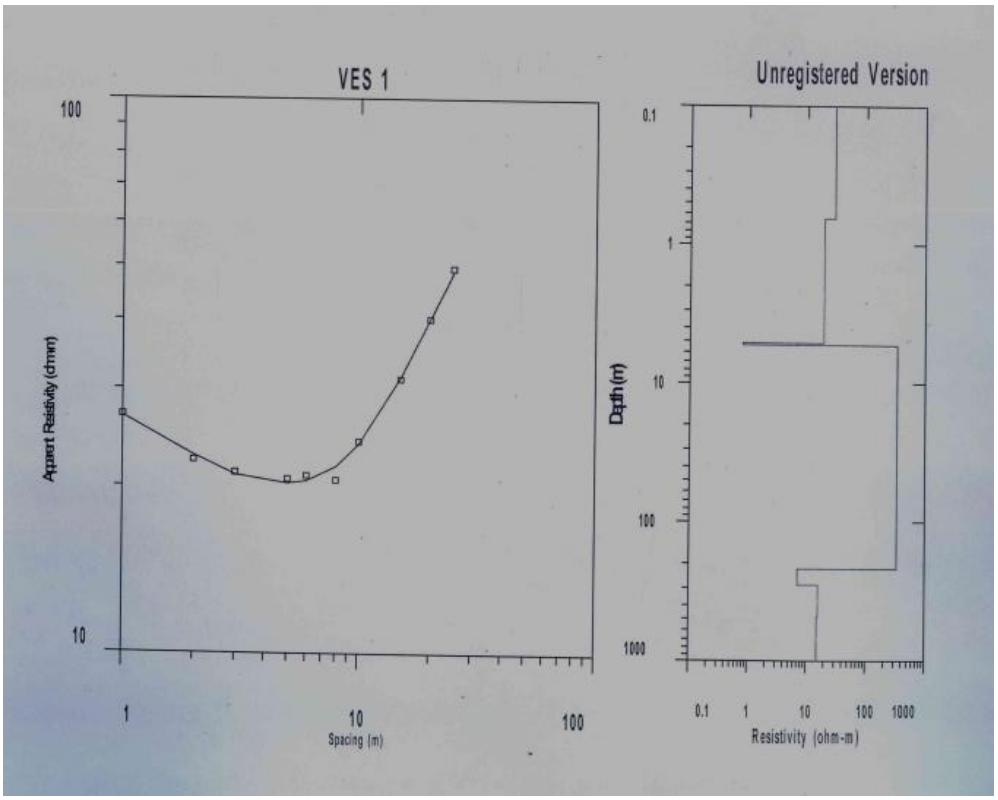

Figure 1. VES 1 Nuhu Bayero Primary School Kaura

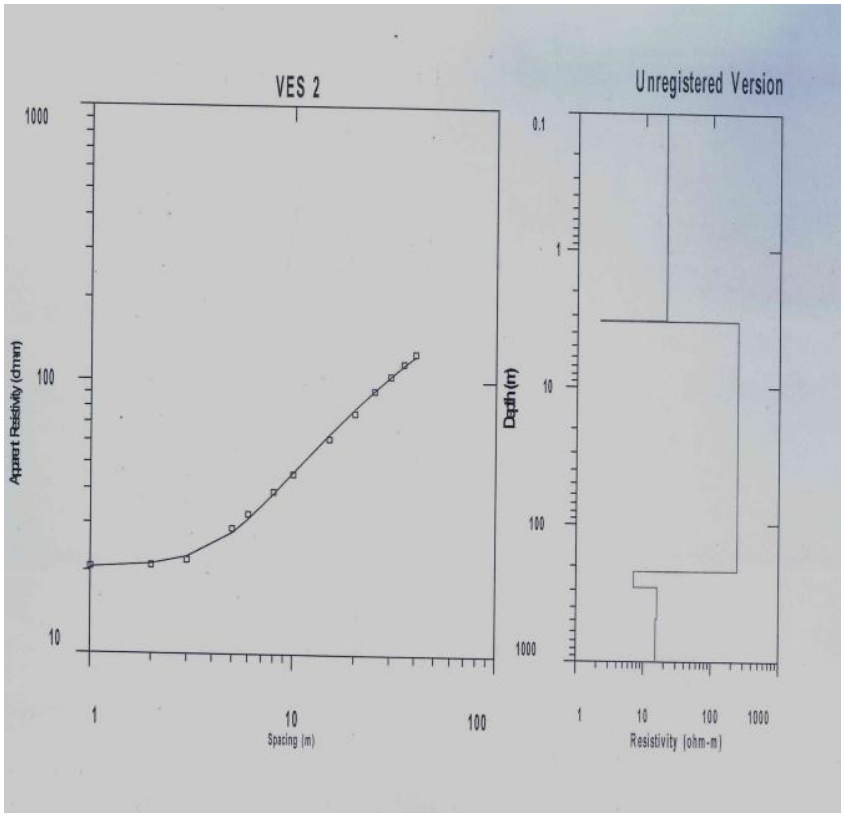

Figure 2. VES 2 Adjacent to Primary School Kaura

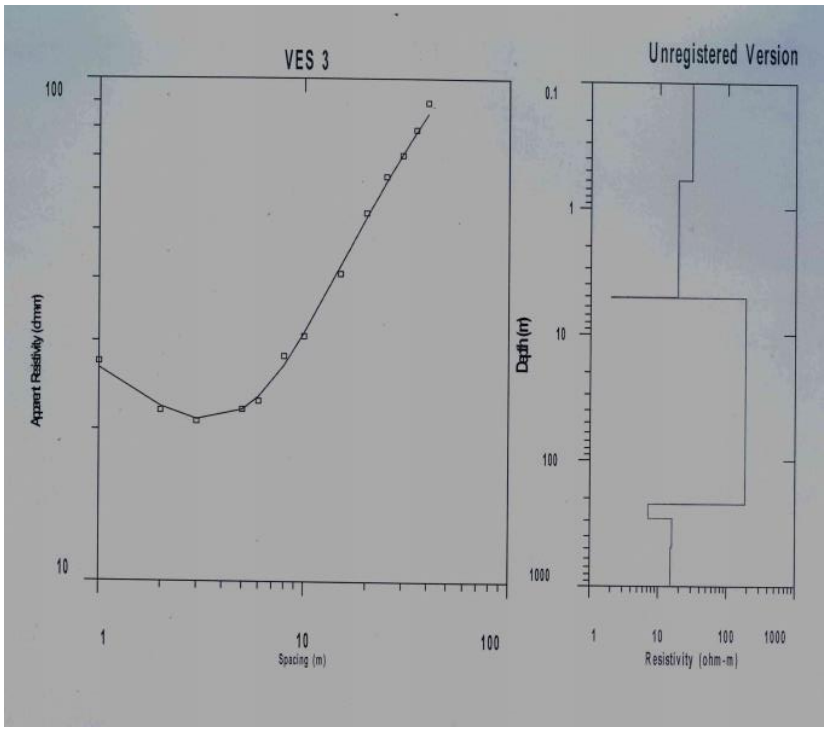

Figure 3. VES 3 Filin Dallatu KauraN Sarki Zaria

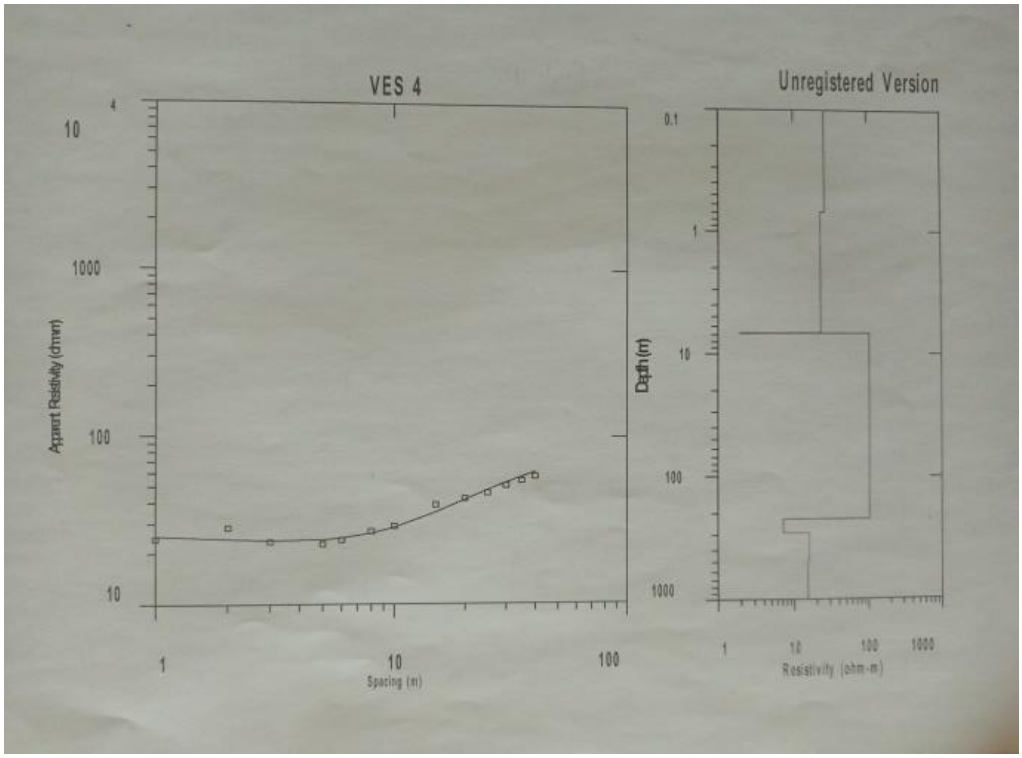

Figure 4. VES 4 Primary Health Care Rimin Doko

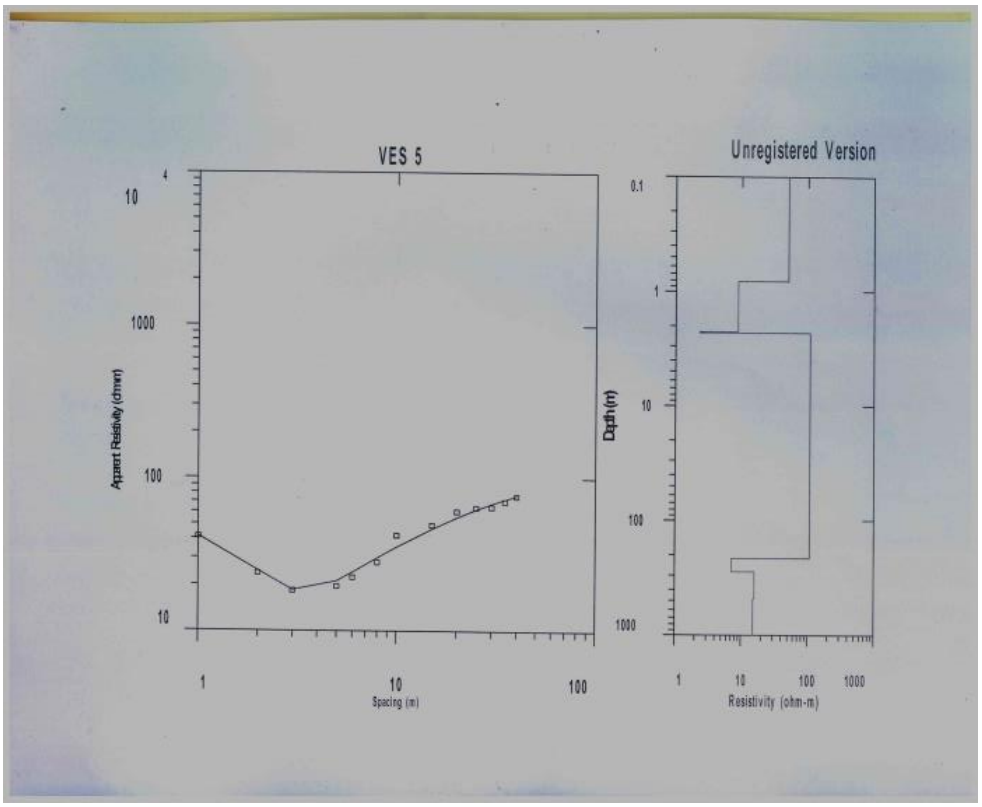

Figure 5. VES 5 Outside Yamusa Primary School Kaura

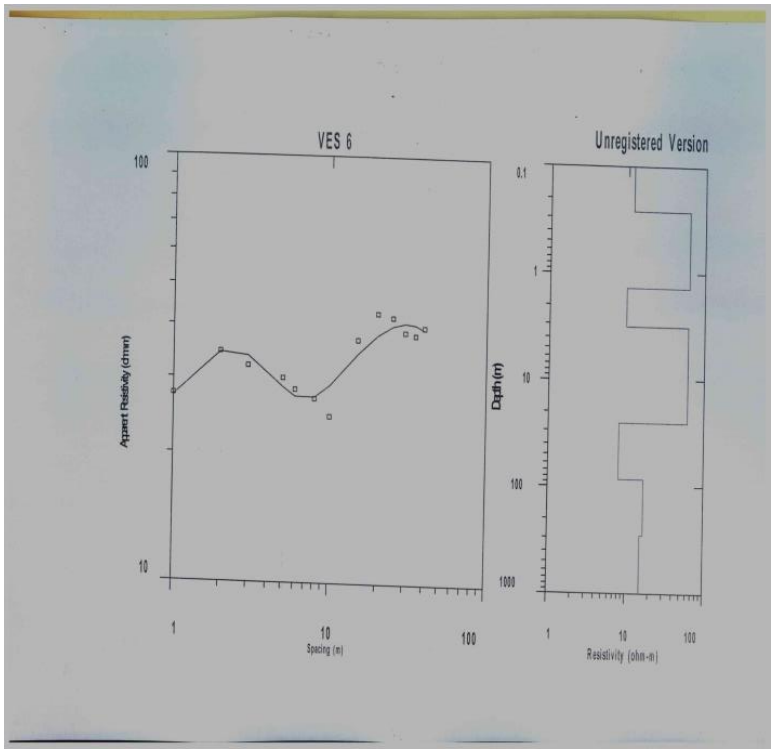

Figure 6. VES 6 Emir Yamusa Primary School Entrance

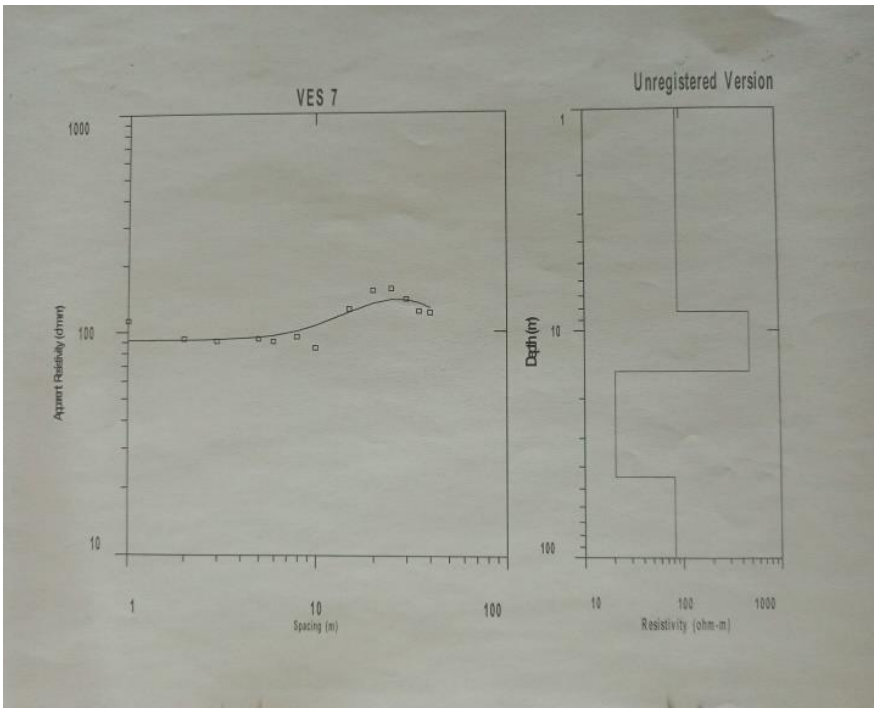

Figure 7. VES 8 Center of Emir Yamusa Primary School

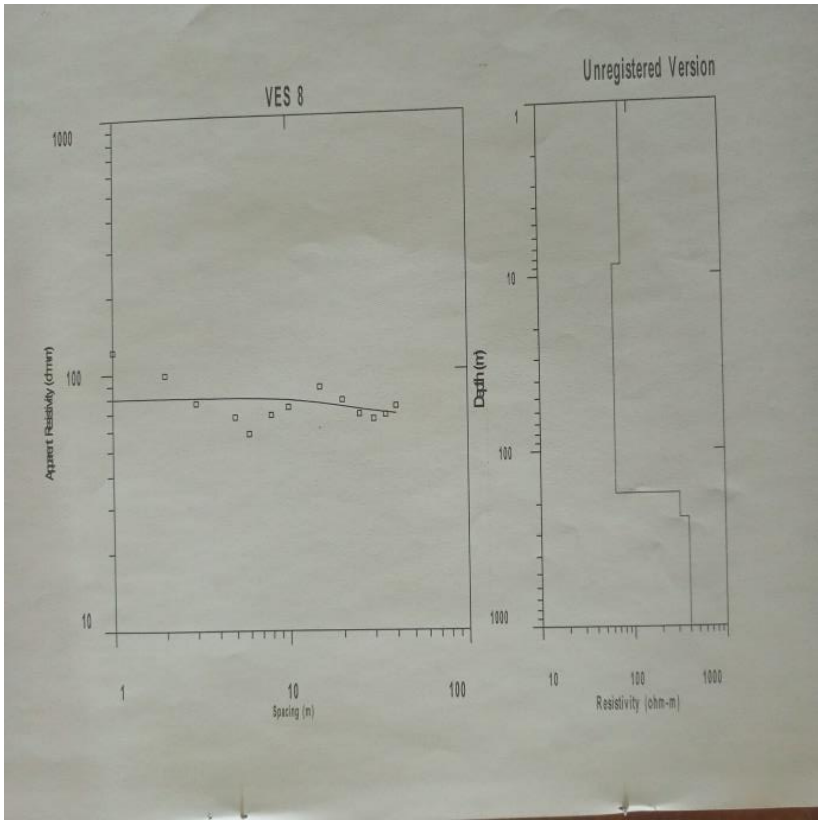

Figure 8. VES 8 Extreme End of Yamusa Primary Part

3.2 Geotechnical Tests

The results for Soil Grain size analysis (Gradation) are show in Table 2 and 3 which is followed by Moisture content, Atterberg limits, Specific gravity and Permeability tests conducted on the soil samples which were also presented in Table 4 and 5 respectively and subsequently discussed below.

3.3 Grain Size Analysis

The results of the Grain size analysis conducted on soil samples at area adjacent to Primary School Kaura (VES2) and at Emir Yamusa Primary School Entrance (VES7), in accordance with BS 1377(1990) Part 2) are shown in Table 2 and 3 respectively. Also, by visual observation on VES1, VES2 and VES3, the sub-soils layers were observed to extend to about 0.5-meter depth consisting of consolidated light reddish lateritic silty/sandy clay. The top (first) layer is underlain by a thick layer of sandy weathered transition zone. The zone consists of fine to medium grained sand mixtures which are characterized by high plasticity starting at about 0.6 to 3 meters depth. Whereas the logs were indicating a gradual change in the soil properties at VES4 and VES5 with higher change noted at VES6, VES7 & VES8 the sub-soils there is consolidated reddish brown lateritic sandy clayey mixture with little silt content. A two layered soil profile was also established. The top layer was noted to extend to about 0.9 m depth, consisting of consolidated reddish brown lateritic sandy clay.

From the results of soil grain size analysis in Table 2 and 3, it is noted that the lateritic soil has 58.165% and 62.120% soil passing sieve No.200 for VE2 and VES7 respectively. Silt content in soil was noted to be increasing with depth, while the clay content decreases slightly for VES2, this can be attributed as the cause of higher permeability (low water retention capacity) and hence making it low yield formation. While at VES7 rich clayey with some fewer silt was observed, this implies lower permeability which make the soil formation to have higher water retention capacity.

Table 2: Grain Size Analysis for Soil Sample VES2

Grain Size Analysis	Weight Retained	Weight Passing	% Passing
2.4mm (7)	1.89	198.11	99.055
1.4mm (10)	3.05	195.06	97.530
0.6mm (600)	19.82	175.24	87.620
0.425mm (425)	5.52	169.72	84.860
0.3mm (300)	15.25	154.48	77.240
0.212mm (212)	13.10	141.38	70.690
0.15mm (150)	17.75	123.63	61.815
0.075mm (75)	7.30	116.33	58.165

Table 3: Grain Size Analysis for Soil Sample VES7

Grain Size Analysis	Weight Retained	Weight Passing	% Passing
2.4mm (7)	1.94	198.06	99.030
1.4mm (10)	3.13	194.93	97.465
0.6mm (600)	10.12	184.81	92.405
0.425mm (425)	7.00	177.81	88.905
0.3mm (300)	15.45	162.36	81.180
0.212mm (212)	12.69	149.67	74.835
0.15mm (150)	18.20	131.47	65.735
0.075mm (75)	7.23	124.24	62.120

Table 4: Results for Gradation, Moisture Content, Atterberg Limits, Specific Gravity and Permeability Tests

Parameter	Depth (m)	Values Obtained	
		VES2	VES7
Moisture Content (%)	1.5	16.42	15.42
	3.0	16.48	16.73
Liquid Limit (LL)	1.5	41	35
	3.0	41	29
Plastic Limit (PL)	1.5	27	21
	3.0	30	21
Plasticity Index (PI)	1.5	14	14
	3.0	11	8
Specific Gravity	1.5	2.78	2.78
	3.0	2.72	2.66

3.4 Moisture Content, Atterberg Limits and Specific Gravity Tests

The results of the Atterberg limit test under which are the results for Liquid limits (LL), Plastic limits (PL) and the Plasticity index (PI) for the soils obtained from all the pit drilled at two separate depth of 1.5 to 3 m were presented in the Table 4. The tests were conducted in accordance with Test 1(A) BS 1377 (1990) Part 2 for the natural soils. The higher Plasticity Index value at area adjacent

to Primary School Kaura (VES2) and lower values at Emir Yamusa Primary School Entrance (VES7), are the causal for lower and higher permeability at VES2 and VES7 respectively.

The results for the Moisture content of the soil samples obtained from VES2 and VES7 sites were determined in accordance with BS 1377 (1990) Part 2 and presented in Table 4, which indicated that the soil's moisture content was noted to be increasing as the depth increases also the moisture content was noted to be higher at VES7 as compared to VES2. This can be attributed to the presence of higher clayey materials in the later.

3.5 Specific Gravity

The results for specific gravity of the soils were determined according to BS 1377 (1990) test (B) for fine-grained soils as presented in the same Table 4 the results at 3m depth was indicating an average specific gravity of 2.69 and 2.64 for the pit with low and high yield respectively. Similarly at depth of 1.5m, average specific gravity of 2.78 and 2.76 were obtained. These imply the presence of a little coarser size clay grains in the site with sufficient yield, hence possessed more voids spaces (cavities) formation for water storage similar attribute was mentioned by Chitra *et al.,* (2018).

3.6 Permeability Test

The permeability test was using falling head permeability method according to the Manual of Soil Laboratory Testing (Head and Epps, 2011). Table 5 indicates the co-efficient of permeability of the soil samples for areas; VES1, VES2, …VES7. The result obtained at VES1, VES2…VES4 were found to be low (2.20×10^{-5} to 2.16×10^{-5} mm/sec) while the coefficients values were noted to be gradually increasing from VES4 to VES8 (5.67×10^{-5} to 7.20×10^{-5} mm/sec) these values implies that the soil is typical of impervious soils consisting silt and clay. Generally, the soil samples indicated low degree of permeability.

Table 5: Co-efficient of Permeability for Soil Samples at Rimin Doko

Sample Location	Sample No	Permeability Coefficient *K* (mm/sec)
VES1	2	2.20×10^{-5}
VES2	2	2.17×10^{-5}
VES3	2	2.16×10^{-5}
VES4	2	5.67×10^{-5}
VES5	2	5.70×10^{-5}
VES6	2	7.07×10^{-5}
VES7	2	7.11×10^{-5}
VES8	2	7.20×10^{-5}

4. CONCLUSION

From the results of the data collected it was observed that VES 4, 5, 6, 7 and 8 shows a better potential of fracturing (aquifer) in the bedrock due to the nature of the curve in the graph compared to VES 1, 2 and 3. Therefore VES 4, 5, 6, 7 and 8 are recommended for drilling boreholes.

To avoid missing of crucial aquifers, especially fractured zones, geological logging is recommended after drilling the borehole to design the string of casings and screens while aquifers delineated should be

properly screened to achieve maximum yield. The borehole should be grouted with cement seal to a depth of 1m to prevent contamination from surface drainage and other source of pollution.

This implies that drilling of boreholes is recommended at Late Emir Yamusa Primary school to area beyond on the south-eastern part of Rimin Doko Kauran Sarki Zaria, having all the better potential aquifers fall within the part.

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