Modelling the Transmissivity of an Aquifer Using Laboratory Tests and Vertical Electrical Sounding in Igabi Lga Kaduna State

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Abstract: ***A combination of particles size distribution, hydraulic conductivity tests and vertical electrical sounding (VES) using schlumberger arrangement was carried out on aquifer material from a single well to model the transmissivity of the formation as viable source of portable water supply. The particle analysis showed the sample is uniformly graded. The relationship between the hydraulic conductivity at various VES sounding depth and electrical conductivities was used to model the transmissivity with Dar Zarrouk parameters. The transmissivity values varies from 784.9 to 3991.4m^2/day. Modelling transmissivity of aquifer by means of incorporating hydraulic conductivity, longitudinal conductance and traverse resistance could serve as veritable tool for ground water resources development and that information, suggest that the ground water potential appears relatively fair for borehole development and that drilling may be done to a depth of at least 60-70m.***

Keywords: Modelling, hydraulic conductivity, transmissivity, Vertical electrical sounding, Ground water

1. Introduction

Ground water accounts for about 0.6% of the volume of water available on the surface of the earth and the 3rd most important reservoir in the hydrologic cycle and a major source of fresh water available for man. In most part of the world, it is the viable source of water supply and also the purest. However with all these attributes ground water need to be explored to assess its potential. Different methods of assessing the potentials of ground water formations or deposits (aquifers) range from hydrologic, geologic and geophysical methods. Information obtained from the geophysical methods or technique can be confirmed by laboratory testing of particle size distribution analysis and permeability tests to ascertain the ease of movement of water within geologic deposits. Estimation of aquifer transmissivity from geo- physical data was carried out by Joel *et* al (2016) using a combination of geoelectric resistivity layer and thickness in the Da-zarrouk parameters involving longitudinal inductance and traverse resistance. The outcome of the estimation reveals that the method is useful in the evaluation of aquifer transmissivity and can serve as a tool for ground water development. Determination of aquifer characteristics which involves hydraulic conductivity and transmisivity tests are made on the basis of data pumping test as suggested by (Olusegun *et al* 2018, Rubin and Hubban 2005). Ground water and aquifers according to Angus Nur *el al* (2015) are characterize by a number of parametrs which can be determined by surface geophysical measurements such as porosity, transmissiviy and conductivity. Angus Nur *et al* (2015) estimation of hydraulic conductivity and transmissivity of Quaternary deposits aquifers using Vertical Electrical Sounding reveals that the results interpreted with Da-zarrouk paramerts can infer the transmisivity variations at other vertical electrical sounding locations where (k) values are known.Geophysical investigations according to (Olusegun *et al* 2018, Rubin and Hubban 2005) appears cost effective and efficient. Studies were conducted on the geophysical and geologic characteristics aimed at estimating the yield of aquifers by (Adeyeye(1974), Agyingi 1991, Akande *et a (2005)l*, Obaje(2009)). Estimation of aquifer parameters done by (Soupios 2007) also proves effective. The application of grain size distribution done by (Idris 2013) was satisfactory evidence. Well pumping test employed by (Apen 2019) to generate hydraulic characteristics proves to be useful for planning and development of ground water. The use of empherical formula based on grain size and permeameter test by (Obone 2018) for the estimation of aquifer hydraulic conductivity of aquifers indicates that ground water yield using the methods is adequate for municipal water supply. In the analysis of aquifer characteristics and ground water quality, (Rajinda and Gopal 2014) obtained drilled samples up to a depth of 60m indicates the presence of impervious strata containing clay which suggest that this could be an impediments to percolation of surface water into ground storage zone. The aim of this study is to use laboratory test results obtained from drilled samples in combination with vertical electrical sounding results to model the transmissivity of ground water formations.

2. The Study Area

Kaduna State which occupies a central position in the Northern geographical region of Nigeria and also lies within the Northern Savana Zone of Nigeria is located on latitude 9^{0}30'N and latitude 11^{0}45'N; longitude 7^{0}E and 8^{0}30'E (Fig 1) . It covers a total land mass of 2,896,000km^2. Igabi Local Government (Fig 2) has an area of about 40km^2 was mapped in part of the Federal Survey Topographic map sheet 124 Igabi – NW Zango Aya, Igabi Local Government Area of Kaduna State. It is located within latitude 10^0 56'00" N and 10^{0}58'45"N and longitude 007^{0}36'30'' E =007^{0}40'58'' E on a scale of 1:25,000. Egba (2013)

The rock types mapped in the area of study include Granite, Gneiss, Migmatite and Laterite, other Lithologies also observed include quartz veins, pegmatite and xenoliths. Structural features being identified are found to be faults, veins,microfolds, foliation, lineation and joints. Some of these structural features observed are attributed to the effect of the pan. African (500+ 10ma) orogeny which produces a North – East and South – West trend direction of most of the rods.Egba (2013)

The economic potentials of this environment in term of minerals and materials resources are limited. There are major roads and footpaths cutting across the mapped area. Valuable resources seen occurring in these areas are construction materials such as hard rock (Gramite and Gneissess), hand dug wells and boreholes were seen sparsely distributed. The mapped area consist of various rocks types mainly igneous and metamorphic rocks types of the Nigeria basement complex having different characteristics features. Description of rocks types was done by examination of various hand samples with aided hand lens.The major lithological units is the area Gramitics rocks (both fine – medium grained and are porphyritic gramites). Other minor lithologies observed in the area include laterite, Migmatite, Gnesis, Quartz veins, Pegmatites and xenoliths.Egba (2013)

2.1 Description of major rock types

Granites:- These are the major rock type in the mapped area observed to be of igneous origin. They are rocks with brelatively fine to course grain texture and contains basically of quartz, micas and orthoclase feldspar. The largest seen outcropping in the area lies at location *$10^0$57'37.7''N and $007^0$37'51.1''E.*Egba (2013)

Granites are mostly seen occurring in the***North*** west of the map making up about 50% coarse grained and 20% fine__. Medium grained of the entire rocks found within the area occurring inform of a dome or hills. Their phenocrysts(mainly feldspar minerals) are aligned in a specific direction as a results of strees undergone and also showing a clear content with other rocks e.g Migmatite and Gnesis as observed in the field. They also show later minor intrusion like veins and Pegmmatite. Egba (2013)

2.2 Topography and drainage pattern

The relief observed in the studied area is relatively undulating with highlands and lowlands where the value of the highest evaluation is 2850m and lowest 675m. outcrops are seen at various location usually forming ridges at times. Drainage pattern is more or less observed and most of the sereams and river channels are having a width of about 5-8m and 3 – 6m deep are virtually dried during the dry season and flow during the raining season (seasonal). Egba (2013)

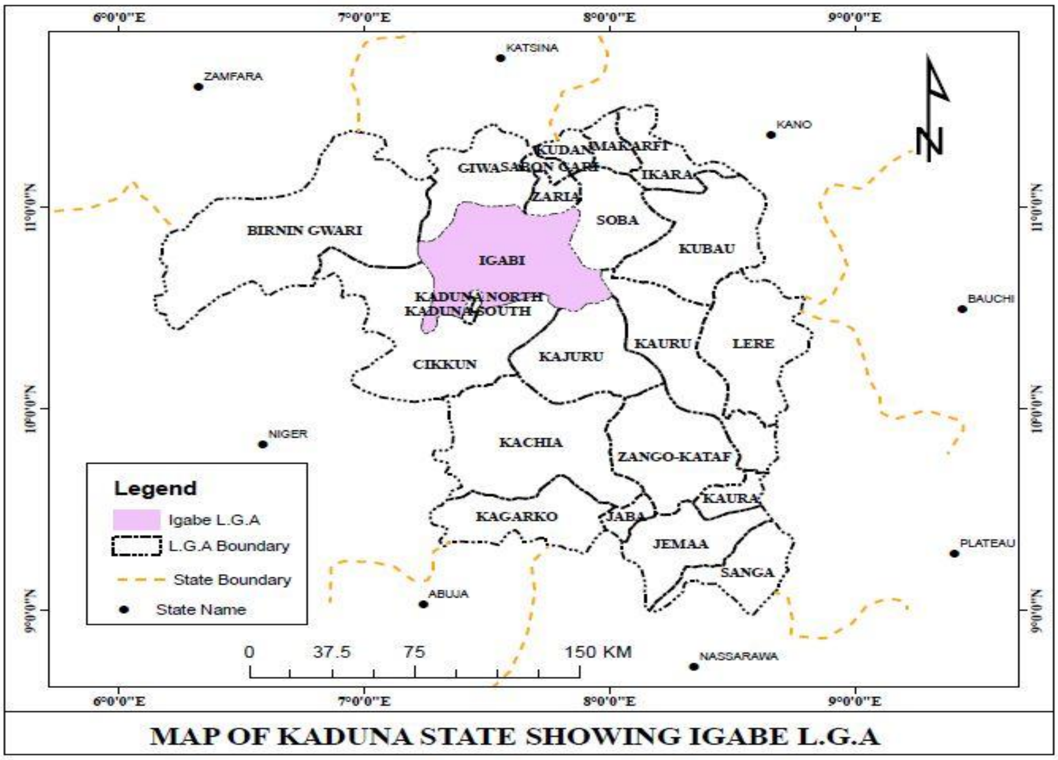

Figure 1: Map of Kaduna State

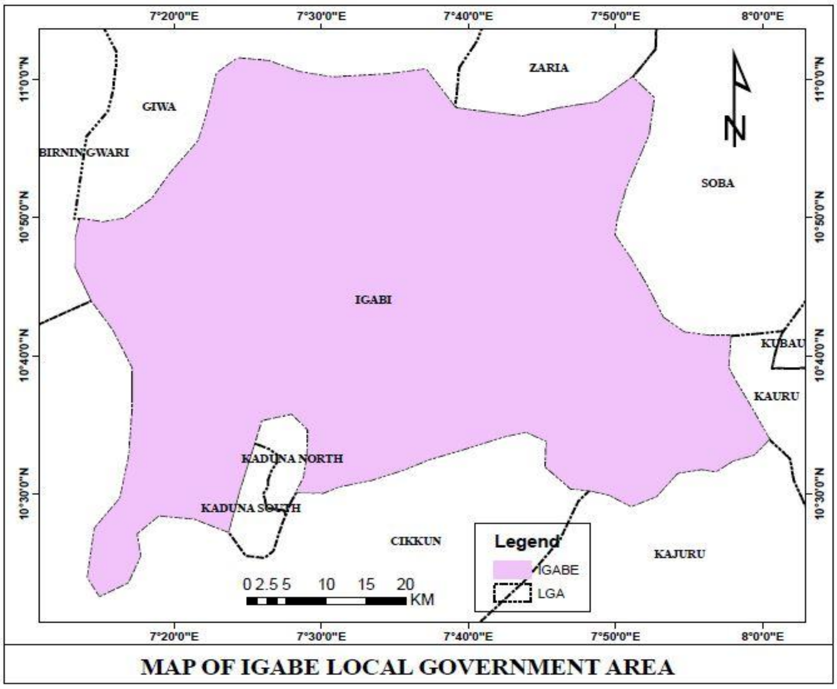

Figure 2: Map of Igabi LGA

3. Materials and Methods

3.1Modelling of geophysical data

Vertical Electrical Sounding (VES) methods are widely used in geophysical investigation (Fitterma and Sterwart 1986).The VES data were measured at 17 point arranged in a grid like pattern using a GL-4200 resistivity meter. A Schlumberger electrode array was applied with current electrodes spacing (AB/2) ranging from 1-17m The site plan for the survey area is presented in Figure (3) Themodelled geologic section for the investigated site (Fig 4) reveals a structure of six geoelectric units which do not necessarily correspond to distinct Lithological layers. These have been inferred to reflect three lithological layers in light of the geological setting in the area. The topsoil, laterites, pebbla and clay has thickness of about 4-6m with resistivity of 844.51 ohm-m. Next is the weathered basement sandy day with thickness of about 10-12m with resistivity of 130 ohm-m. Undemeath it is the weathered basement sandy layer having thickness of about 24»27 m with resistivity of 133 ohm-m. Following is the basement consisting of fractured/ partially fracturedportions with individual thickness estimate of about 35-60m and resistivity of 146-201 ohm-m. At the base of the investigated column is fresh basement of resistivity greater than 800 ohm-m. The apparent resistivity is shown in Figure 5

3.2 Particle size analysis

This method of test is determination of the percentage of individual particles particle present in a soil or sand sample. This analysis is a basic test which consists of sieving a measured quantity sand through a series of successful smaller sieves. The sand sample was poured into a riffle box aimed at getting an appreciable specimen that would contain all particles present in the sample. Dry sieving was accomplished by passing the particles through a nest of sieve of various sizes The sieves were shaken on a mechanical sieve shaker for a period of 10 minutes so that each sieve could retain particles not finer than sieve and weight of particles retained in each determine from where percentage retained and percentage passing were deduced. The particle size distribution analysis shows not only the range of particles present in the sample but also the type of distribution of the various size particles. From the grading curve shown in Fig 6 the resulting data of this sample contains sandy particles which depicts the steepness of the clean sand curve indicating that the sand sample contain a large number of particles which are essentially the same size, this sand sample would therefore be referred to as uniformly graded sample. Furthermore from the gradation curve, D_{10}, D_{30} and D_{60} were deduced from the curve which correspond to the particles size for 10% finer, 30% finer and 60% finer and the uniformity coefficient (C_v) as well as the coefficient of curvature (C_c) were calculated using the following expressions

$$C_v = \frac{D60}{D10} \tag{1}$$

$$C_c = \frac{D30^2}{D60 \times D10} \tag{2}$$

From the curve, , $D_{10} = 0.38$, $D_{30} = 0.53$ and $D_{60} = 0.76$ so using the expressions above C_v and C_c of the sample are 2 and 3.67 which shows that the sample is uniformly graded.

3.3 The constant head permeameter test

The hydraulic conductivity of soils/sand is a measure of its capacity to allow flow of water through pore spaces between the solid particles. The degree of hydraulic conductivity is determine by applying a hydraulic pressure gradient in a sample of saturated sand and measuring the consequent rate of flow.

The constant head permeameter samples were obtained at a depth of about 35-60m of the drilled samples. In the test, samples were placed in between porous stone in a cylindrical jar. The water supply at the inlet was adjusted such that the difference of head between inlet and outlet remains steady. The settling was left for 24h to maintain a constant rate of flow. The water which flows through the sample during a known period was collected. The coefficient of permeability for the aquifer material was calculated by using Equation (3) and used to evaluate the transmissivity of the drilled sample Equation (4).

$$k = \frac{QL}{Aht} \quad (3)$$

Where Q is the quantity of water collected, over time t, L is the length of sample, A is the area of sample = Π (radius)^2, h is the constant head coefficient and t is the time of test.

$$T = K\sigma R \quad (4)$$

Where T is the transmissivity= (aquifer thickness × hydraulic conductivity), R is the traverse resistance (aquifer thickness × resistivity) and σ is the electrical resistivity. The results is presented in Table (1).The k/σ constant was calculated by using the K value obtained from constant head laboratory test K= 216 σ obtained from p = 140.82 Ohm-m therefore $\sigma = \frac{1}{p} = \frac{1}{140.82}$ = 0.0071Siemens/m

4. Results and Discussions

The transmissivity values estimated from a single well using the Da zarrouk parameters presented in Table 1 was calculated using K (216m/day) valueobtained from constant head permeability test con ducted in the laboratory. From the table, it can be observed that the longitudinal conductance (S), aquifer thickness (h), resistivity (R) hydraulic conductance were used to estimate the estimate the aquifer parameters and the transmissivity. Longitudinal conductance, traverse resistance for each aquifer thickness and depth were calculated by incorporating the resistivity and thickness observed from The VES data modelling. The hydraulic conductivity as a function of traverse resistance and thickness was also calculated. The modelled transmissivity as a function hydraulic conductivity, electrical conductance and resistance was estimated it wasobserved that the Transmissivity value of 3991.4 m^2/day was high at the highest thickness of 19.73m.

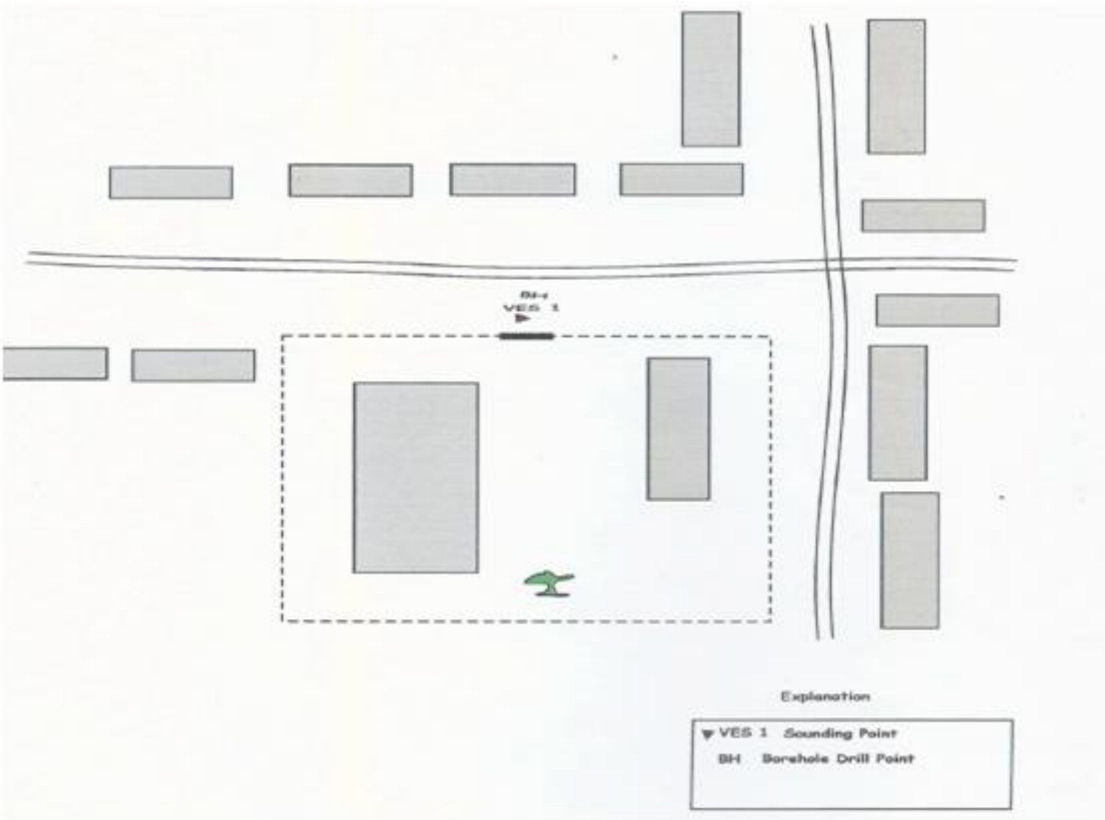

Figure 3: Site plan for survey area

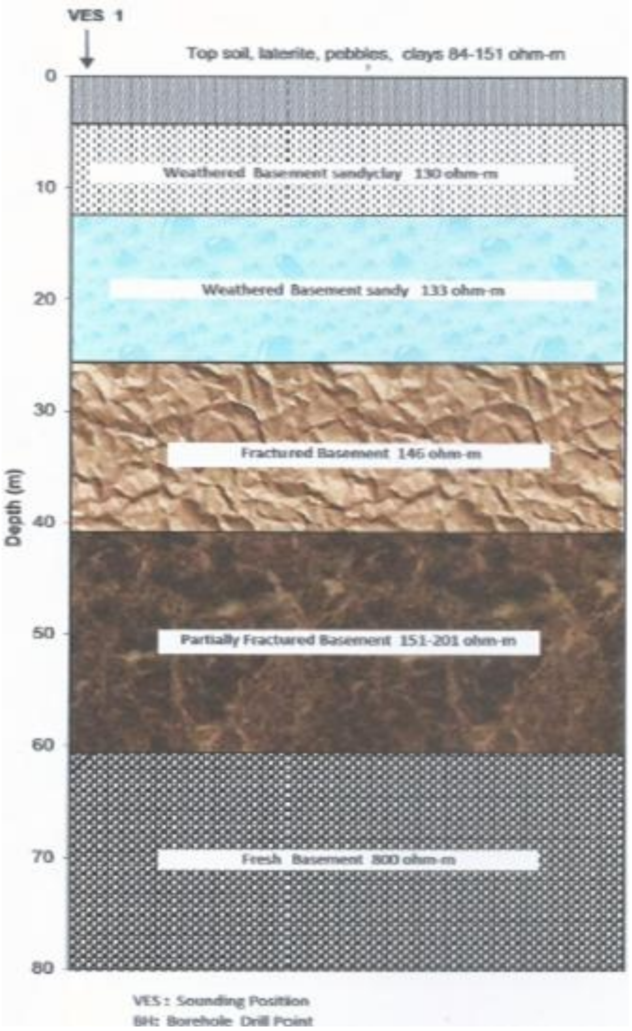

Figure 4: Modelled geologic section

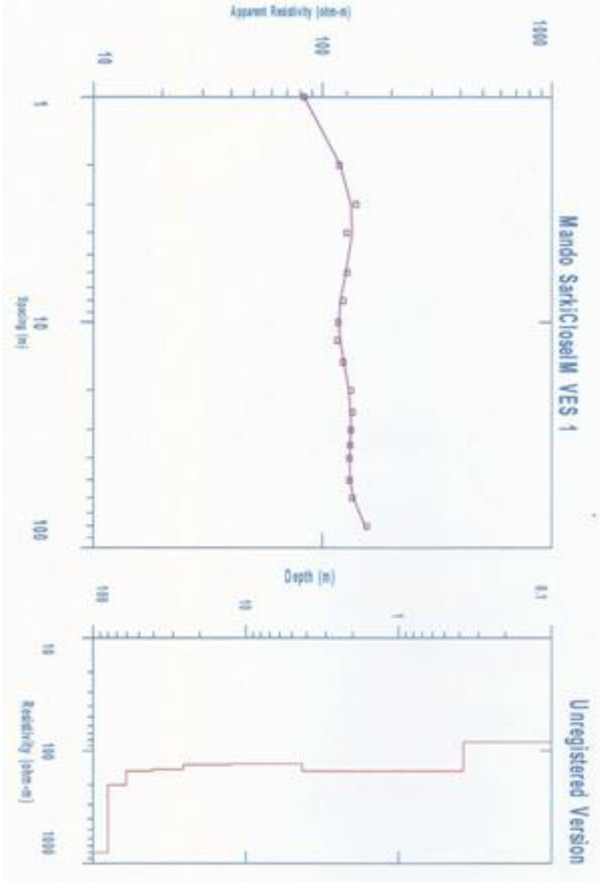

Figure 5: Apparent resistivity

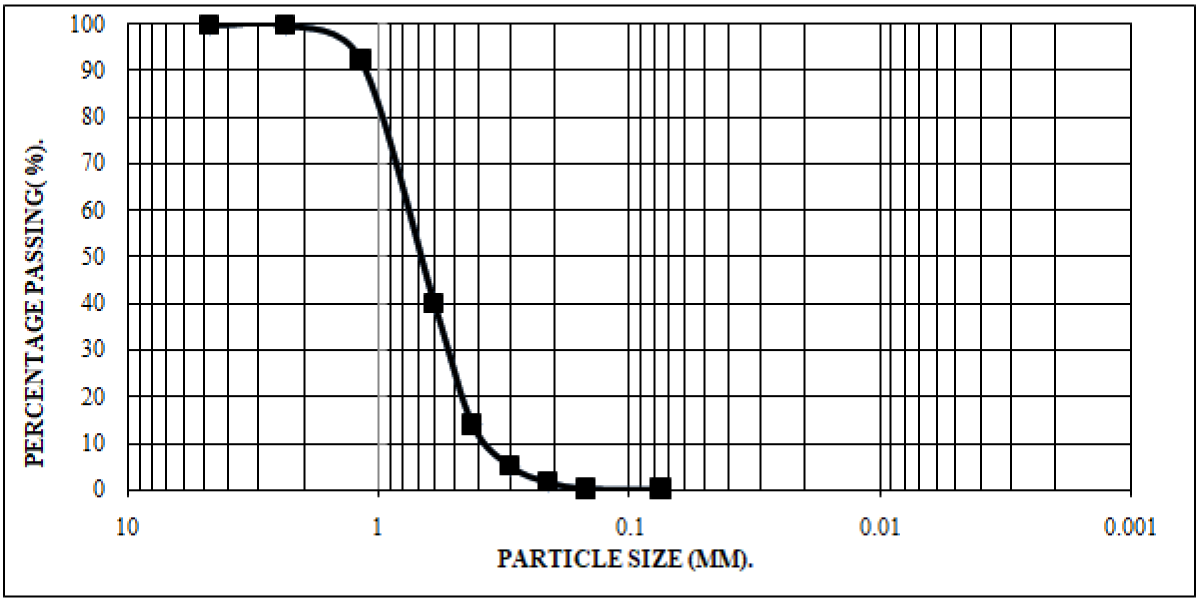

Figure 6: Particle size distributions

Table 1: Modelled Transmissivity values

VES ID	Aquifer Depth (m)	Aquifer Thickness(m)	Resistivity Ωm	$S=\frac{h}{p}$	$T=(\frac{K}{\sigma})S$	$K=\frac{T}{h}$
1	10	8,376	83.65	0.1001	3045.2	363.56
2	20	3.88	150.3	0.0258	784.9	202.2
3	30	8.19	130.4	0.0628	1910.5	233.2
4	40	13.17	132.6	0.0993	3020.9	229.3
5	50	15.22	146.6	0.1038	3157.8	207.4
6	60	19.73	150.3	0.1312	3991.4	202.3
7	70	9.41	200.9	0.0468	1423.7	151.29

5. Conclusion

A geophysical investigation and laboratory analysis was carried out at No4 Sarki close Idi Musa Mando using Shlumberger configuration and constant head laboratory test. Outcome of the investigation reveals that the geology of the area is predominantly basement rocks composed of gneisses and migmatites ground water potential appears to be relatively fair for borehole development and that drilling may be done at VES 1 as indicated in the site plan in (Fig 1) to a depth of at least 60-70m.

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