International Journal of Science and Advanced Innovative Research
ISSN: 2536-7315 (Print) 2536-7323 (Online)
Volume 6, Number 2, June 2021
http://www.casirmediapublishing.com

ESTIMATION OF TRANSMISSIVITY VALUES FROM SURFACE GEOELECTRICAL METHOD IN PART OF MUBI, ADAMAWA STATE

Lazarus G. Ndatuwong
Adamawa State University, Mubi
Department of Pure & Applied Physics
Email: ndatuwong@gmail.com

ABSTRACT

An estimation of transmissivity distribution in part of Mubi metropolis of the basement rock terrain using surface geoelectrical method was carried out in this work. Thirteen (13) Vertical Electric Sounding (VES) were conducted in the area using SAS 1000 Terrameter with three (5) of the VES points located near five boreholes with an existing pumping test result. The resistivity data were modeled using IPI2Win and WinResist modelling software. The general shape of the resistivity curves model shows a highly resistive basement which considered the longitudinal conductance as the dominant Dar-Zarrouk parameter. Aquifer longitudinal conductance at each of the VES points were calculated using the well-known Dar-Zarrouk parameter equation outline in this work. Transmissivity values obtained from the pumping test result are plotted against the aquifer longitudinal conductance values calculated from the VES data close to the boreholes. A linear regression relationship between transmissivity, T and the longitudinal conductance, Lc was established and used to compute the transmissivity values at each of the VES points where pumping test was not conducted. The result of the estimated transmissivity values and the transmissivity values obtained from the pumping test result were compared. The close agreement between the calculated transmissivity values from analysis of VES data and transmissivity values obtained from pumping test data attests to the validity of the method.

Key words: Aquifer, Transmissivity, Dar-Zarrouk, Vertical electrical Sounding (VES), Longitudinal Conductance.

INTRODUCTION

Much geophysical investigation of groundwater is directed towards the determination of the spatial distribution of aquifer hydraulic parameters such as fluid transmissivity, transverse resistance, longitudinal conductance, hydraulic conductivity and aquifer thickness and depth. Fluid transmissivity, longitudinal conductance and electric transverse resistance are important parameters in groundwater exploration. Determination of these parameters provides a good knowledge of the potential of porous media, because they relate fluid flow to electric current conduction, in terms of layer thickness, permeability and resistivity (Ariyo et. al., 2018). Besides, they are useful parameters for aquifer protection and prediction of contaminant transport (Shevnin et. al., 2006, Ndatuwong and Yadav, 2014).

The most suitable and reliable means of computing values of the aquifer parameters is usually through the analysis and interpretation of pumping test data (Ayers, 1989; Kruseman and deRidder, 1994). Pumping test is quite technical and expensive process that requires carrying out a long duration pump test for a well in practice. An alternative approach to simplify this process is the use of surface geoelectrical measurements (Ahamed and deMarsily, 1987; Khan et al., 2002). This method is a non-invasive, relatively cheap and quantitative evaluation technique. It is also used as an effective tool for ascertaining the subsurface geological framework of an area and thus being used routinely for aquifer zone delineation and evaluation of the hydrological characteristic of the aquifer. Though the geoelectrical methods alone, even under favorable conditions, do not replace test drilling to ascertain groundwater condition, yet in many cases can reduce the number of test drillings by giving a better selection of borehole locations (Yadav and Abolfazli, 1998).

Many authors have used resistivity determined from surface measurements to estimate aquifer properties including yield, hydraulic conductivity and transmissivity. Singhal et al., (1998) infer that in an alluvial area, where Darcy flow is deemed to be valid, hydraulic conductivity and transmissivity of aquifers can be estimated with reasonable accuracy at aquifer level by using relations between hydraulic and resistivity properties. Senthil et al., (2001) has brought out the relationship between hydraulic properties and resistivity parameters of the Thiruvanmiyur-Muttukadu alluvial aquifer. Majumdar et al., (2005) stated that, the estimation of hydraulic conductivity, transmissivity, specific capacity and porosity are feasible from surface resistivity measurements and useful relations can be developed between aquifer resistivity with aquifer hydraulic properties of alluvial aquifers. A mathematical equation to estimate hydraulic aquifer property from surface electrical measurement was developed by Niwas et al., (2006). Ekwe et al., (2006) have also used the established relationship between aquifer characteristics and geoelectric parameters to estimate hydraulic conductivity and transmissivity values of all the sounding locations including areas where boreholes were non - existent. The specific objective of this study is to estimate and map-out the aquifer transmissivity values of the study area using an empirical regression relation obtained from the correlation between the aquifer longitudinal conductance calculated from geoelectrical data obtained from resistivity survey and information obtained from pumping test result of exiting boreholes in the study area.

LOCATION OF STUDY AREA AND GEOLOGY

The study area is located in Mubi town. The town is located within the Precambrian Basement Complex in the Northern part of Adamawa State. The rocks in the area are the Migmatite-gneisses and the older granites. Some parts of the study area overlying the basement rocks are the alluvial deposits, which are derived from the weathering of the basement rock uphill and in situ. Geologic log data indicate that the thickness of the alluvial deposits to the bedrock range from about 5m to 25m along the river Yedsarem. Two aquifer systems have been identified in the study area based on geological reconnaisance, the nature of the water and analyses of borehole lithologic logs. These are the fractured basement (mainly migmatic granites) aquifer and the unconsolidated weathered overburden aquifer (*Obiefuna et al, 1997*)

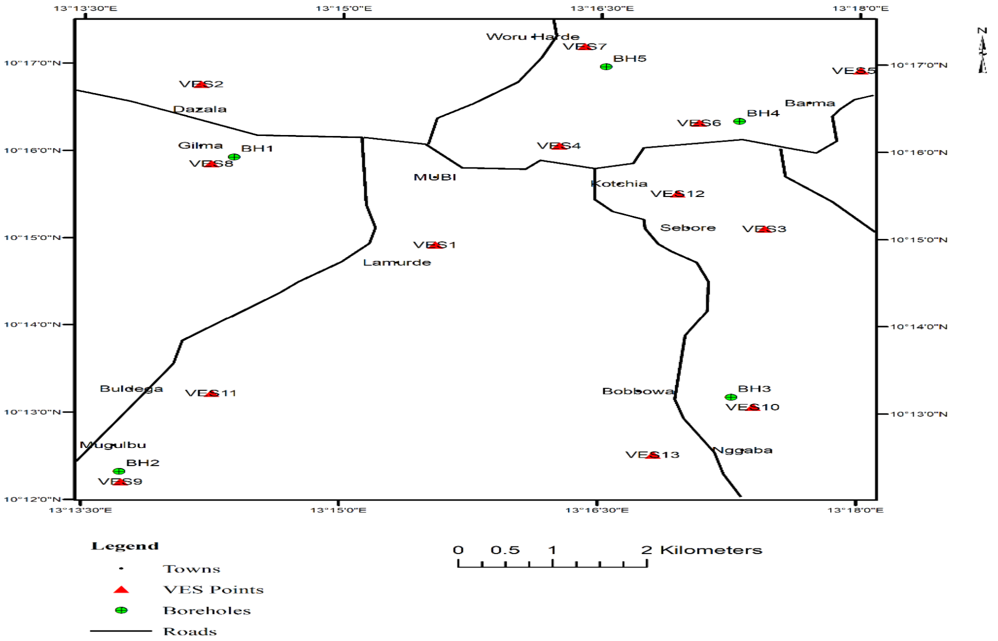


Fig. 1: Study area

MATHEMATICAL FORMULATION

For the interpretation and understanding of the aquifer model, some parameters related to different combination of thickness and resistivity of geoelectrical layer are necessary, these are the Dar Zarrouk parameters which consist of the transverse resistance, T_r and longitudinal conductance, L_c (Zohdy et al., 1974; Maillet 1974). If we consider the aquifer material as a prism of unit cross-section, with thickness h (m) and electrical resistivity ρ (Ωm); the transverse resistance T_r (Ωm^2) normal to the face of the prism, and the longitudinal conductance L_c (mho) parallel to the face of the prism can be given as (Patra and Nath, 1999):

$$T_r = h\rho = \frac{h}{\sigma} \qquad \text{(i)}$$

and

$$L_c = \frac{h}{\rho} = h\sigma \qquad \text{(ii)}$$

where σ is the inverse of the electrical resistivity known as the electrical conductivity (Ωm^{-1}).

Niwas and Singhal (1981) established an analytical relationship between aquifer transmissivity, T and transverse resistance, T_r on one hand, and between transmissivity, T and longitudinal conductance, L_c on the other hand, based on the analogy between Darcy's law of groundwater flow and Ohm's law of current flow. From well-known Darcy's law, the water discharge, Q (m^3/s) may be expressed in the form;

$$Q = KIA \qquad \text{(iii)}$$

and the differential form of Ohm's law as;

$$J = \sigma E \qquad \text{(iv)}$$

where K is the hydraulic conductivity, I is the hydraulic gradient, A is the area of cross-section perpendicular to the direction of flow, J is the current density, σ is the electrical conductivity (inverse of resistivity in a homogeneous, isotopic medium), and E is the applied electrical field. These two fundamental laws of fluid flow and current flow may be utilized to find a probable relationship between electrical and hydraulic characters of the formation.

Thus, for a lateral hydraulic flow and current flowing transversely, the transmissivity, T of the aquifer is given as;

$$T = \frac{K}{\rho}T_r = K\sigma T_r = Kh \qquad \text{(v)}$$

For current and fluid flows in a lateral direction, the Transmissivity, T of the aquifer is;

$$T = K\rho L_c = \frac{KL_c}{\sigma} = Kh \qquad \text{(vi)}$$

Niwas and Singhal (1981) further observed that either of the two propositions, Kσ or K/σ = constant could be true for an area under study, also valid for other areas with similar geological setting and water quality. Depending on the geological conditions, transmissivity can be directly related to the transverse resistance or to the longitudinal conductance. It is proportional to the longitudinal conductance for a highly resistive basement where electrical current tends to flow horizontally, and proportional to the transverse resistance for a highly conductive basement where electrical current tends to flow vertically (MacDonald et. al., 1999).

Since transmissivity, longitudinal conductance and transverse resistance are bulk parameters, estimates of the appropriate proportionality constant can be calculated by relating aquifer pumping test results and surface resistivity measurements at a few points in a study area. Transmissivity variations over the rest of the area can then be easily determined from additional surface resistivity measurements (Okiongbo and Odubo, 2012).

DATA COLLECTION

Thirteen (13) Vertical Electric Sounding (VES) were conducted in the area using SAS 1000 Terrameter with five (5) of the VES points located near boreholes with an existing pumping test result. The Schlumberger array was employed with maximum half-current electrode spreading (AB/2) of 100m and half-potential electrode spreading (MN/2) of 0.5 - 5m. The measured resistance, R values obtained from different conducting horizons was converted to apparent resistivity values by taking the product of the resistance as measured by the Terrameter and the geometrical factor; a parameter which is dependent on the potential and current electrode arrangement.

The existing boreholes data is that of a single-well pumping test carried out at constant rate on the boreholes to give information about the drawdown and aquifer characteristics resulting from specific pumping rate. The drawdown result with respect to time was analysed using Cooper-Jacob's straight-line method in order to estimate the transmissivity and hydraulic conductivity of the boreholes. Detail of this analysis method can be found in standard groundwater text (Todd, 1980; Freeze and Cherry, 1979).

RESULTS AND DISCUSSION

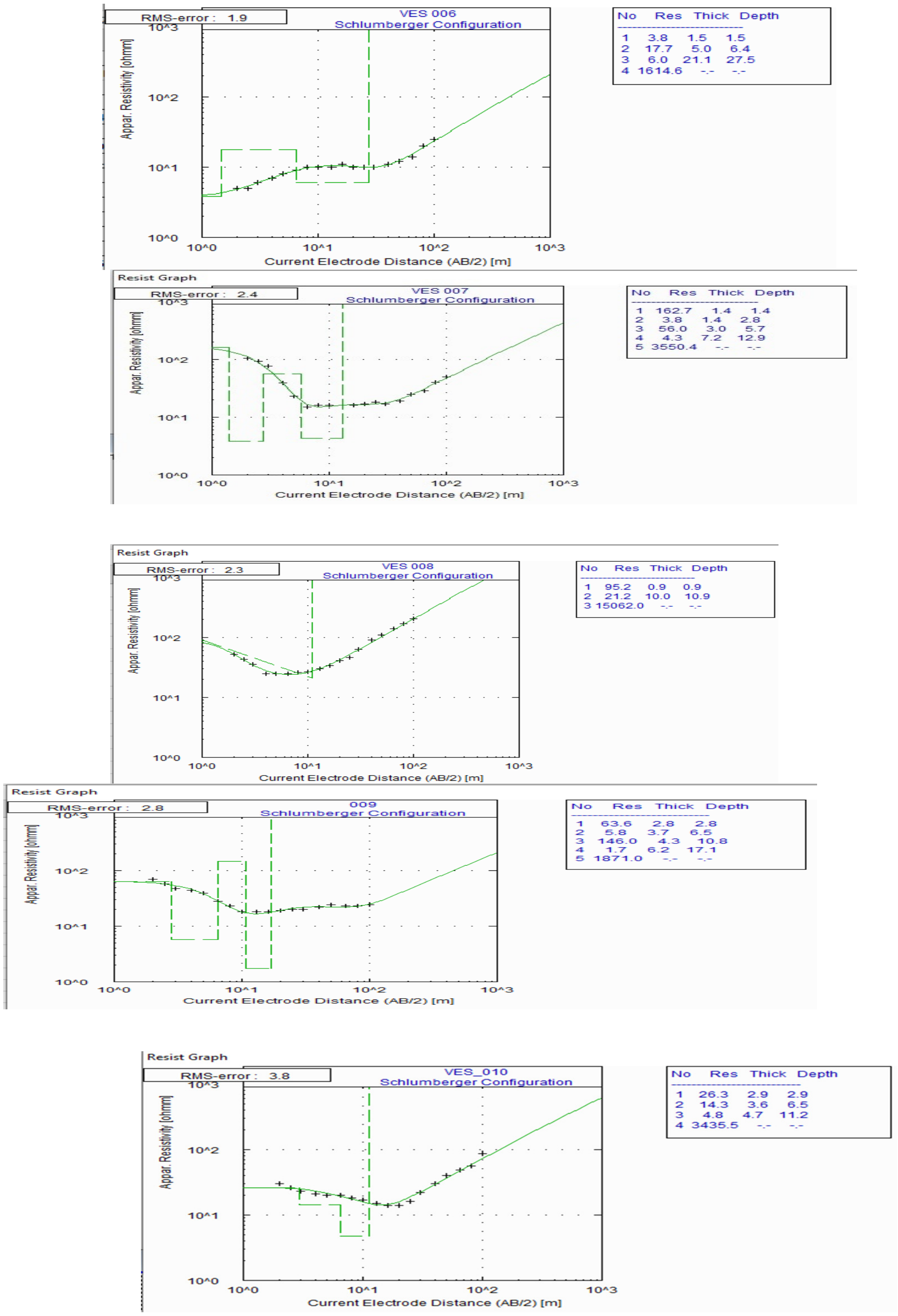
The resistivity data obtained were subjected to two computer assisted iterative interpretation software (IPI2Win and WINRESIST) using a 1-D inversion technique. The intentions of the use of these two softwares is to increase the acceptability of the interpreted models. The WINRESIST programme requires that the operator introduce the number, thickness, and resistivities of the subsurface layers. These parameters can be automated from the model of IPI2Win iterative result, hence the need for using the software as first approximation on the resistivity data. Those parameters of the subsurface obtained from the result of the IPI2Win iteration are transformed, refined or modified by the WINRESIST programme to obtain a best fit relation to the field data. The method of iteration was performed until the fitting error between field data and synthetic model curve became least and constant. Thus, the software yields the number, thickness and resistivity of the various layers. The resistivity model interpretation reveals four to six layers below the subsurface as presented in table 1.

Table 1: VES interpretation result of the study area.

VES No.	Layers Resistivity (ohm-m)						Layers Thickness (m)				
	L1	L2	L3	L4	L5	L6	T1	T2	T3	T4	T5
1	74.8	249	33.6	14.3	67520		0.3	0.5	14.5	10.4	
2	48.9	369.4	13.5	19416			1.6	2	7.5		
3	16.1	3	15	6.2			0.4	0.5	9		
4	23.3	172.9	9.3	98.4	8.8	4378.9	0.3	0.5	1	6.1	15.6
5	746.4	101.1	2.6	24680			2.1	0.5	3		
6	3.8	17.7	6	1614			1.5	5	21.1		
7	162.7	3.8	56	4.3	35550		1.4	1.4	3	7.2	
8	84.8	8.9	30.1	19606.7			1.2	0.8	11.1		
9	63.6	5.8	146	17	1871		2.8	3.7	4.3	6.2	
10	26.3	14.3	4.8	3435.5			2.9	3.6	4.7		
11	180.9	37.7	5	64021			1.3	5.7	5.8		
12	99.4	476.5	8.5	7432.9			1.4	1.4	5.9		
13	46.2	21	4.4	3447			0.7	5.1	4.9		

VES interpretation result shows that most of the VES points are made up of four layers with three VES points having five and one having six layers. The subsurface layer varies in thickness and apparent resistivity values as shown on table 1. The subsurface layer formation comprises of top soil/alluvium sand, lateritic and sandy clay, clayey and consolidated sand, weathered and fresh basement rock. In most of the VES points, the first layer is made up of the top-soil/alluvium sand and lateritic sandy soil. The second layer comprises of lateritic and sandy clay, clayey and consolidated sand. The third layer is made up of weathered basement rock in most of the VES point. This layer is the major aquifer of the study area. Beyond the weathered basement rock is the fresh basement rock. This is the bed rock that extends to infinity.

The model resistivity curves at locations close to the five existing boreholes that has pumping test result are presented in figure 2.



No	Res	Thick	Depth
1	3.8	1.5	1.5
2	17.7	5.0	6.4
3	6.0	21.1	27.5
4	1614.6	-.-	-.-

No	Res	Thick	Depth
1	162.7	1.4	1.4
2	3.8	1.4	2.8
3	56.0	3.0	5.7
4	4.3	7.2	12.9
5	3550.4	-.-	-.-

No	Res	Thick	Depth
1	95.2	0.9	0.9
2	21.2	10.0	10.9
3	15062.0	-.-	-.-

No	Res	Thick	Depth
1	63.6	2.8	2.8
2	5.8	3.7	6.5
3	146.0	4.3	10.8
4	1.7	6.2	17.1
5	1871.0	-.-	-.-

No	Res	Thick	Depth
1	26.3	2.9	2.9
2	14.3	3.6	6.5
3	4.8	4.7	11.2
4	3435.5	-.-	-.-

Fig. 1: Model curves of VES points near the existing boreholes.

The general shape of the resistivity curves shows a highly resistive basement which considered the longitudinal conductance as the dominant Dar-Zarrouk parameter. Thus, according to Niwas and Singhal (1981) the transmissivity of the aquifer for such formation is proportional to its longitudinal conductance. Therefore, the available transmissivity, T values computed from the pumping test data is plotted against the longitudinal conductance, L_C values calculated from the VES data as presented in figure 3.

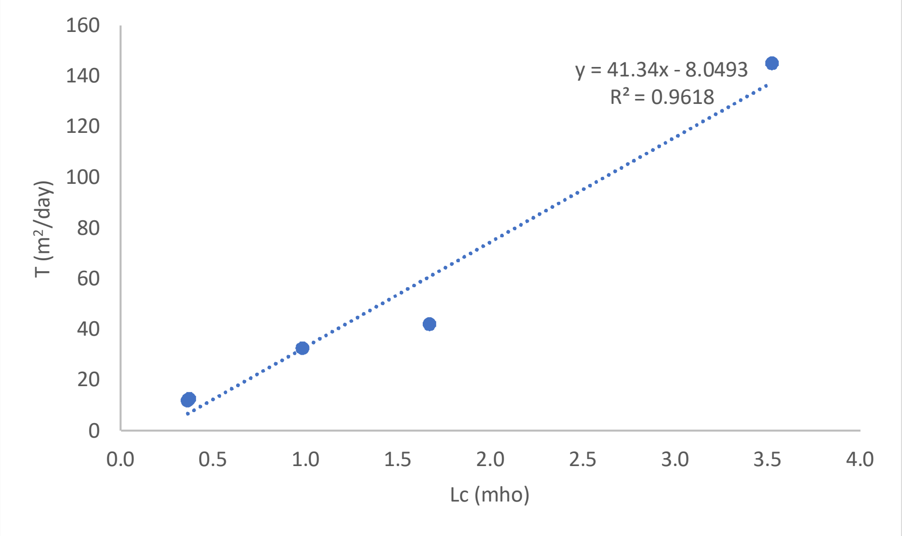


Fig. 3: Relation between measured transmissivity (T) and longitudinal conductance (L_c)

The scatter plot reveals a linear relationship between transmissivity, T and the longitudinal conductance, Lc. The regression line equation fitted to these data is given as equation (vii) with a good R-squared value (0.9618) which implies an excellent correlation between the two parameters. This shows that the model equation fits very well to the data and can be used to estimate values of transmissivty at points were pumping test was not carried out.

$$T = 41.34Lc - 8.0493 \qquad \text{(vii)}$$

Substituting the value of longitudinal conductance, L_C determined using the Dar Zarrouk method outlined in this study into equation (vii), the transmissivity values at each of the VES points where pumping test was not conducted were calculated and presented on table 2.

Table 2. Aquifer geoelctric parameters with measured and estimated Transmissivity values.

Longitude	Latitude	VES No.	L_C, (mho)	Measured T values from pumping test (m^2/day)	Estimated T values from this study (m^2/day)
13.25	10.25	1	0.73		21.94
13.23	10.27	2	1.67		60.81
13.29	10.25	3	0.60		7.14
13.27	10.27	4	1.77		61.12
13.30	10.28	5	1.15		39.43
13.28	10.27	6	3.52	145.15	137.42
13.27	10.29	7	1.67	42.25	65.18
13.24	10.26	8	0.37	12.70	16.69
13.23	10.20	9	0.36	12.10	20.58
13.29	10.22	10	0.98	32.80	32.37
13.23	10.22	11	1.16		39.85
13.28	10.26	12	0.69		6.96
13.29	10.21	13	1.11		37.84

The estimated transmissivity values obtained from this study varies from 6.96 – 137.42 m^2/day and seen to be directly proportional to the longitudinal conductance calculated from the resistivity data. The result of the estimated transmissivity values was compared with the transmissivity values obtained from the pumping test result carried out at five locations on the study area. The computed results are in good agreement with that of the obtained pumping test values. The computed transmissivity values are interpolated to prepare a transmissivty map of the study area as presented in figure 4.

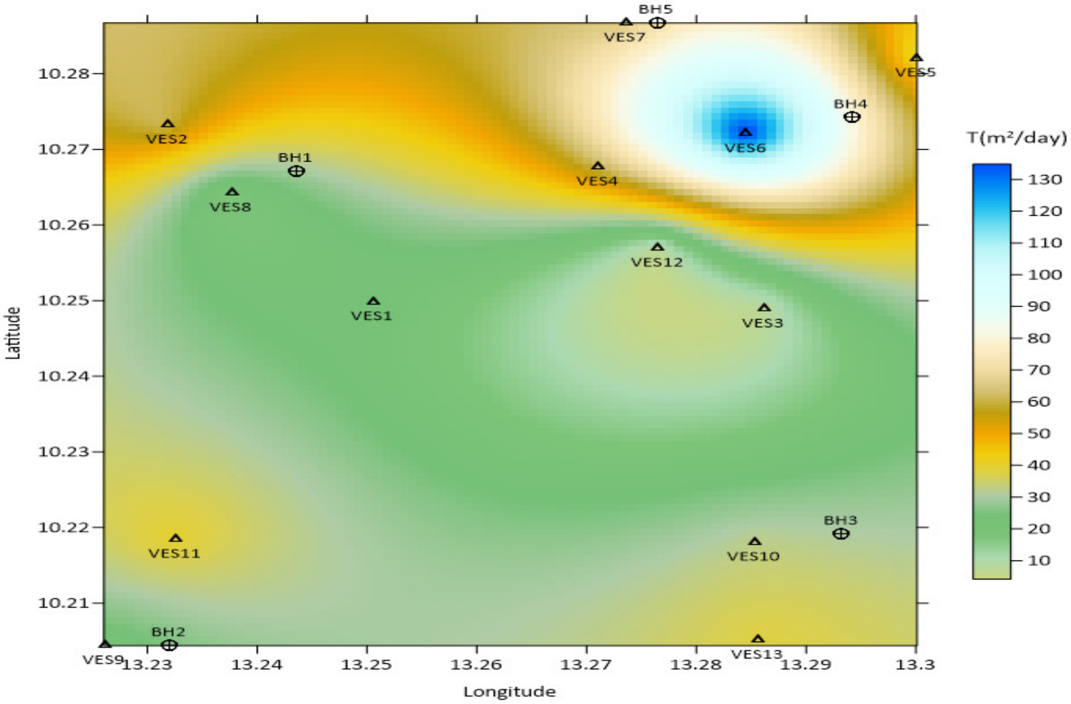


Fig. 4: Transmissivity distribution map of the study area.

The result of the interpolation shows a variation in transmissivity value across the study area. High values are seen along the northern axis of the study area, while the central part is dominated with low transmissivity values. The southern axis exhibits medium values of transmissivity.

CONCLUSION

Determination of aquifer parameter from drilling of wells is often expensive. The use of Dar Zarrouk transmissivity technique outlined in this study in determining the aquifer transmissivity values from VES is a cost-effective alternative. The method is advantageous in resistivity data to estimate transmissivity at points were drilling was not possible or not carried out. The result obtained from this work gives a useful first approximation of the transmissivity variation and could be used to site exploratory boreholes. The close agreement between the calculated transmissivity values from analysis of vertical electric sounding data and transmissivity values obtained from pumping test data attests to the validity of the method.

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