

## Exploration for Groundwater Aquifers, using Vertical Electrical Sounding (VES) method, in Wad Hamid area – River Nile State, Sudan

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**ABSTRACT**-Geo-electrical measurements using the Vertical Electrical Sounding (VES) method was utilized in determining aquifer characteristics of Wad Hamid area. Three geologic units were recognized in the area; Quaternary deposits, Cretaceous Sandstone Formation and the Basement Complex rocks. 122 VES using the Schlumberger configuration were acquired for the study area. A maximum half electrode spacing of 900 m was utilized for data acquisition. All these soundings were processed using IX1D software. Geo-electric sections were constructed from which the aquiferous layers were delineated. Hydraulic parameters (hydraulic conductivity and transmissibility) were computed at the existing borehole and VES sites.

**Keywords:** Geoelectrical method, groundwater exploration, Nubian Sandstone Aquifer geometry and resistivity contrast.

*المستخلص في طريقة القياسات الكهربائية تستخدم طريق السير العمودي الكهربائي (VES) وذلك للحصول على خواص وصفات الخزان الجوفي لمنطقة ود حامد – حيث تم التعرف بواسطة هذه التقنية على ثلاثة وحدات جيولوجية هي ( رسوبيات العصر الرباعي، تكوينات العصر الكريتاسي و معقدات الصخور الأساسية). تم تنفيذ عدد 122 سير عمودي كهربائي بإتباع توزيع شلمبرجير ( Schlumberger ) حيث كانت المسافات بين قطبي التيار 900 متر وذلك للحصول على البيانات المطلوبة بصورة مثلي، ومن ثم تمت معالجة البيانات ببرنامج ( IX1D ). وبناءً على البيانات المستخلصة من البرنامج تم رسم القطاعات الجيوكهربائية التي تبين التتابع الليثولوجي في المنطقة وتحديد الطبقات الحاملة للمياه. تم حساب المعاملات الهيدرولوجية للخزان الجوفي عند الآبار ومن ثم عمم على مواقع الأسبار العمودية الكهربائية (VES).*

### INTRODUCTION

In semi-arid areas in Sudan, far from River Nile, the groundwater constitutes the main source of water supply for domestic, industrial and irrigation purposes. In the study area, the proposed agricultural scheme is designed to be irrigated by groundwater from Cretaceous Sandstone aquifer. The geometrical parameters and the hydraulic characteristics of the aquifer in the study area are not known.

The idea of establishing an agricultural scheme in the area of Wad Hamid encourages the owner to know more about the groundwater potentiality of the Cretaceous Sandstone aquifer in the project area. The realization of such a program

requires data from hydrological, hydrogeological, geological and geophysical surveys, drilling and pumping tests as well. Knowledge of aquifer characteristics, namely the hydraulic conductivity (permeability) and transmissivity are important for determining the storage and potentiality. This information can be obtained from surface geo-electrical method and pumping test data.

Many researchers have studied and reviewed relationships between geo-electrical parameters of subsurface layers and aquifer characteristics. Those researchers were; [11] [21] [17] [4] [19] [15].

Geophysicists have realized that the integration of aquifer parameters calculated from existing borehole locations and

subsurface resistivity parameters extracted from resistivity measurements can be highly effective, since a correlation between hydraulic and electrical aquifer properties can be possible as both properties are related to the pore space structure and heterogeneity [1]. According MacDonald, 1999, interpolating aquifer properties between boreholes is often difficult with little or no data in which to base these extrapolations. Therefore, in areas with few pumping test information, the spatial distribution of aquifer properties cannot be confidently calculated. The application of surface resistivity method however, can provide useful method for obtaining information on aquifer properties in

areas where pumping test data are sparse and subsurface conditions are appropriate.

**Location and physiological features of the Study area**

The study area lies within the River Nile State, about 120km north Khartoum town, situated between longitudes; 32° 36' 00" E to 32° 52' 48" E, and Latitudes; 16° 27' 36" N to 16° 56' 24" N, Fig. 1. It covered an area of 840 km<sup>2</sup> and is located in the River Nile State.

The study area, so far is affected by the tectonic evolution that created Sabaloka Ring dyke on the southern part of River Nile State. The geology of the area comprises different type of rocks, metamorphic (gneiss and migmatite), igneous (Sabaloka igneous complex) and the Cretaceous Sandstone [5], shown in Figure 2.

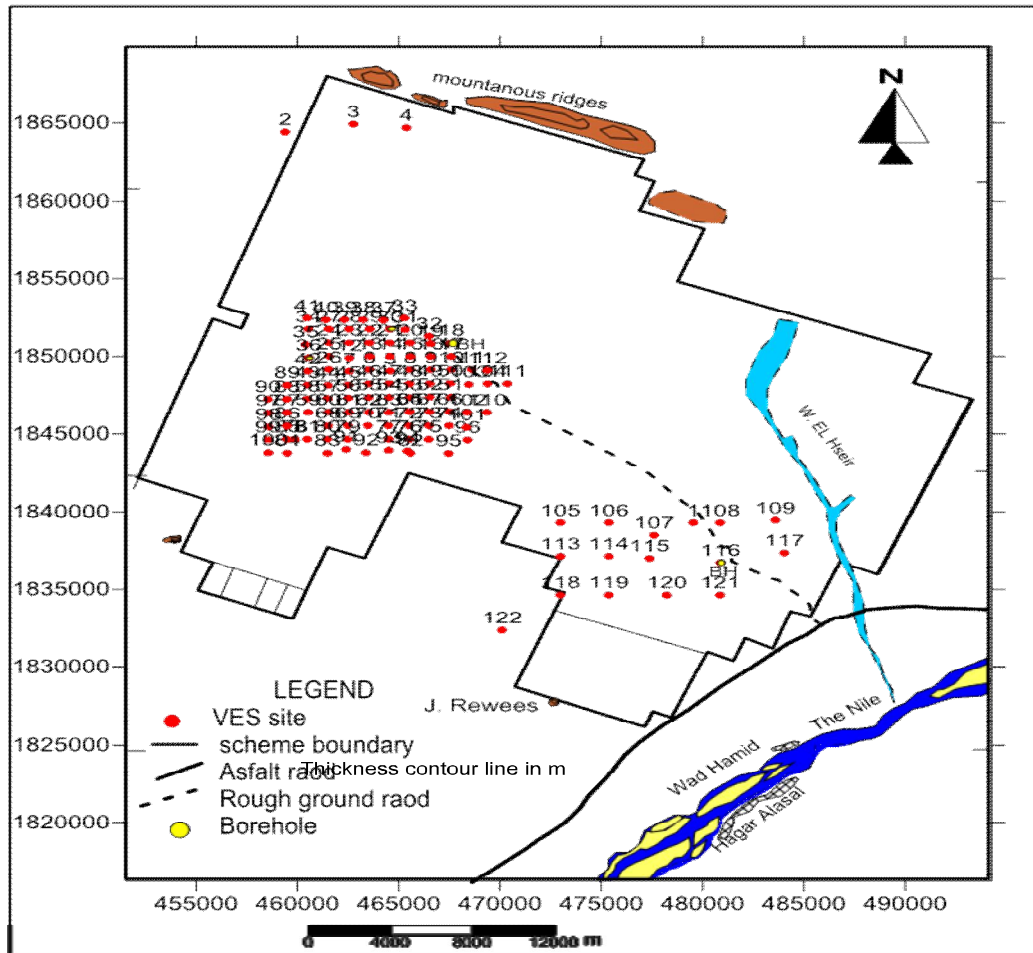


Figure 1: Location map of the study area

Based on field and petrography evidence, structural relationships, and in the absence of radiometric dating, the basis of borehole data, the

geological map prepared by Geological Research Authority of Sudan [8], satellite Image and field checks at selected sites within the area, The

detailed geology of the Study Area will be described and classified as Quaternary to recent deposits, Cretaceous Sandstone Formation and Precambrian - Cambrian Basement rocks as in the following litho-stratigraphic,

1. Superficial deposits (Quaternary – Recent)
2. Cretaceous Sandstone Formation (Mesozoic - Cretaceous)
3. Basement complex rocks (Pre Cambrian), shown in Table 1.

In the present work, from hydro-geological view point the area can be classified into three hydro geological units with respect to their permeability;

- Semi pervious unit, superficial deposits,
- Pervious unit, Sandstone layers of Cretaceous Formation
- Impervious unit, basement complex rocks.

The area characterized by semi-arid climate, with average annual rainfall of (50 – 100mm) during the period, (August – September). The highest daily mean temperature is about 43°C during the summer period (April – October) and the daily average mean temperature is amount to 16°C during the winter time (November – March).

**Methodology**

The electrode arrangement used in data acquisition was the Schlumberger array of electrodes. For a Schlumberger survey, the two current electrodes A and B and the two potential electrodes M and N are placed in line with one another. The configuration is illustrated in Figure 3.

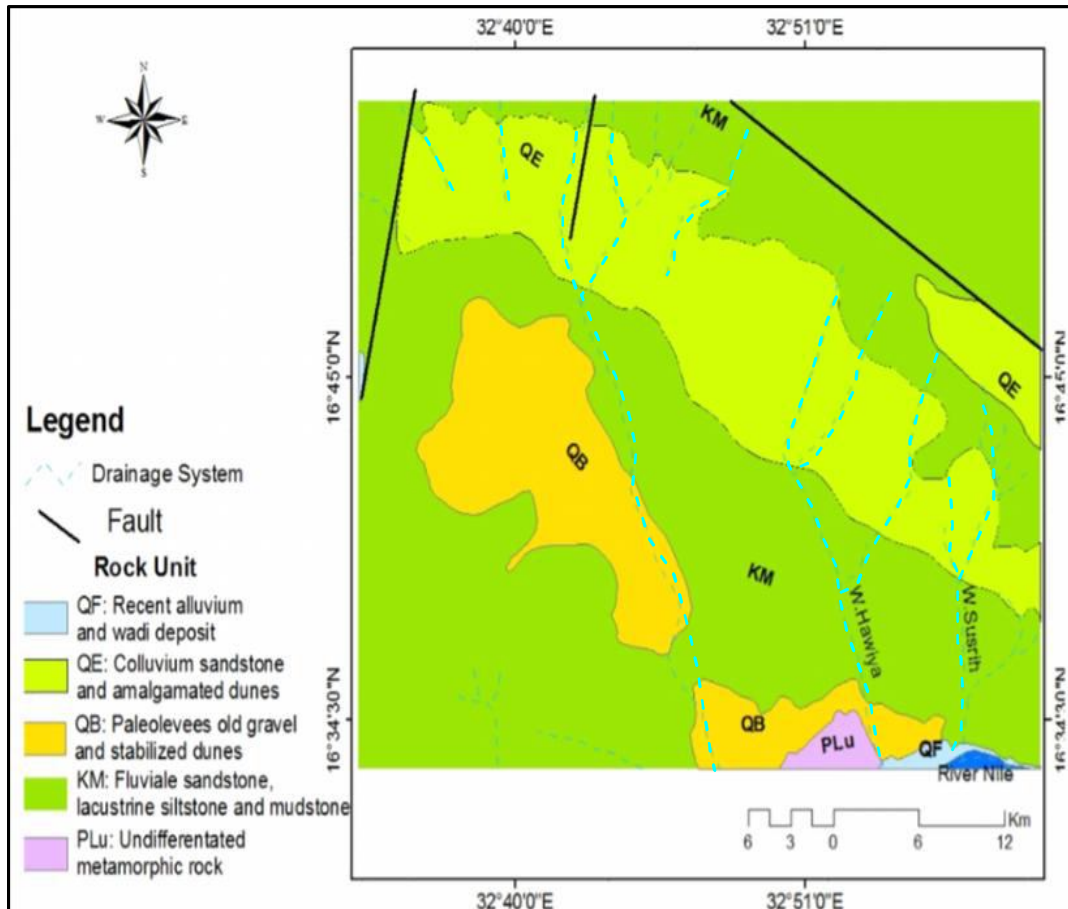


Figure 2: Physiographic and Geological of the study area, (after Mojahid<sup>[18]</sup> in 2015.)

TABLE 1: GEOLOGIC SEQUENCES IN THE STUDY AREA

Formation	Lithology and Environments Deposit	Average thick. (m)	Age
Superficial deposit	Gravels, sands, sandy clay, clays and intercalation. Alluvial and wind sand	0 - 7	Quaternary to Recent Deposits
Nubian Formation	Sandstone, Mudstone, siltstone and conglomerates. Continental	7 - 138	Mesozoic-Cretaceous
Basement Complex	Igneous, gneisses, schist, Ultramafic and quartzite dykes	∞	Pre-Cambrian

The ratio of the distance MN to the distance AB at the beginning is in the range of AB 3times to 5times MN. Considering a symmetrical linear electrode configuration with the current electrodes as illustrated in Figure 3, the potential difference between the measuring electrodes for a homogeneous earth is then obtained by;

$$\Delta V = (\rho I / k) \tag{1}$$

Where  $\rho$  : The resistivity of the homogeneous earth,  $k = \pi \left( \frac{AM \times AN}{MN} \right)$  : The geometrical factor known as array constant.  $\Delta V$  : The voltage difference in volts between the two potential electrodes, M and N,  $I$  : The current passing through the electrodes A and B, The apparent resistivity can be determined in the field by measuring,  $\Delta V$  and  $I$ , using the following equation<sup>[12][22]</sup>.

$$\rho_a = k \left( \frac{\Delta V}{I} \right) \tag{2}$$

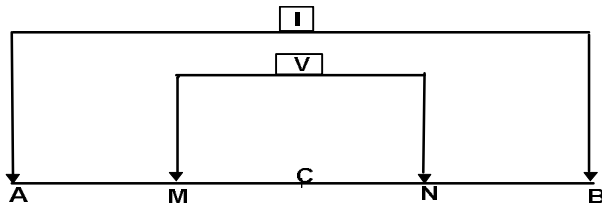


Figure 3: Sketch diagram of Schlumberger configuration

**Data acquisition and interpretation**

One hundred twenty-two (122) vertical electrical soundings (VES) were conducted at the flattest part in the study area Figure 4. The maximum current electrodes spacing used in this study ranges between 700m and 900m.

More realistic sections of the earth can be obtained only after interpretation of the data in terms of true variations of the resistivity distribution. This is a very important step because it allows the estimation of the true position and depth of an anomalous region. The resistivity field curves of (VES) are classified based on shape; most of them are (HK, HKH and HA) curve types.

Eight boreholes were drilled at the selected sounding sites to be used for calibration and correlation purposes. Geophysical well logging was carried out for these five boreholes. Five parameters were measured; these are resistivity's (long normal, short normal & single point), spontaneous potential, and natural gamma. This measurement enables determination of formation resistivity, pore water resistivity and aquifer thickness.

All measured vertical electrical sounding (VES) were processed using IX1D software, Copyright 2001, 2002 by Interpex Limited. This software performs an approximate initial layer model from VES observed data.

**Quantitative Interpretation**

The result of the geoelectrical survey was processed and quantitatively interpreted using available geological information and presented as geoelectrical sections along the various profiles. Many authors such as <sup>[23][24][9]</sup> studied the quantitative interpretation of the geoelectrical resistivity measurements.

In this study before making the geoelectrical sections firstly depths to Basement rocks are corrected using the depth relation equation in Figure 6.

$$Y = 1.015 X + 4.984 \tag{3}$$

The ( $R^2 = 0.942$ ) coefficient of determination is a statistical measure of how well the regression line approximates the real data points. This indicates

that the regression line perfectly fits the data. Consequently, Depths to basement are calculated at each VESs location and depth to Basement contour map is plotted in Figure 7. It shows that the depth to base rocks ranges from 75m to 150m.

6	VES36 ,B.H36	136	144
7	VES43 , B.H43	142	146
8	VES116 , BH1	91.5	96

**Aquifer parameter calculated from VES data**

The transmissivity and hydraulic conductivity of the aquifer of Wad Hamid area can be estimated using gravimetric method by applying the relationship between transmissibility (T) and transverse resistance (Tr), longitudinal conductance and (C) hydraulic conductivity (k).

TABLE 2: TRUE AND INTERPRETED DEPTHS

No.	VES & BH No.	H <sub>t</sub>	H <sub>int.</sub>
1	VES10, B.H10	135	138
2	VES18 , B.H2	133	147
3	VES25 , BH25	139	144
4	VES26, BH26	136	141
5	VES30, B.H30	128	140

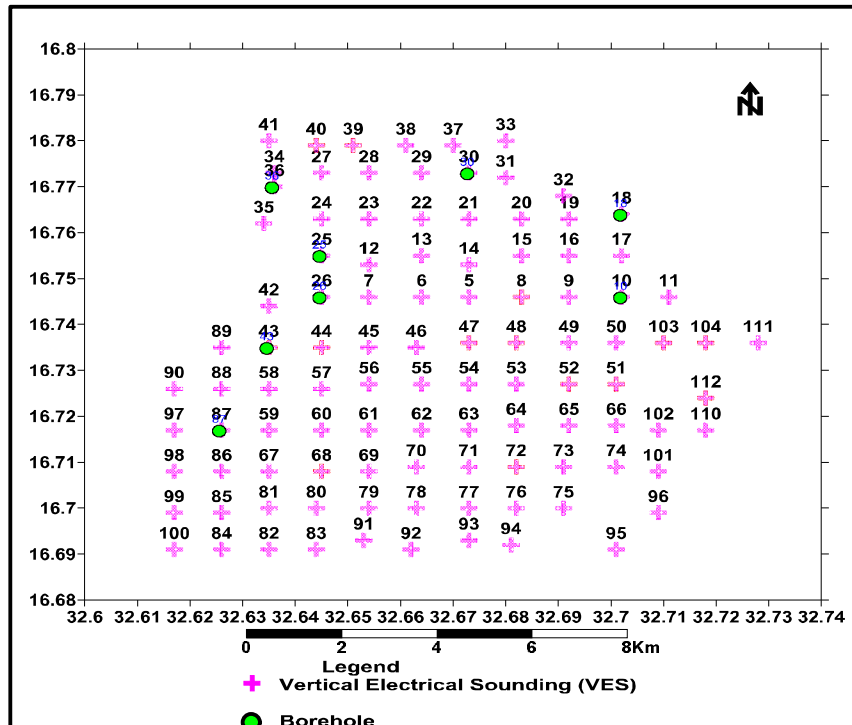


Figure 4:Location of VES and boreholes in the area

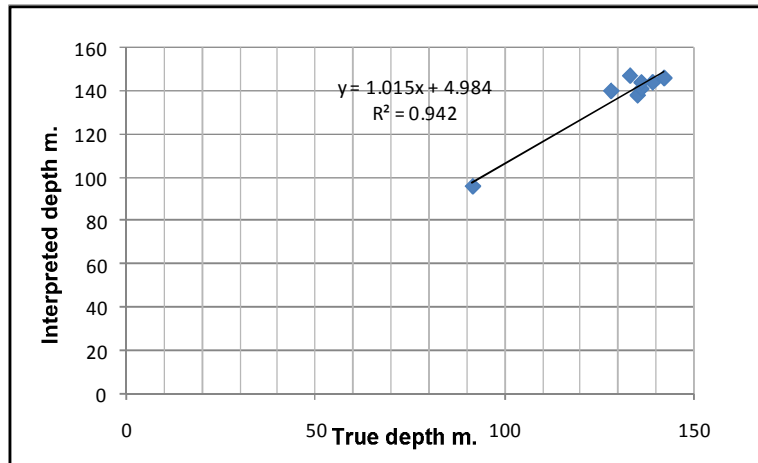


Figure 6: True depth versus interpreted depth

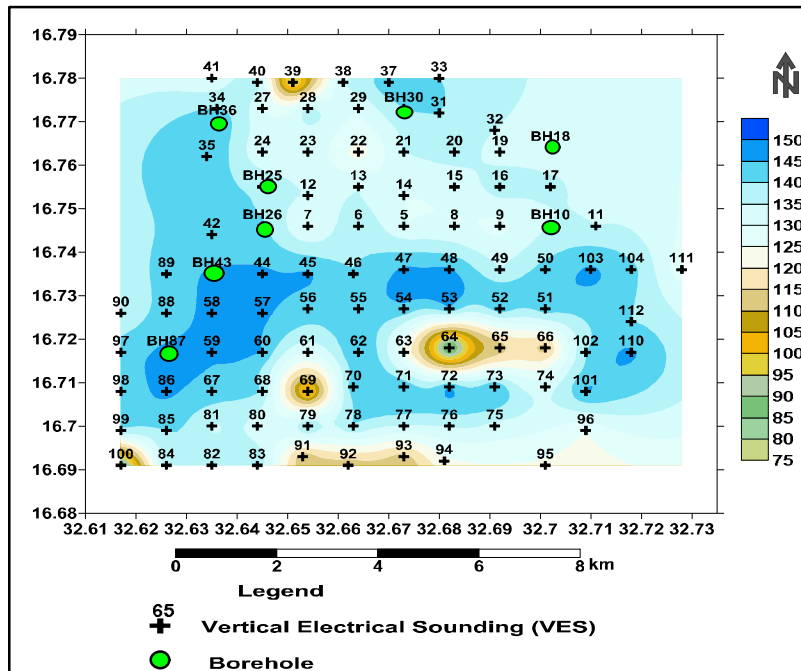


Figure 7: Depth to Basement contour map

VES No - BH	Aquifer Resistivity ( $\Omega \cdot m$ )	Aq u. Thi ck. m	Trans. Resis. $hX\rho$ ( $\Omega m^2$ )	Measured Transmissivity ( $m^2/d$ )	k (m/d)	Modeled Transmissivity ( $m^2/d$ )
10 BH10	52	57	1859	1388	26.7	1501
18 BH2	52	44	2200	1600	26.7	1549
25 BH25	53	38	6336	2120	40	2124
26 BH26	41	41	1040	1353	33	1389
30 BH30	82	46	598	1400	31	1326
36 BH36	49	35	1540	1421	29	1457
43 BH43	58	58	1824	1600	44	1358
87 BH87	55	59	3245	1750	33	1694
116 BH1	46	42	1932	1430	20	1512

TABLE 4: AQUIFER PARAMETER FROM VES DATA

**Calculating the Aquifer Transmissivity and Hydraulic conductivity**

The aquifer of wad Hamid area consists of gravel, coarse to medium sandstone and clayey sandstone. Transmissivity of an aquifer is generally assumed to be controlled by the thickness of the specific layer and the presence of fine/clay particles<sup>[1]</sup>. Assuming that the transverse resistance is

$$T = \beta * Tr + 1243 \quad (4)$$

Where T: Transmissibility in ( $m^2/day$ ), Tr.: Transverse resistance ( $\Omega m^2$ ),  $\beta$ : regression constant.

The strong statistical correlation between aquifer transmissivity and transverse resistance ( $R^2 = 0.909$ ) indicates that the geoelectric sounding method is suitable for the study area, giving a  $\beta$  value of 0.139. This relationship could be attributed to the influence of hydraulic and

electrical anisotropy as well as the variations in the geology, grain size, as well as shape of pore channels. The transmissivity (T) value at each of the 102 VES locations were then calculated using the transverse resistance from the resistivity survey.

Consequently, the hydraulic conductivity (K) is calculated using equation (5).

$$T = k \times h \quad (5)$$

Where T: Transmissibility in m<sup>2</sup>/d, K: Hydraulic conductivity in m/d, h: Aquifer thickness in m.

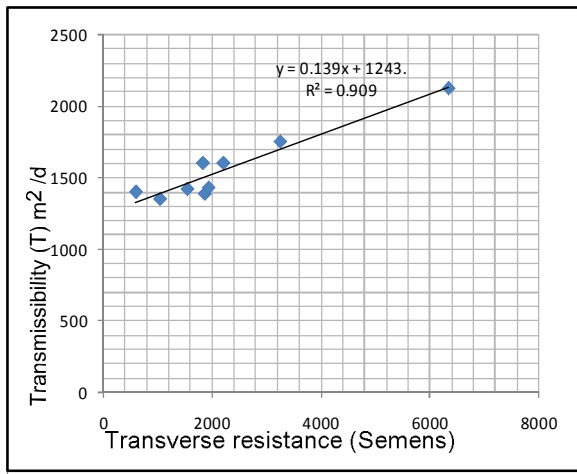


Figure 8: Transverse resistance versus Transmissibility

The most prevalent hydraulic conductivity values in the study area range between 24 and 40m/day, they are characterized by dark and light blue color in Figure 10, which show the most favorable areas for groundwater potential.

From VES interpretation the aquifer formation resistivities vary between 10Ωm to 230Ωm, this means that the aquifer lithology ranges from fine clayey sandstone to medium to coarse grains sandstone.

### Aquifer Delineation

Electrical methods primarily reflect variations in ground resistivity. The electrical resistivity contrasts existing between lithological sequences<sup>[3][4]</sup> in the subsurface are often adequate to enable the delineation of geoelectric layers and identification of aquiferous or non-aquiferous layers<sup>[20]</sup>(Schwarz, 1988). The geoelectric sequence suggests a subsurface geology characterized by of sands/gravels, clay/siltstone and sandstone occurring at varying depths with variable thicknesses. Layers sequence in the project area is illustrated by the geo-hydrogeological section (A – A') bisected the area from the southwest to the northeast, Figure 11.

From the subsurface structure of the area obtained by the geo-electrical section Figure 11 and the depth to basement map Figure 7 it can be said that the whole area is affected by Sabaloka tectonic events.

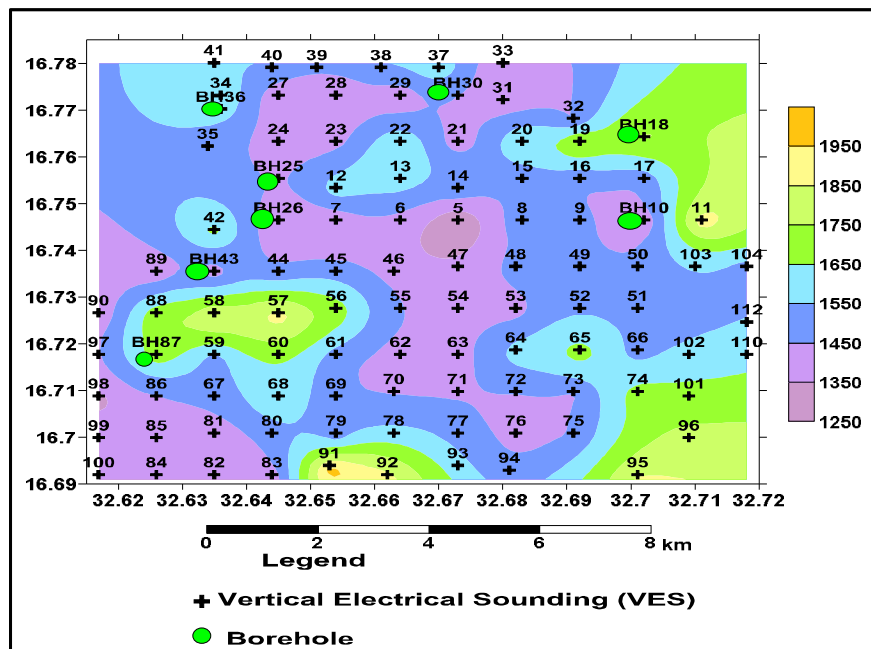


Figure 9: Spatial distribution of transmissibility in the study area

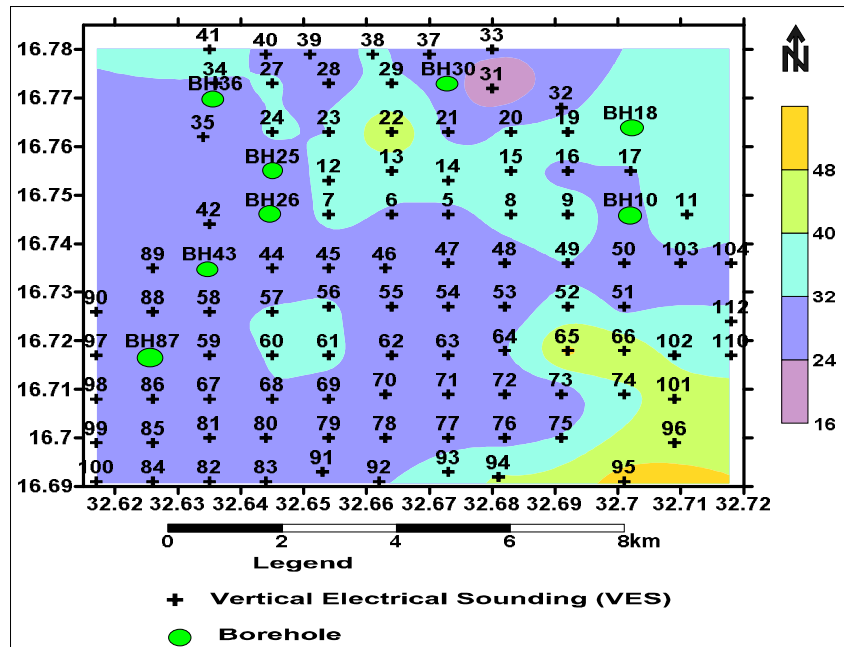


Figure 10: Spatial distribution of hydraulic conductivity in the area

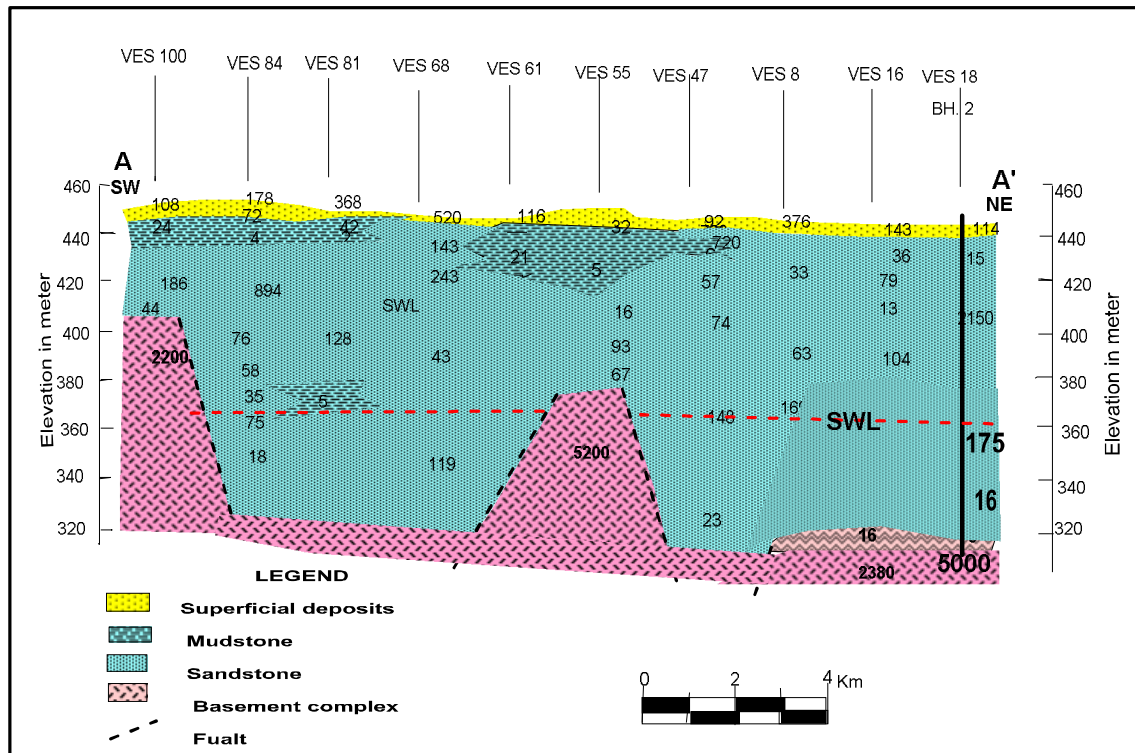


Figure 11: Geo electrical section – pro.(2)



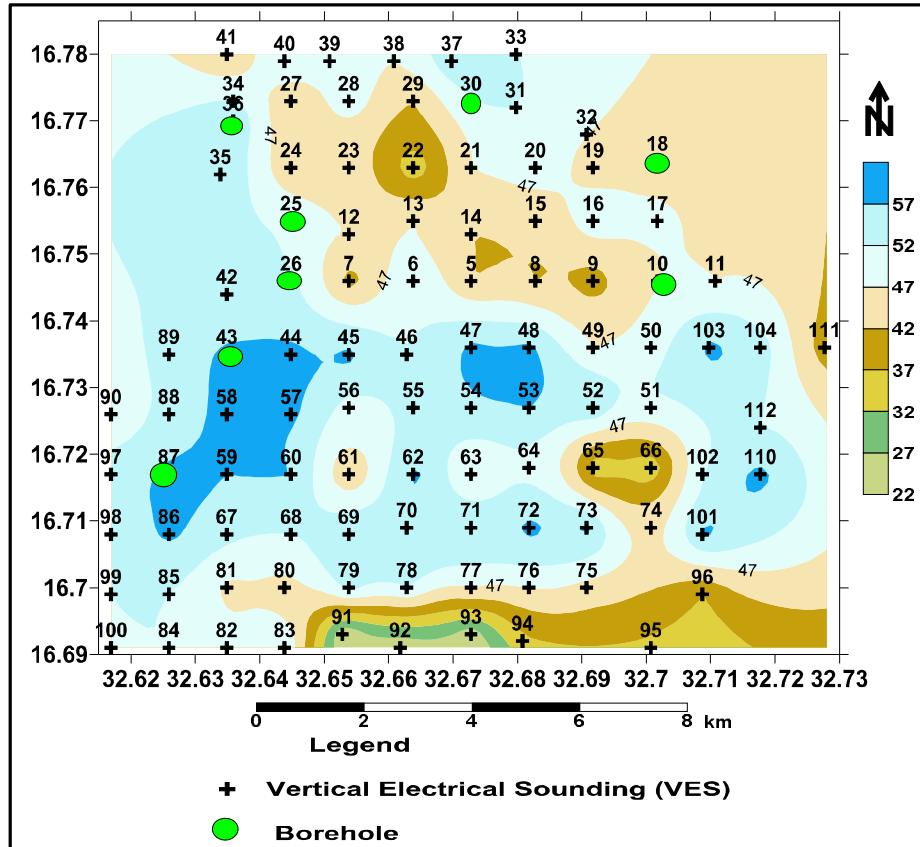


Figure 12: Spatial distribution of aquifer thickness

The undulated surface of the basement rocks (horst and Graben) affected the groundwater flow in the area; as a result, it also deteriorates groundwater quality at some localities, because it reduces the groundwater velocity.

The aquifer thickness variation is illustrated by aquifer thickness contour map in Figure 12. The aquifer thickness ranges from 22m (BH10) to 57m (BH 87).

**Conclusion and Recommendation**

Fast, simple relatively inexpensive and reliable method of estimating the transmissivity distribution has been demonstrated in the Wad Hamid area. The results of the study show useful estimation of the transmissivity and hydraulic conductivity can be recommended when using exploratory boreholes. Transmissibility value known at one point can be used to extrapolate the hydraulic conductivity over the whole area. It was necessary to establish a working relationship between transmissivity and the transverse resistance from which the value of  $\beta$ , was computed in the field for further modeling of the

transmissivity values from the VES measurements.

Result of this study has shows that the aquifer resistivity in the study area varies from 10 $\Omega$ m to 230 $\Omega$ m. The depth to the Basement rocks in the study area varies from 75m (BH1) to 148m (BH87). Consequently, the aquifer thickness in the study area varies from 18m to 58m.

The aquifer transmissibility and hydraulic conductivity vary from 1250 to 1950m<sup>2</sup> /day and 16 to 48m/day respectively.

The geo-electric cross sections show four geo-electric layers with the litho stratigraphy comprise superficial Quaternary deposits (Aeolian and alluvial deposits), Cretaceous sandstone Formation and Cambrian Basement complex rocks. The Cretaceous formation consists of medium to coarse grained sandstone with little content of claystone and siltstone intercalations. The lithostratigraphy of Wad Hamid area is characterized by Qoz sand (superficial deposits) at very shallow depth with a thick layer of sandstone extending over the whole area.

This study has helped to delineate the aquiferous horizons within the study area. Data from VES interpretation indicates that the aquifer layers that composed of sandstone of medium to coarse sand grains covered the whole area with varies thickness. This finding is in agreement with the borehole data drilled at different locality within the area. This method can be applied in other areas of similar geological condition.

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