Interpretation of Remote Sensing, Electromagnetic and Geo-electric Sounding Data for Groundwater Resources Exploration: A case study of the El Obeid area, Western Sudan

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Abstract: Scarcity of groundwater is a major problem in Basement terrain of El Obeid area. The proposed model is essentially based on integration of lineament and drainage data to delineate potential target zones for groundwater resources in the study area. Using land Sat Images, lineaments have been described as linear structural elements and thought to be developed over fracture zones. Target zones are indicated by overlap of the high-intensity lineament contours and low-intensity drainage contours. The results of analyses in the study area indicate that the locations of lineaments mapped on the basis of remote sensing data. The lineaments can be very helpful in sitting successful wells at zones (C and D) which exhibited a higher lineament density and frequency compared to the other zones. The subsurface column consists of three resistivity layers. The first layer is a surface layer composed of very dry superficial deposits, followed by an intercalation layer of weathered and fractured basement, then an impermeable hard basement complex.

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1. Introduction

Groundwater occurrence in the crystalline basement terrain can be very irregular due to abrupt discontinuity in lithology, thickness, and electrical properties of the overburden and weathered bedrock (Omosuyi, et al 2008). A large percentage of the population resides in the rural areas with no direct potable water for domestic uses, so the groundwater supply for the people depend on hand-pumps.

The role of lineaments and drainage is defining groundwater potential zones in crystalline rock terrain. The digitalization of lineaments was carried out through visual analysis at the screen of Land-sat were applied to scenes to extract more information also used as an aid to lineaments identification. According to Edet, et al. (1994), for crystalline basement areas, high lineament length density corresponds to areas of outcropping bedrock and thin regolith, whereas, low lineament length density is indicative of buried bedrock and thick regolith.

The exploration technique outlined below were targeting probable sites of weathered and fracture zones for follow-up remote sensing, geophysical surveys and borehole drilling. Remotely sensed data is one of the keys to understanding groundwater occurrence, especially in areas with igneous and metamorphic rocks of poor primary porosity, commonly referred to as hard terrain. The present investigation was principally aimed delineating groundwater target areas within the cross Khors as Khor Tagat based on available Land-sat imagery that was used to assess the groundwater potentials of these target areas.

Geophysics plays a major role for characterizing the hard rocks for groundwater studies. The measurements of geophysical surveys are made in the field for several methods will be available for groundwater exploration. Most of the available geophysical methods have been applied here to study the aquifer system of a hard rock terrain (electromagnetic and electrical resistivity methods) are quite helpful in estimating the depth and thickness of the water bearing zones.

2. Material and Methods

The study area lies in North Kordofan State (NKS) in the west-central Sudan, bounded by latitudes 13º 08´ to 13º 47´ N and longitudes 30º 00´ to 30º 37´ E, covering an area of 1995 square kilometers (Fig. 1). The study is investigating the geological setting within which groundwater professionals operate. The focus is on the nature of geological deposits, their mechanism and history of formation, and their characteristics. The geological materials of the study area as unconsolidated of superficial deposits, consolidated deposits, as metamorphic, and igneous rocks, The various rock types ranging in age from recent to

Precambrian rocks including granite, gneiss, quartzite and mica schist (Fig. 1).

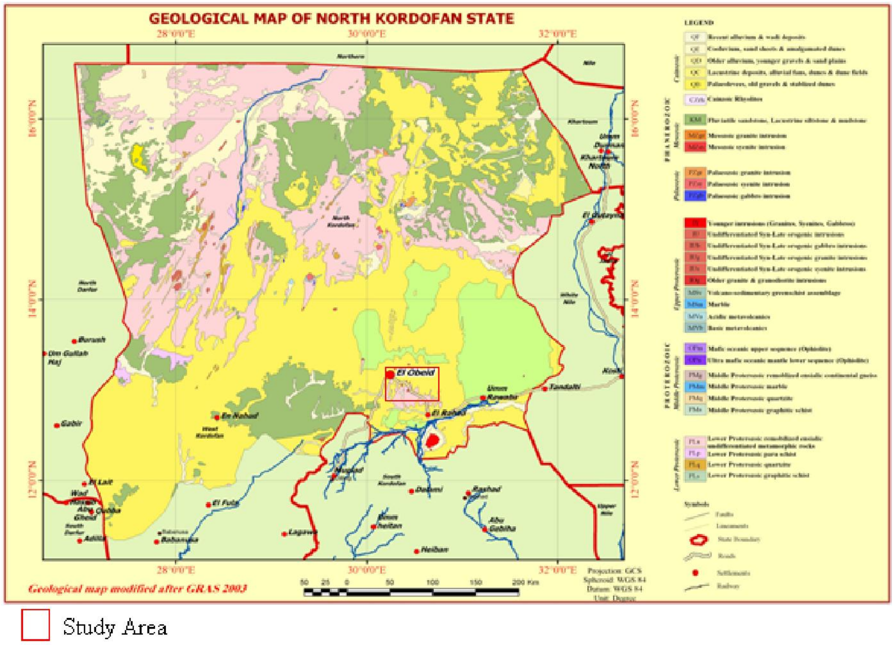

Figure 1: Location and geological units of the study area (Modified after GRAS, 2003).

In the study area geological structures include; folds, faults, joints and veins with several orientations, based on remote sensing interpretation and field studies (Photos 1 and 2). The border folds zone characterized by an anticline and syncline system with a variable dip and strike trend from northwest to southeast direction. The folded zone is much wider (tens meter) which consists of a series of relatively small and narrow anticlines separated by synclines, that were greatly influences the drainage pattern (Photo 2). Joint systems are observed in the study area between different rock units. The major structures observed in the gneiss and schist rocks are dominantly jointing. These include sub-vertical and sub-horizontal joint sets that are parallel to the foliation rocks, which are formed by stress changes after cooling. (Elhag and Elzien, 2013) studied the quartzite vein NE-SW trending at J.Abu Gour southeast of J.Kordofan with many meters width is exposed in the drainage divide in the southern boundary of the watershed.

Land-sat Imagery for the digital elevation model (DEM) was used to extract lineaments pattern systems. Edet, et al (1998) show that interpretations of imagery have complementary roles of parameters that were evaluated includes lineament and drainage patterns (lineament-length density and lineament frequency). Lineament maps produced from DEM digital data were used for the preparation of the total number and cumulative length for all lineaments within each sector. The directional filtering lie in the crystalline rocks was using for different directions that appear to be more lineaments with orientations of W-E and N-S trending of fractures relatively cross Central African Shear Zone (CASZ). These lineaments have a control over the drainage in the area; there were playing an important role in water circulation within the basement as shown in the image interpretation (Photos 2 and 3).

In the study area the EM data (Fig. 2) were collected at 20m intervals along profiles, with profile lengths ranging from 160 to 200m which are used with the corresponding transmitter frequencies (f) as (880, 1760, 3520 and 7040 Hz). After a good matching curves for Ketola and field curve can be determine depth of the conductor (h), and angle of dip (α) by using equations as follows:

$$W = \delta \mu w a h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$L = t + 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, W dimensionless response parameter.

δ conductivity (mho/m).

μ magnetic permeability (Henery/m) equal $4\pi x10^{-7}$.

w angular frequency equal 2πf.

a coil separation (m).

h thickness of the conductor (m).

L length of two peaks (m).

t width of the conductor (m).

Photo 1: Type rocks in the study area including structures of small (chevron) folds typical anticline and syncline sequence, fractured metamorphic rocks in gneiss and schist and quartz veins.

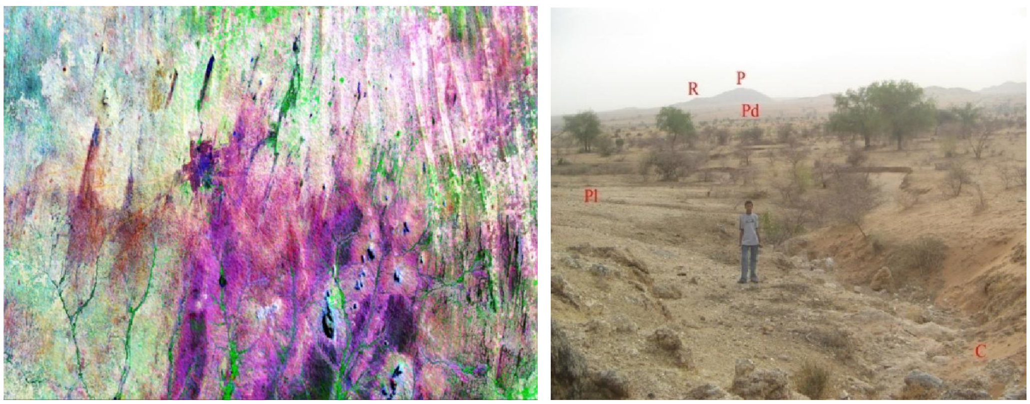

Photo 2: Description of main geomorphological feature types (P=Peak, R=Ridge, Pd=Pediment, Pl=Plain and C=Channel).

The profiling data are presented as plots of filtered real (IP) and filtered imaginary (Q) against station position. Typical electromagnetic profiles from the study area are shown in (Fig. 2). The EM anomalies vary significantly; some are sharp while others are broad, and are characterized with varying width extent. Zones with peak positive filtered real anomalies are inferred conductive, typical of water–filled fissures (Alvin et al., 1997), or effect of appreciable depth to bedrock (White et al., 1988). These zones are considered priority areas for depth sounding. On the other hand, the electrical resistivity technique is the most commonly applied method among all the geophysical methods for groundwater exploration, because of the large variation of resistivity for different formations and the changes that occur due to the saturated conditions.

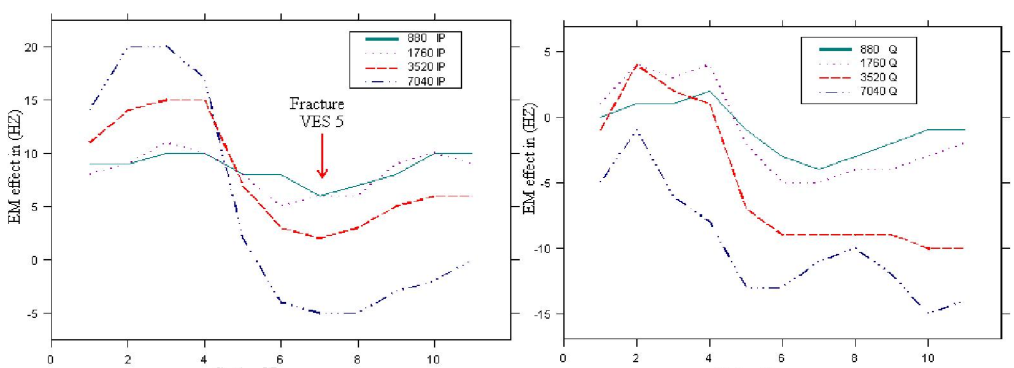

Figure 2: VLF – EM Profiles from Tagat area.

3. Results

In the study area, the total number of lineaments approximately 37 was from zone C and 7 from zone E of the basement complex. The lineament range in length from about 71 to about 13 km (Table 1) of the zones above mentioned respectively, as shown in (Fig. 3). On the other way, lineament length density range from 0.03 to 0.19 km^{-1} and lineament frequency is 0.02 and 0.11 in zones B and C respectively (Table 2). Therefore, high lineament frequency areas are expected to have a high lineament intersection and length density (Fig. 4), as well as, well production increases with increasing lineament density (Edet, A. E., 1993). These differences in lineament intensity probably reflect differences in the geology. According to (Ahmed, et al 1984), lineaments (dykes silicified or shear fracture zones, open faults or joint systems) constitute more reliable sources for groundwater in crystalline rocks.

The analysis of drainage patterns was carried out based on two parameters, the drainage-length density (Dd), and drainage frequency (Df). The values of these parameters are summarized in (Table 2). The greatest values of Dd and Df (0.26 km^{-1} and 0.04), whereas, the smallest values (0.04 km^{-1} and 0.009) respectively. The latter values are consistent with the relatively low value of lineament length density and the local geology.

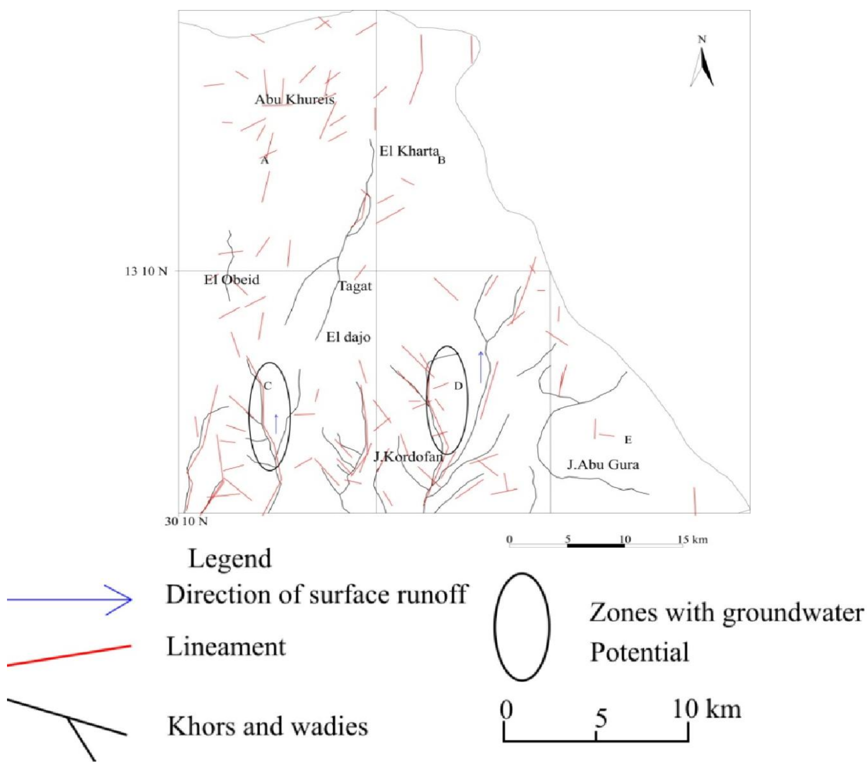

Figure 3: Lineament map of the basement complex, derived from the enhanced land-sat imagery.

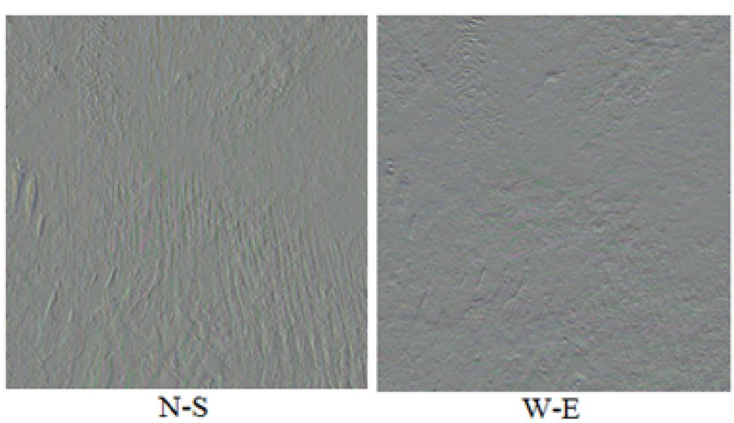

Photo 3: West-east directional filter applied to the study area using Land-sat image.

Table 1: Lineament parameters derived from land-sat imagery.

Zone	Area (km^2)	Lineaments		Drainage	
		Total length (km)	Number of lineaments	Total length (km)	Number of drainage
A	585.0	55.8	29	23.1	5
B	452.0	15.4	8	-	-
C	383.5	71.2	37	88.5	16
D	383.5	50.0	26	100.0	12
E	191.5	13.5	7	23.1	3

Table 2: Some parameters and features obtained from land-sat analysis.

Zone	Lineaments		Drainage	
	Density Ld (km^{-1})	Frequency Lf	Density Dd (km^{-1})	Frequency Df
A	0.10	0.05	0.04	0.009
B	0.03	0.02	-	-
C	0.19	0.11	0.23	0.042
D	0.13	0.07	0.26	0.031
E	0.07	0.04	0.12	0.016

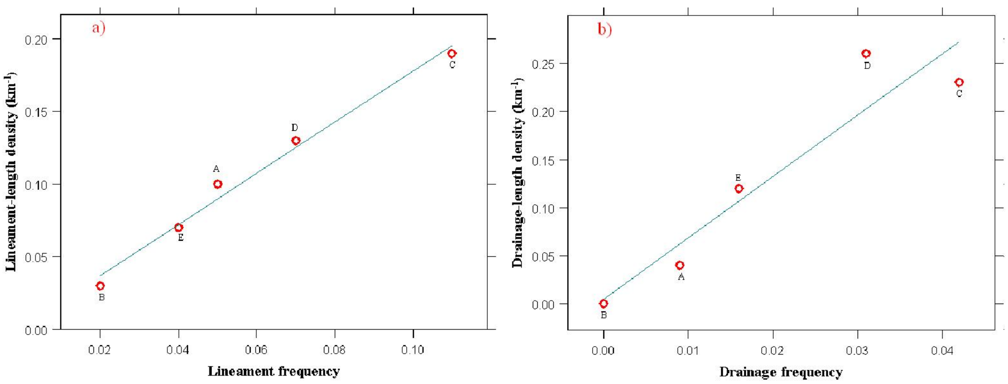

Figure 4: Relationship between length density and frequency based on land-sat interpretations a) lineaments, and b) drainage pattern in the study area.

According to Zohdy et al. (1980), the longitudinal conductance (S) (Table 3), is determined from the slope of the terminal branch of a Schlumberger curve, rising at an angle of 45° (here called S-line). The value of S is numerically equal to the inverse of the slope of this line (Kalenov, 1957; Keller and Frischknecht, 1966), and its usually determined, very quickly, by the intercept of the extension of the S-line with the horizontal line $\ell_i = 1$ ohm-m (Fig. 5), and its defined as:

$$S = \sum_{i=1}^{n} h_i/\ell_i \quad \text{.......... (3)}$$

Where, h_i thickness in meter.

ℓ_i resistivity in ohm.m.

(Ahmed, et al. 2008) announce resistivity of rock formations varies over a wide range, depending on the material, density, porosity, pore size and shape, water content and quality, and temperature. There are no fixed limits for resistivities of various rocks: igneous and metamorphic rocks yield values in the range 10^2 to 10^8 ohm.m while sedimentary and unconsolidated rocks, 10^0 to 10^4 ohm.m. Depending mainly on the above mentioned the resistivity values in the study area range between 10 to 1120 ohm.m (Fig. 5), that refer to various geological setting in the area.

Table 3: Groundwater parameters correlated with lineament-length density.

Location	Lineament-length density km^{-1}	Temperature °C	Conductivity µs/cm	Well yield m^3/d	Transmissivity m^2/d	longitudinal conductance S ohm^{-1}
J.Kordofan	0.13	29.0	708	314.4	80.5	1.3
El Kharta	0.03	27.5	1250	528	13.2	2.0
Abu Khureis	0.10	30.3	850	86.4	47.2	1.7
J.Abu Gour	0.07	28.2	800	280	5.8	3.4
Tagat	0.19	30.1	1800	158.4	65.5	1.1

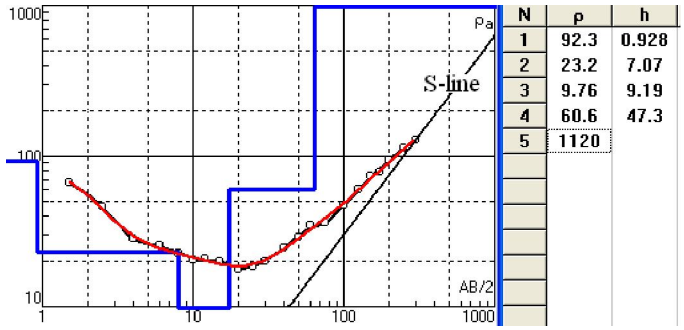

Figure 5: The acquired field data (VES # 1).

4. Discussion

In general, areas with different intensities have differences in probability of groundwater development potential, especially in basement complex. For the purpose of this study, is deduced the rating of zones for groundwater potential. Therefore, lineament frequency for the area has been categorized as presented. This is also in agreement with the lineament intersection and length density is categorized and computed for the area in (Table 3). Based on this, the zone C has a high rating, whereas, the zones D and A generally, has a high-medium rating, and zone B is low rating (Fig. 3). The potential target zones are indicated by overlap areas of high-intensity lineament contours (0.15 values), and low-intensity drainage contours of less than 0.15 contour values (Figs. 5 and 6). Fair amount of groundwater supplies are also expected on the upper Khor and Wadis reaches that cross-cut a lineament (Fig. 3).

Table 3: Categorization of lineament-length density and lineament frequency according to rating of zones for groundwater potential in the study area.

Category	Ld (km^{-1})	Lf	Rating
1	> 0.15	> 0.1	High
2	0.15-0.05	0.1-0.05	Medium
3	< 0.05	< 0.05	Low

The results of the analysis are presented the zones C and D exhibited a higher lineament density and frequency compared to the other zones. In addition, the drainage density is higher in the zone D. This clearly shows a direct relationship between drainage density and lithology. Thus, areas with low drainage density tend to indicate rocks with high permeability and porosity. Generally the area can be classified into high potential zone of lineaments density contour is more than 0.13, moderate potential zone of lineaments density range between 0.08 to 0.13, and low potential zone of lineaments density of less than 0.08 (Fig. 5). The high potential areas with respect to the high lineaments density are suitable for groundwater exploration; whereas, they are not suitable for surface water, storage hence the losses of storage water due to the underground flow through the fractures media is expected. In the case of drainage density parameters, the high drainage density areas are considered to be low capabilities for groundwater recharge, where the water drains as surface runoff. However, the over-lab of these areas to the areas of high lineaments density zones may be of great importance in water storage and movements in the basement areas.

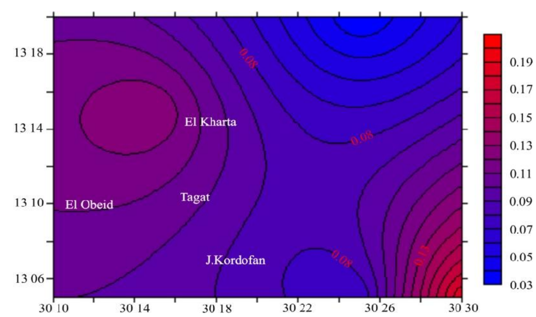

Figure 5: Lineament density contour map of the basement rock area.

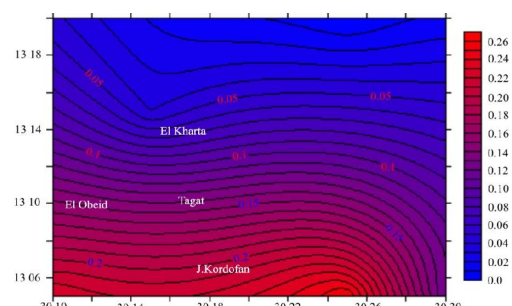

Figure 6: Drainage-intensity contour map, of the basement rock area.

The field data was carried out during the rainy season where the temperature is below 30°C during day time, which causes a decrease of the earth's surface resistance to values. The interpreted VES stations are used to produce two geo-electric cross sections and The VLF-EM geo-electric section along VES (5) in the area is shown in (Fig. 7).

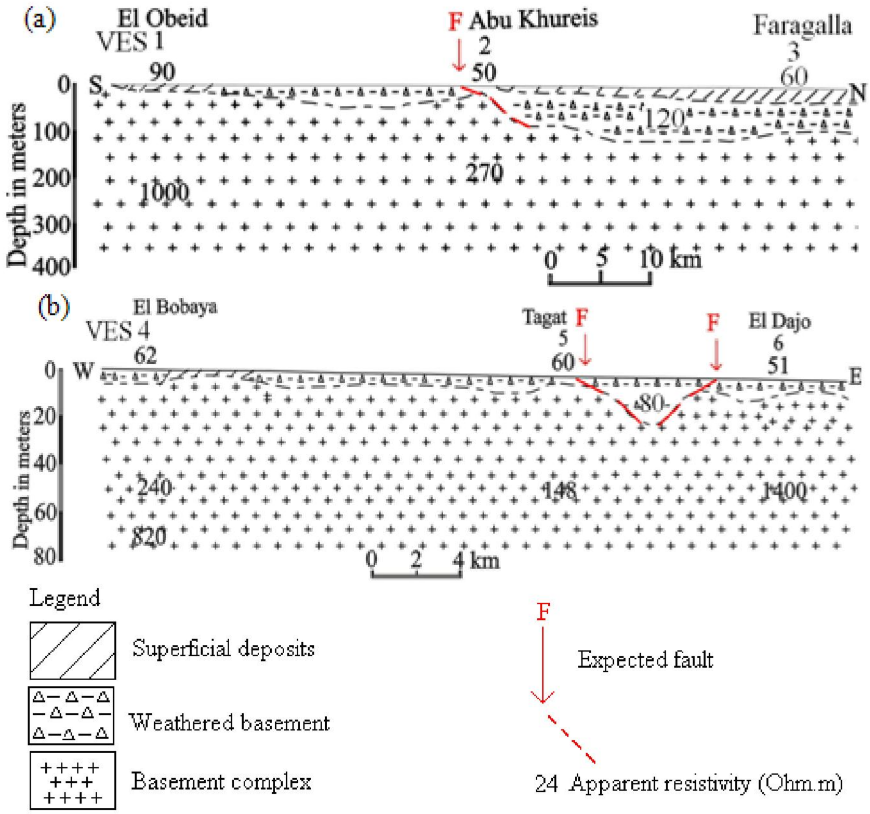

Figure 7: Generalized subsurface geo-electric cross-sections for delineation of stratigraphic.

This section revealed occurrence of a major fracture zone at depth of about 30m. The depth of the fracture range from 20 to 70m delineated from the interpretation of the VES data along this profile closely correlates with the EM anomaly pattern. A total of three subsurface layers are recognized in the geo-electric cross sections and controlled by a drilled borehole as follows:

1. A surface layer composed of very dry superficial deposits (sand or clayey sand). It has a resistivity > 50 ohm.m and a thickness ranging between 1–5m.
2. Weathered and fractured basement layer of gneiss and schist with resistivity ranging between 25-150 ohm.m and thickness ranging between 40-60m.
3. Hard basement complex shows increase in the resistivity value attains 800 ohm.m (Fig. 7).

The pseudo section has been done in the study area to recognize that the general vertical and horizontal variations in the apparent resistivity of the sub-surface layers. Figure (8) show the contour map of the depth, thickness, and true resistivity. This section is constructed by plotting the apparent resistivity values, as registered on the sounding curve at a given electrode spacing as observed, along vertical lines located beneath the sounding stations on the chosen profile. The upper layer resistivity is very low does not exceed 30 ohm.m in the southern part of the target area, and the lower layer in the pseudo section have ranges of resistivity between 40 and 100 ohm.m, that may indicate change in the rocks of the sub-surface layers from sand and clay at the upper to weathered, fracture and tight basement complex respectively. The depth to the aquifer increases towards the southeastern part of the study area, starting with 40m and increasing to about 70m. The depth to the top of the aquifer increases from 30 to 60m towards the southeastern of the study area (Fig. 8). The absence of the aquifer in the north part of the study area (VES station 2) structural regime of J. Abu Khureis in the form of faulting that affects the saturated area and prevents groundwater from moving (Fig. 7).

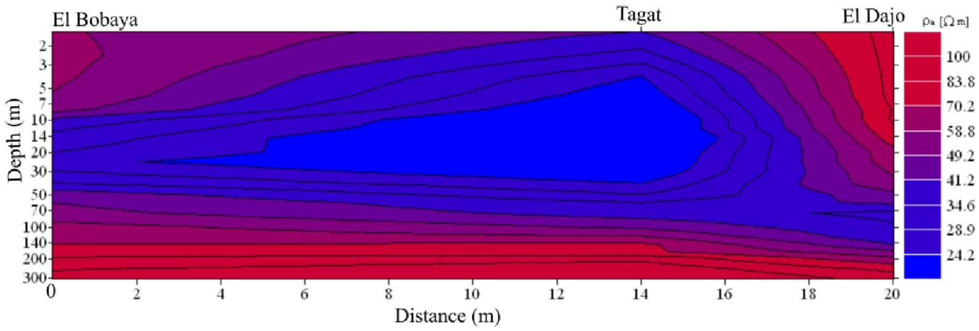

Figure 8: Northeast-southwest vertical electrical resistivity contour section in study area.

Groundwater in the area occurs under water table and semi-confined conditions in the weathered and fractured basement rocks (gneiss and schist) respectively. These rocks are fine to coarse grained and of pink and grey color. The yield of boreholes sunk in weathered and fractured part of basement rocks is generally low in average less than one liter per second. The occurrence and movement of groundwater in massive rock units is mainly controlled by fractures and other discontinuities. The map (Fig. 9) is a contour map derived from the composite thickness of the aquifer units (Overburden Thickness) delineated across the study points. Areas with thick aquifer units, or extensive fracture zones, are considered priority areas for groundwater development.

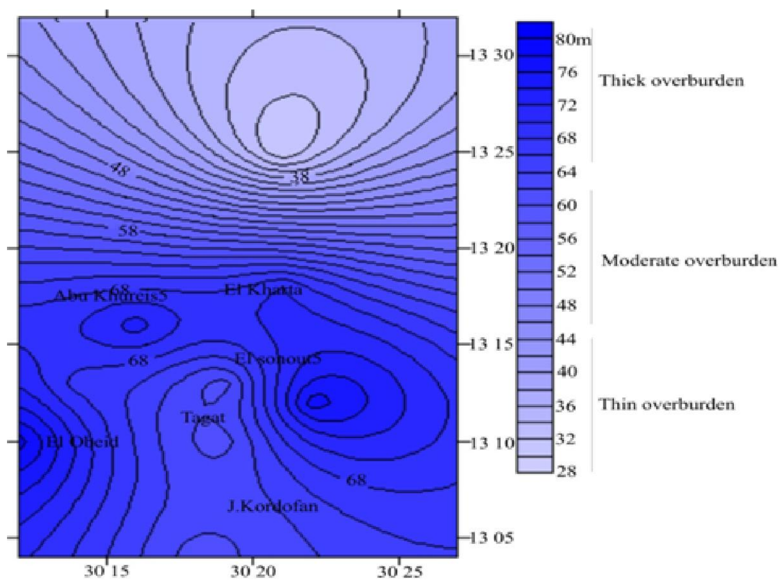

Figure 9: Overburden thickness map of the study area.

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