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INTEGRATED GEOPHYSICAL TECHNIQUES TO DELINEATE THE GROUNDWATER ACCUMULATION IN WADI HAFAFIT, EASTERN DESERT, EGYPT

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تكامل التقنيات الجيوفيزيائية لتحديد تجمعات المياه الجوفية بوادى حفافيت بالصحراء الشرقية، مصر

الخلاصة: تقع منطقة الدراسة في الجزء الجنوبي الغربي من الصحراء الشرقية في وادي حفافيت والتى تتميز بمناخ جاف طوال العام وتمتد حوالي ١٦كم. وتقع هذه المنطقة فى الحزام الجبلي للبحر الحمر وتتميز بصخور متحولة ونارية مقطوعة بوادى حفافيت المغطى بالرواسب الوديانية كما أن المنطقة تشمل تضاريس عالية تنحدر عموماً ناحية الجنوب الشرقي. وتهدف هذه الدراسة إلى تنمية هذا الجزء الهام من الصحارى المصرية عن طريق حفر أبار للمياه حيث تقع المنطقة على طريق الشيخ سالم– الشيخ الشاذلي مسافة ٤٠ كم ويوجد بجوارها بعض المناجم حيث يمكن إمدادها بالمياه الجوفية كما تساعد على توطين البدو وكذلك اختيار انسب الأماكن لإقامة سدود لتساعد فى تغذية الخزان الجوفي. وقد استخدمت فى هذه الدراسة عدة طرق جيوفيزيائية تكمل بعضها البعض. شملت طريقة المقاومة الجيوكهربية بعمل عدد ١٠ جسات جيوكهربية رأسية بطول الوادي والطريقة الجيوكهربية ثنائية الأبعاد والطريقة السيزمية بعمل بروفيلين لكل طريقة وتم تفسير النتائج الحقلية كماً وكيفاً لكل طريقة على حدة لتقييم ظروف تواجد المياه الجوفية وتحديد سمك وامتداد الطبقة الحاملة للمياه ومعرفة تأثير التراكيب التحتسطحية على تواجدات المياه الجوفية.

ويبين التفسير الجيوكهربى التتابع التحتسطحى فى منطقة الدراسة حيث يتكون من ثلاث طبقات هى (ا ، ب ، ج). طبقة "أ " هى طبقة جافة وتتكون من رواسب وديانية والطبقة "ب" وهى الطبقة الحاملة للمياه وتتكون من رواسب وديانية بينما طبقة "ج" هى طبقة صخور القاعدة وتنقسم إلى طبقتين: الأولى (ج١) العلوية هى طبقة صخور القاعدة المتشققة وحاملة للمياه والثانية "ج٢" السفلية وهى تمثل طبقة صخور القاعدة الصماء (غير متشققة) وتتميز بمقاومات عالية جداً. كما أظهر تفسير نتائج القياسات الجيوكهربية والسيزمية ومضاهاتها بعضها البعض أن أفضل الأماكن لإقامة سد هو عند موقع الجسة رقم (٧) حيث يمثل نهاية الخزان من الناحية الجنوبية الشرقية واقامة سد فى هذا المكان يساعد فى تغذية الخزان الجوفي القريب من السطح فى وادي حفافيت بالمياه مما يزيد من جودة المياه وحيث أن السد سوف يقلل من أخطار السيول ويقلل من سرعتها، وأن أفضل الأماكن لحفر الآبار تكون على مسافة لا تقل عن ٥٠٠ متر من مكان الصدع ناحية الشمال الغربى. و أخيرا تتأثر المنطقة بصدوع عادية وقواطع أدت إلى رفع صخور القاعدة على ارتفاعات مختلفة عاكسة تأثير التراكيب التحتسطحية التى أثرت على تتابع الطبقات وبالتالي على تواجد المياه الجوفية.

ABSTRACT : *The area under study extends in wadi Hafafit covering about 10km^2. It occupies the southern portion of the Eastern Desert, and is characterized by arid climate most of the year. Geomorphologically, the area lies in the Red Sea mountainous belt (igneous and metamorphic rocks) dissected by wadi Hafafit which covered by wadi deposits. It characterized by high land surface that generally slopes southeastward.*

The aim of this study is to delineate the groundwater accumulation and to find out suitable sites for drilling some water wells and testing the subsurface sequence to construct dams for supplying the study area with groundwater for development and to decrease the danger effect of the flooding. It is also aimed to determine the distribution of the main aquifers and the effect of the subsurface structures on these aquifers by using integrated geophysical techniques and aid of the drilled wells data.

For this study, ten Vertical Electrical Soundings (VES'es) of Schlumberger configuration, the 2D electrical resistivity imaging and the shallow refraction seismic profiles were carried out. The field data have been interpreted both qualitatively and quantitatively, in which geoelectrical profiles are constructed to evaluate the groundwater aquifers and to show the effect of the subsurface structures on the groundwater. The geoelectrical interpretation showed that the succession of the area consists of three geoelectrical layers ("A", "B" and "C"). Layer "A" is adry wadi deposit and layer "B" represents the water bearing formation of wadi deposit, while layer "C" represents the basement rocks and is divided into two sub-layers, the upper one "C1" is water bearing layer of fractured basement, while the lower one"C2" is massive basement rocks having the highest resistivity value in the area.

The area is influenced by faults which resulted in uplifting or downlifting of the basement rocks at different levels reflecting the influence of the subsurface structures on the geologic succession and consequently, the groundwater occurrences.

The integrated results obtained from the geoelectric (VES &2D) and geoseismic surveys shows that the potentiality of water bearing formation is good in the NW part of the study area due to presence of a graben structure forming the suitable thickness of wadi deposits and fractured basement rocks, while it is of limited potentiality in the SE part due to the uplift of the basement rocks. Generally, the groundwater potentiality decreases with depth due to presence of massive basement rocks at shallow depth, and the location of VES 7 is recommended suitable site for constructing the dam due to its shallow depth to basement rocks, acting as barrier. This dam will increase the recharge of the near surface aquifers and help in the increasing the quality of the groundwater in the study area.

INTRODUCTION :

Wadi Hafafit, occupies an area of about 10 km^2 (Figs.1 and 2). It is bounded by latitudes. 24° 40' and 24° 45' N and longitudes 34° 31' and 34° 35' E.Wadi Hafafit area is very important for future sustainable development especially for land reclamation and tourism expansions. In this respect, the exploration and evaluation of the groundwater resources are needed. The importance of the study area arising from their presence at the southern part of the Eastern Desert in which most of the mineral resources of Egypt are present. Also El-Sheikh El Shazly is very important village which lies near the study area, where visitors and tourists come to it from Egypt and other Islamic countries by a branch of Idfu-Mersa Alam road at Sidi Salim extending southward passing through wadi Hafafit. This study is preformed by WEP project, (2004). (world food project), development of Bedouin communities, Red Sea.

The study aims to delineate the groundwater accumulation and to find out the best suitable sites for drilling some water wells and estimate the subsurface rocks for constructing dams for supplying the study area with the groundwater needed for the development.

The selected area comprises wadi Hafafit, and lies in the Red Sea mountainous belt in the southern part of the Eastern Desert, Fig.(2).

The present geophysical work has been carried out with the following main objectives:

1- Delineation of the subsurface geologic setting i.e, the surface of the basement rocks and the structures affecting the area.

2- Delineation of the groundwater aquifers.

3- Studying the subsurface lithological extension to locate the best sites for production wells and constructing the dams.

To achieve these objectives, the following aspects have been considered:

1. Reviewing the previous information about geomorphology, geology and hydrogeology in the study area.

2. Carrying out detailed geophysical techniques such as the Vertical Electrical Soundings, the 2D electrical resistivity imaging and the shallow refraction seismic investigations.

3. Presentation of the geophysical results in the form of cross sections.

GEOMORPHOLOGIC AND GEOLOGIC BACKGROUND:

The southern portion of the Eastern Desert is characterized by arid climate (long hot summer and short warm winter , low rainfall and high evaporation rates) most of the year.

Geomorphologically, the concerned area lies in the Red Sea mountainous belt which consists of immense of igneous and metamorphic rocks, trending in a NW-SE direction and characterized by high land surface that generally slopes southeastward and covered by wadi deposits. The ground elevation ranges from + 456 m. to +525m above sea level. Some wadis dissect the high mountains as wadi Hafafit which is narrow in width and covered with wadi deposits.

The surface geologic map shows that, the southern part of the Eastern Desert is mainly covered by rock units ranging in age from Pre-Cambrian to Recent. (Fig. 2).

The basement rocks in the area lie unconformably by sedimentary rocks belong to recent ages El-Ramly (1990) and El-Gaby (1990). The private companies have drilled a hand dug water wells in the area, and revealed that, the detection of the basement rocks (as a marker bed) at different levels reflects the influence of the structures on the geologic succession and consequently, the groundwater occurrences. Structurally, the major structure in the Eastern desert is a part of the Arabian Nubian shield. The investigated area and its vicinities is mainly affected by fractures and faults which is belonging to two main trends NE-SW (Erythrian trend) and NW-SE trends, parallel to the axis of Red Sea (Youssef, 1968 and El-Kaliuobi, 1987).

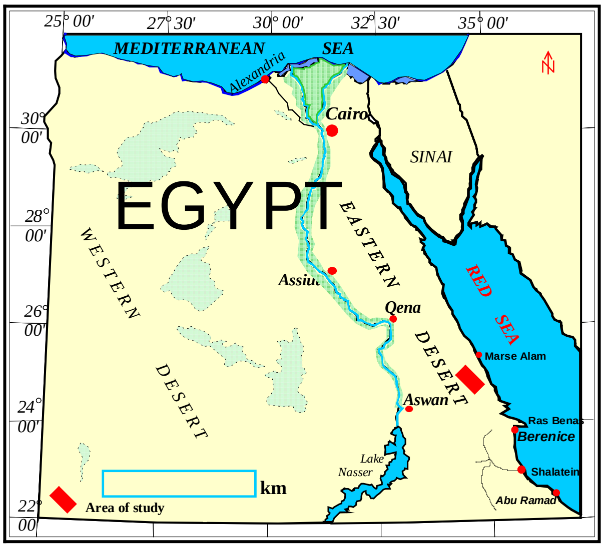

Fig. (1): Geographic situation of the study area.

GEOELECTRICAL STUDIES:

1- FIELD WORK AND DATA ACQUISITION:

Vertical Electrical Soundings (VES):

A total of ten Vertical Electrical Sounding Stations (VES) were carried out in the investigated area (Fig. 3). Some of these vertical electrical soundings were conducted close to a water well. Schlumberger configuration was applied using Terrameter SAS 300- C resistivity meter, where the spreading of the current electrodes AB ranges from 2 m to 1000 m. A land survey was carried out in order to determine accurate locations and ground elevations of the sounding stations on the topographic map.

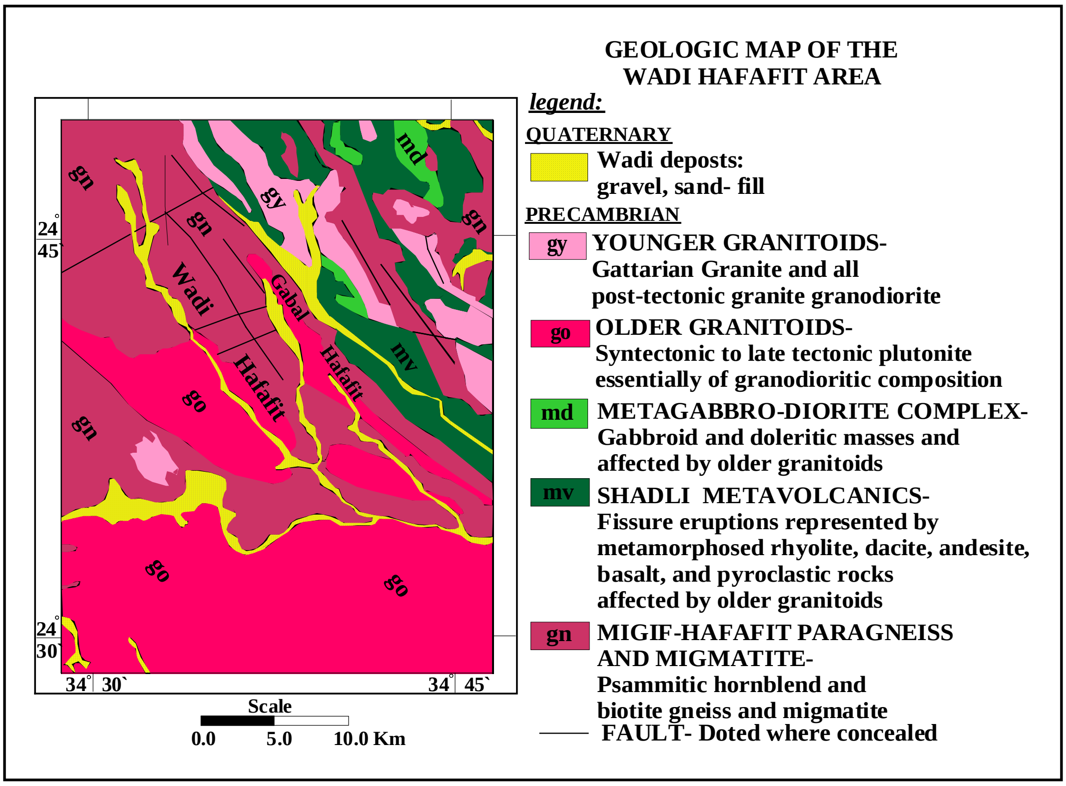

Fig. (2): Geologic map of the Wadi Hafafit area (Modified after EGSMA 1978).

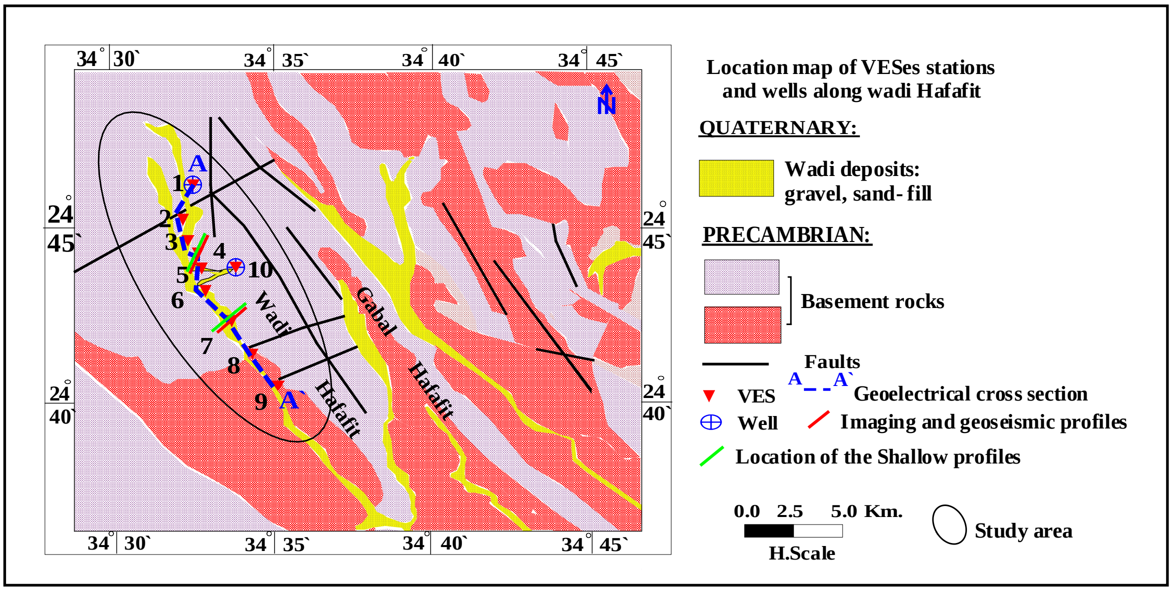

Fig. (3): Location map of the VES stations, Wells, 2-D geoelectrical resistivity imaging, and the shallow seismic profiles in Wadi Hafafit.

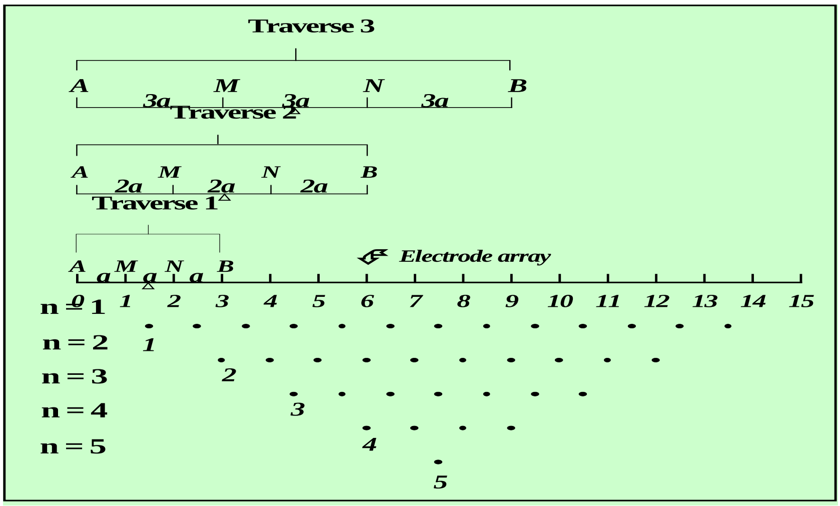

Fig. (4): The measurement sequence for building up the imaging section.

Two-Dimensional (2D) geoelectrical imaging (Tomography).

Electrical Tomography or 2D electrical resistivity imaging is a survey technique developed for investigation areas of complex geology, groundwater, fractured zones and engineering investigation. This method produces continuous image for the distribution of the electrical properties for the subsurface (Griffiths and Barker 1993).

The geoelectrical imaging technique with Wenner array involves measuring a series of constant separation traverses (datum levels) with the electrode separation being increased with each successive traverse (Fig. 4). The measurements continued successively to reach the last datum, which is represented by only one point with the largest electrodes separation (equals one third of the total length of the profile). In the Wenner electrode array the measurements start at the first traverse with unit electrode separation "a" started with 5m and increased at successive traverse by one unit i.e. 2a, 3a, 4a, …… na, where n is multiplier i.e. 10, 15, 20,……and 40 m.

To study the subsurface sequence and structures, high-resolution, 2D geoelectrical imaging (Tomography) measurements have been carried out along two profiles (Figs. 3). The first is near the site of VES No. 4 , has a trend SW-NE direction closed to Hafafit well with a length of 120m, while the other is selected after interpreting the VESes data, this profile is constructed near the site of VES No. 7 in SW-NE direction with a length of 90m.

Shallow Refraction Seismic:

Two layout geoseismic layouts were carried out, Fig.(3). The first lies at VES sation No.4 , has a trend SW-NE direction closed to Hafafit well and overlapping to the image profile, while the other is selected near VES No. 7 in SW-NE direction closed to the image profile. The seismic technique was applied by using 12-channel signal enhancement seismograph (Model EG & G-1225, Geometric) and a geophone spread cable of total length 120m with 12 take–outs of polarized connectors for each geophone.

Normal and reverse shooting were performed for each lay-out at distance of 6m from the first geophone, along the two geoseismic profiles were carried out crossing to wadi Hafafit area in NE-SW direction. The distance between each two successive geophone is 5 or 10m, depending on the seismic profile distance. The time distance curve for both normal and reverse refraction shooting were plotted for each profile to determine the velocities and thicknesses of different geoseismic layers to obtain the vertical sequence characterizing each site.

2- INTERPRETATION OF THE FIELD DATA:

Interpretation of the Vertical Electrical Soundings (VES):

The field data have been interpreted quantitatively by using the computer program RESIX-PLUS, ver.2.39 (Interpex, 1996). It is an interactive, graphically oriented, forward and inverse modeling program for interpreting the resistivity curves in terms of a layered earth model. The initial model has been constructed in view of the lithologic succession data of the existing wells.

Interpretation of the imaging measurements:

The computer program (RES2DINV) developed by Loke (1996) automatically determines a two-dimensional resistivity model for the subsurface using the data obtained from the imaging survey.

The program interprets the true resistivity structure using the “2D smoothness constrained inversion”. A finite difference model of the resistivity distribution is generated and adjusted to fit the data iteratively. The smoothness constraint prevents unstable and extreme solutions.

Interpretation of Shallow seismic measurements:

The present seismic refraction data are interpreted using Delay-Time and Ray-Tracing methods by using the computer program Seis REFA” (ver. 1.30 –1989), passing through the following steps:

- Construction of Time distance curve (T-X) for each layout using the first arrival time at each geophone.

- Defining the different refractors of the layouts.

- Determining the velocity and corresponding thickness of each geoseismic layer using SIPT1 program.

3- DISCUSSION OF THE RESULTS:

The qualitative interpretation of the field curves indicates that the general types of the vertical electrical sounding curves are QHA or KHA. Generally, the resistivity values on the first cycle of the resistivity curves represent the surface variations and reflect heterogeneity characterizing the first layers. In going downwards on the field curves (second & third cycles) Fig. (5), the field curves show nearly the same type, which reflects homogeneity and continuous aerial extension of the deep layers. The high resistivity values for the last geoelectrical zone represent the upper surface of basement rocks or the base of the aquifer in wadi Hafafit, where the basement rocks are present at shallow depth. This is marked on the right-hand side of the field curves (Fig. 5).

The comparison between the interpreted data of the vertical electrical sounding and the lithologic data of drilled well revealed that, the geoelectrical succession of the area under study consists of three geoelectrical layers {A, B and C}. The parameters of the geoelectrical layers such as thicknesses and resistivities are tabulated in (Table 1).

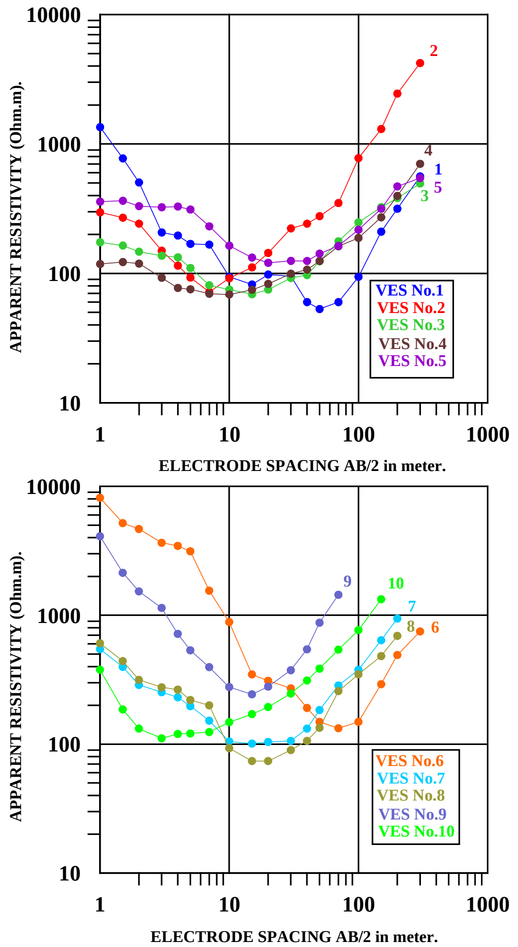

Fig. (5): The field resistivity soundings curves in Wadi Hafafit.

Table (1). Resistivities and corresponding thicknesses of the geoelectrical layers in Wadi Hafafit.

VES N0.	Geoelectrical layer (A) Wadi deposits (Dry layer)		Geoelectrical layer (B) Wadi deposits (water bearing layer)		Geoelectrical layer (C) basement rocks: (C1) (water bearing fractured basement layer)		Geoelectrical layer (C) basement rocks: (C2) massive basement	
	ρ 1	h1	ρ 2	h2	ρ 3	h3	ρ 4	h4
1	2196	8.5	-----	-----	155.8	3.4	2862	-----
2	180	6.6	-----	-----	171.1	3.86	7315	-----
3	120	12.84	-----	-----	152.8	2.12	1100	-----
4	136	18.65	39.8	3.78	139.8	3.56	1149	-----
5	440	21.5	77.2	3.83	155.6	3.7	5411	-----
6	9247	22.56	65	3.2	132.3	4.2	6914	-----
7	347	14.91	------	-----	-----	-----	3173	-----
8	405	12.3	------	-----	-----	-----	7611	-----
9	2600	6.88	------	-----	------	-----	7945	-----
10	1152	16.5	68.8	2.5	165.3	2.4	7143	-----

The geoelectrical cross section (A-A` Fig. 6) shows that the geoelectrical succession consists of three layers from top to base as follows:

- The first geoelectrical layer (A) consists of thin geoelectrical layers grouped together in one geoelectrical layer of Wadi deposits composed of boulders, sand, gravels and clay. This layer is characterized by a wide resistivity values range from 120 to 9247 Ohm.m with thickness range from 6.6m. to 22.6m.

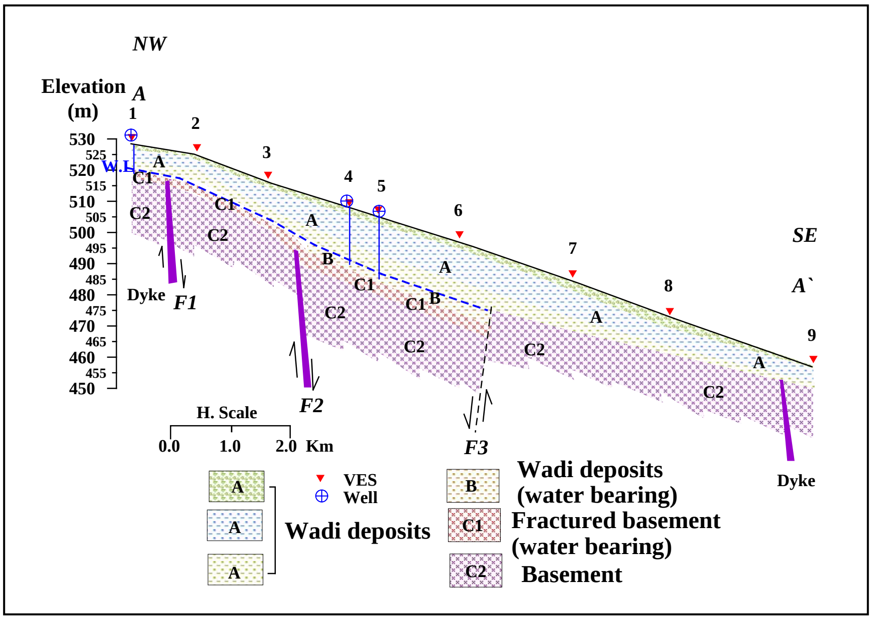

Fig. (6): Geoelectrical cross section A-A` along Wadi Hafafit.

- The second geoelectrical layer (B) represents the water bearing and consists of wadi deposits and characterized by resistivity value range from 40 to 77 Ohm.m with thickness of about 4m.

- The last geoelectrical layer (C) is represented by basement rocks and is divided into two sub-layers, the upper one (C1) is represented by water bearing fractured basement which characterized by resistivity values range from 132 to 171 Ohm.m with thickness range from 2.0m. to 4m., while the lower one (C2) consists of massive basement rocks having the highest resistivity value reached 7945 Ohm.m.

\- The depth to water ranges from 6.6 m to 22.5 m in the study area and the salinity of water range from 903 to 3377 ppm.

\- Structurally, there are three faults expected (F1, F2 and F3) forming graben structure at VES No. 4, 5 and 6 respectively and there are three dykes affecting the area reflecting the influence of the structures on the groundwater aquifer (Fig. 6). These dykes confirmed from geologic field observations.

According to the available geologic information about the study area and the measured depth to water, the obtained resistivity ranges have been assigned to rock types.

The imaging section lies at VES No.4 (Fig. 7). The image shows different resistivity zones with variable thickness. These zones can be described, from top to bottom, as follows:

1- The first zone represents the surface cover of dry wadi deposits (3.6m.) and has a resistivity value about 75 Ohm.m. It varies from one point to another along the profile.

2- The second zone represents dry wadi deposits and has resistivity values ranging from 40 to 160 Ohm.m. Its thickness is about 16 m.

3- The thrid zone represents a water bearing layer that consists of wadi deposit. It attains a resistivity value range from 120-200 Ohm.m with a thickness of about 4m.

4- The last zone represents fractured basement rocks. It exhibits a resistivity value >200 Ohm.m with undulated upper surface.

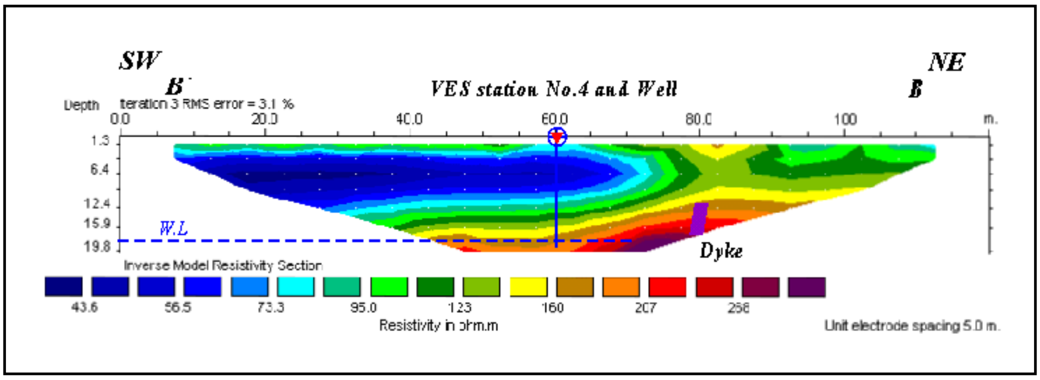

Fig. (7): 2D resistivity imaging profile (B-B`) at the VES station No. 4.

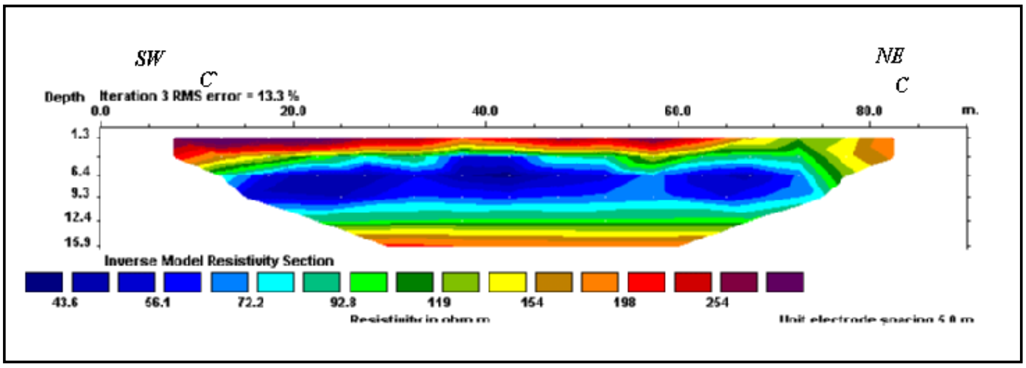

Fig. (8): 2D resistivity imaging profile (C-C`) at VES station No. 7.

The section (B-B`) is effected by subsurface structure (dyke) at the NE part of the profile. This is confirmed from the field observation. Moreover, the level of the water-bearing layer shows remarkable variations along the distance of the profile.

The other imaging section lies at VES No.7 (Fig. 8). The image shows different resistivity zones with variable thicknesses. These zones can be described, from top to bottom, as follows:

1- The first zone represents the surface cover which has a resistivity value >250 Ohm.m. and with a thickness of about 4.4m.

2- The second zone is represented by dry zone and has a resistivity values range from 40 to 160 Ohm.m that can be assigned to dry wadi deposits, having 10m in thickness.

3- The thrid zone is represented by dry zone and has a resistivity value of >160 Ohm.m that can be assigned to basement rocks.

The section (C-C`) is not effected by subsurface structures. So, this site is suitable for dam constructing. This dam will minimize the dangers of the surface runoff, decrease the surface runoff speed, increase the recharge of the near surface aquifers and help in increasing the quality of the groundwater in the study area.

In view of the above-mentioned discussion, it is obvious the effect of the impact of subsurface structures on the successions. The 2D resistivity can determine more information about the area, which is affected by subsurface structures. This method can suggest a site for constructing dam. The site at VES No. 7 is suitable for constructing dam (Fig. 8).

Interpretation results comprising velocities and thicknesses of each geoseismic layer are shown in table (2). Two geoseismic cross sections (D-D' & E-E', Figs 9&10 respectively) are constructed in two sites as shown (Fig. 3) and the description of each site can be discussed as follows:

According to the velocities of the geoseismic cross section D-D' at VES station No. 4, the subsurface sequence can be differentiated into three layers; the first layer "A" is represented by dry layer and divided into two sub-layers A1 and A2, while Layer "B" is represented by water bearing wadi deposits and layer "C1" is represented by water bearing fractured basement (Table 2 and Fig. 9).

Table (2): Interpreted seismic data of the selected dam sites

Section	Direction and length	Geophone distance (m)	layer "A"				layer "B" wadi deposits water bearing		layer "C1" fractured basement water bearing
			Sub-layer "A1" surface cover		Sub-layer "A2" dry wadi deposits				
			Velocity (km/sec)	Thick (m)	Velocity (km/sec)	Thick (m)	Velocity (km/sec)	Thick (m)	Velocity (km/sec)
D-D'	SW-NE 12.0 m	10	0.37	<3	1.7	16.5	2.2	3.6	3.2
E-E'	SW-NE 90 m	5	0.30-0.91	6	1.7	--	--	--	---

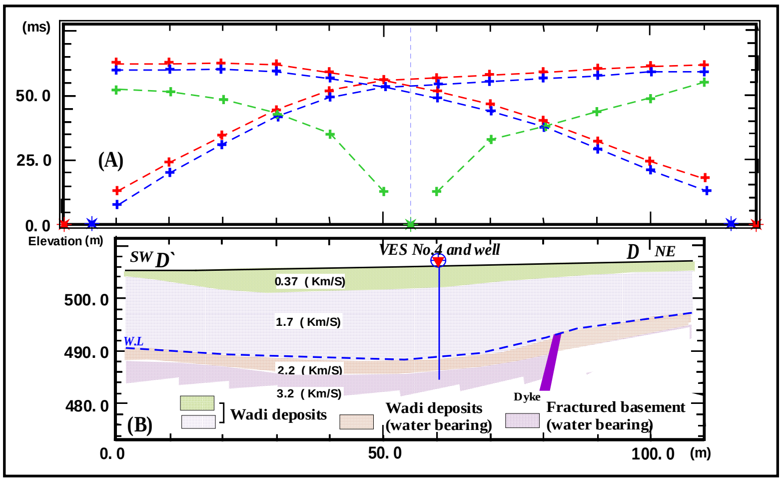

Fig. (9): Geoseismic cross section D-D' at VES station No. 4.

The first geoseismic layer is represented by surface layer “A1”. It has a velocity 0.37 km/sec and consists of wadi deposits of boulders, gravel, sand and clay, covering the surface of wadi Hafafit. Its thickness is about 2.8m. The second sub-layer “A2” has velocity 1.7 km/sec and is considered as dry wadi deposits. Its thickness is about 16.5m. The second geoseismic layer “B” is represented by water bearing wadi deposits and has a velocity 2.2 km/sec and its thickness is about of 3.6 m. The last layer “C1” has the highest velocity in the area 3.2 km/sec. It represents water bearing fractured basement rocks. The profile is effected by subsurface structure (dyke) at the NE part of the profile; this is confirmed from the field observation and the 2-D imaging profile.

According to the velocities of the geoseismic cross section E-E’ at VES station No. 7 , the subsurface sequence can be differentiated into two sub-layers “A1” and “A2” (Table 2 and Fig. 10).

The surface layer “A1” has a velocity range from 0.30 to 0.91 km/sec and consists of wadi deposits of boulders, gravel, sand and clay, covering the surface of wadi Hafafit. Its thickness is about 6m. The second sub-layer “A2” has a velocity 1.7 km/sec and is considered as dry wadi deposits. No indications for finding groundwater or structures along this profile.

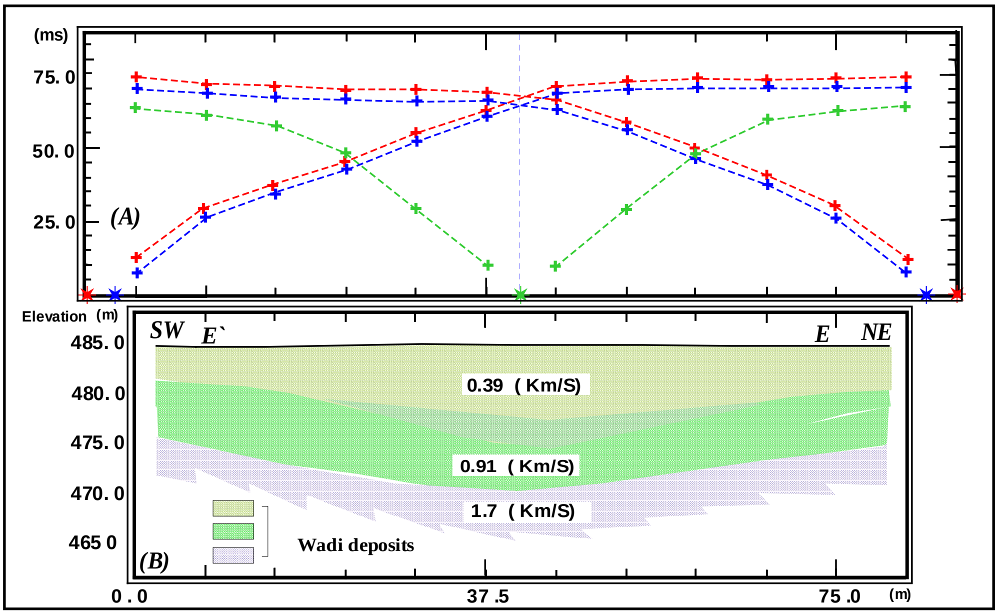

Fig. (10): Geoseismic cross section E-E’ at VES station No. 7.

CONCLUSION AND RECOMMENDATIONS

1-The geoelectrical interpretation showed that the succession of the area consists of three geoelectrical layers “A”, “B” and “C”. Layer “A” is dry and consists of wadi deposit, and layer “B” represents the water bearing formations and consists of the same deposits of layer “A”. The layer “C” represents the basement rocks and is divided into two sub-layers, the upper one “C1” (fractured basement), while the lower one “C2” is representing by the massive basement rocks having the highest resistivity in the area.

2-Data of the recent wells revealed that the basement rocks is detected at different depths ranging from 6.6 to 25 m in the study area. The detection of the basement rocks (as a marker bed) at different levels reflects the influence of the structures on the geologic succession and consequently, the groundwater occurrences.

3-The results of geoelectrical survey and well data reveal the presence of three normal faults (F1, F2 and F3) in the study area. These faults play the main role in the groundwater collection in the area.

4- The potentiality of water bearing formation is good in the NW part of the study area due to presence of a graben structure forming the suitable thickness of wadi deposits and fractured basement rocks, while it is of limited potentiality in the SE part due to the uplift of basement rocks.

5- The location of any new water wells should be away from the fault location for not less than 500m from VES No. 6 to the NW. Generally, the groundwater potentiality decreases by depth due to presence of massive basement rocks at shallow depths.

6-The integrated results of the geoelectric and geoseismic (VES &2D) surveys show that the location at VES station No. 7 is suitable for constructing the dam due to the uplift of basement rocks, and this site is not affected by subsurface structures. This dam will minimize the dangers of the surface runoff , decrease the surface runoff speed, increase the recharge of the near surface aquifers and help in increasing the groundwater quality in the study area.

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