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Comparison between vertical electrical soundings acquired by Schlumberger and Wenner arrays: a case study.

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Abstract: Direct current (DC) resistivity is considered one of the most common geophysical methods that is widely used in many applications. In DC resistivity data acquisition, different electrode arrays are used, and this leads to variations in the acquired data for the same location and for almost the same electrode spacing and consequently affecting the inverted model parameters.

For this purpose and as a case study to demonstrate to what extent the implemented electrode array is affecting the acquired field data, ten vertical electrical sounding (VES) have been carried out at Triple-M Farm at Abu Suwayer area, Ismailia governorate using both of Wenner and Schlumberger arrays at the same location. The minimum half space of electrode space (AB/2) in the case of the Schlumberger array was 1 m, while the maximum half space of electrode space (AB/2) was 200 m. On the other hand, the minimum third of electrode space (a) in the case of the Wenner array was 0.5 m, while the maximum third of electrode spacing (a) was 100 m.

The ten VES data for both the Wenner and Schlumberger arrays are modeled using the IPI2WIN program. The results indicate that there is a good match between the results obtained by both arrays. The variations of inverted parameters are discussed in detail generally, there is a good match between the acquired data by both the implemented electrode arrays. However, and due to the nature of the sensitivity of each electrode array to lateral homogeneity, small differences are found in some acquired VES data. Moreover, it is found that the investigated depth is limited in the case of data using the Wenner array.

keywords: : Electrical Resistivity; Wenner array; Schlumberger array; VES.

1.Introduction

Direct current (DC) resistivity is considered one of the most commonly used geophysical methods in different applications (6). This wide usage is because of its low cost, and its ease of data acquisition. It is widely used in different applications such as groundwater exploration (8), groundwater pollution (2), sea water intrusion (5), hydraulic parameters (4) and other purposes.

This study aims to compare the data acquired by both the Schlumberger and Wenner array at the same location and for almost the same electrode spacing, and to demonstrate the difference in results between both data. Theoretically, the electrode configuration affects the acquired resistivity data so this study will help to know the effect of using different electrode configurations and to know the effect of simplification that we usually assume in the calculation of geometric factor for some electrode configurations.

2. Materials and methods

VES is considered one of the three modes of the survey in the DC resistivity method (7). It is used to know the vertical variation of resistivity with depth at the same point (4, 5). The most common electrode configuration that is used with the VES survey is the Schlumberger array (5, 1). VES data is usually interpreted using one-dimensional (1D) models and programs such as IPI2WIN (6), some algorithms written in different programming language such as MATLAB (5) or automatically such as Zohdy inversion technique (10).

The electrode configuration represents the arrangement of current electrodes and potential electrodes on the field. There are many electrode configurations such as Schlumberger, Wenner, Dipole-Dipole, Pole-Dipole, Pole-Pole and Square (1). In the case of using the Schlumberger array for VES, the two potential electrodes are kept constant while the two current electrodes are moved away from the investigation point (7). While in the case of using the Wenner array for VES, the four electrodes are moved away from the investigation point simultaneously. This is one of the reasons that leads to the wide usage of the Schlumberger array instead of the Wenner array in VES (5, 6, 8); due to the simplicity in the field. Schlumberger array has also better resolution and greater investigation depth (8)

Apparent resistivity can be measured according to the relation $\rho_a = k\frac{V}{I}$; ρa is the apparent resistivity, V is the potential difference between the potential electrodes, I is the current between the current electrodes and k is the geometric factor (8). The geometric factor is related to the electrode configuration (9).

The acquired data has been taken in a research farm (Triple M Farm) which belongs to Triple M Construction Company. It is located on Ismailia-Cairo Desert Road, Abu Suwayr area, Ismailia governorate, Egypt, shown in (fig.1.). Terrameter SAS 300C DC resistivity equipment has been used to acquire the data.

Ten VES are carried out along two perpendicular profiles as shown in (fig.2.). At each station, data using both Schlumberger and Wenner arrays has been implemented. The maximum current electrode spacing of both the Schlumberger and Wenner arrays is limited by the accessibility of the available space in the field. In the case of data acquired by the Schlumberger array, the (AB/2) ranges from 60 meters to 200 meters. While in the case of data acquired by the Wenner array, the (a) ranges from 30 meters to 100 meters

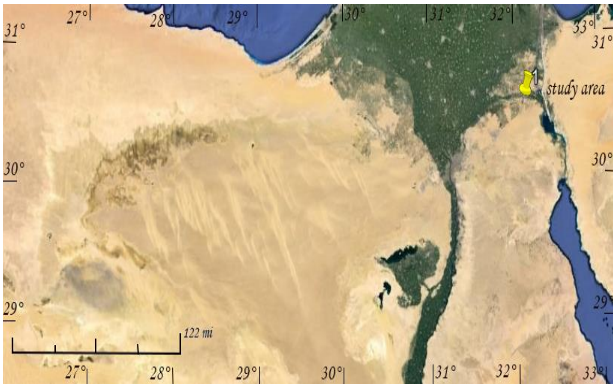

Fig. 1. Base map shows the location of Triple M Farm where the data is acquired.

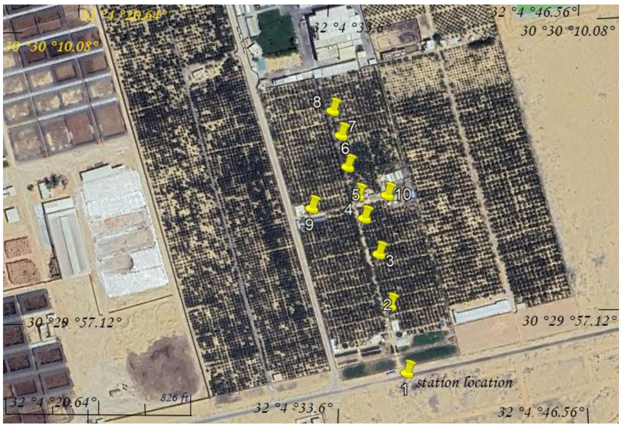

Fig. 2. Base map shows the location of acquired VES stations.

3. Results and Discussion

For each of the acquired VES, the data was drawn as a relationship between electrode spacing and apparent resistivity. All model parameters, including true resistivities and thicknesses of all geoelectrical layers, for each VES were achieved by using the IPI2WIN program **(**3**)**. The root mean square (RMS) error in all accepted models doesn't exceed 5%.

To make it easier to comparison between both Wenner and Schlumberger data with the same coordinates are drawn in the same figure, where apparent resistivity is plotted on the y-axis and electrode spacing on the x-axis. The electrode spacing in this case represents half the distance between the two current electrodes which equals AB/2 in the case of the Schlumberger array and 1.5*(a) in the case of the Wenner array where (a) is the 1/3 of the total electrode array in case of Wenner array.

It should be assumed that at the same station number of geoelectrical layers is the same for the Wenner and Schlumberger array for two main reasons. The first one is the degree of freedom (i.e. they have the same number of model parameters). The second one is that both arrays must give the same number of layers because the location doesn't change even if their model parameters vary from each other.

Table 1 lists the geoelectric model parameters for the ten VES acquired by the Schlumberger array. Table 2 lists the geoelectric model parameters for the ten VES acquired by the Wenner array. In the following, more details about each VES are discussed.

Table 1: Geoelectrical model parameters for VESes data obtained by Schlumberger array.

VES no.	Geoelectrical model parameters: ρ in (Ωm) and h in (m)												
	ρ1	h1	ρ2	h2	ρ3	h3	ρ4	h4	ρ5	h5	ρ6	h6	ρ7
1	63	1.92	213	2.82	53	8.65	501	18.8	0.8				
2	14.2	0.621	125	0.623	36.8	0.149	22.9	7.41	108	11.3	6.1		
3	42.5	0.5	26.3	4.26	2822	11.3	36.2						
4	40.6	0.5	13.1	0.164	293	0.489	40.6	0.937	99.1	36	0.488		
5	199	0.5	35.5	0.151	139	3.56	49	24.1	66.2				
6	151	0.278	312	0.307	7.44	0.778	26.5	43.4	0.271				
7	70	0.869	36.8	0.86	4.96	0.609	25.1	26.7	0.114				
8	36.6	0.5	47.9	1.05	18.2	2.3	62.4	27.3	0.738				
9	28.5	0.5	75.7	0.395	18	0.772	163	8.55	482	1.32	18.8	17.3	10517
10	33.3	0.498	98	0.347	12.9	0.815	85.2	2.48	56.9	2.83	15.2	42.4	5.99

Table 2: Geoelectrical model parameters for VESes data obtained by Wenner array.

VES no.	Geoelectrical model parameters: ρ in (Ωm) and h in (m)												
	ρ1	h1	ρ2	h2	ρ3	h3	ρ4	h4	ρ5	h5	ρ6	h6	ρ7
1	97.3	0.575	34.2	0.947	52.1	6.42	83.7	8.12	13.9				
2	16.6	0.529	45	1.51	19.8	1.46	46.7	8.39	11.1	12.7	62.9		
3	130	0.25	33.5	1.71	27	19.3	16.7						
4	102	0.25	9.01	0.215	150	0.401	30.9	17.8	31.8	15.7	4.97		
5	301	0.268	54	0.393	120	1.78	39.5	27.6	3.69				
6	51.9	0.0375	918	0.17	2.45	0.387	247	2.29	14				
7	36.1	0.25	267	0.426	7	1.31	143	4.41	10.9				
8	29	0.722	141	0.372	9.68	1.52	102	4.57	16.9				
9	18.5	0.25	88	0.256	5.87	0.477	226	1.28	10.9	3.25	46.5	15.1	5.11
10	44.1	0.912	9.49	0.582	146	1.22	47.2	3.98	22.8	22.9	8.65	17	27.7

The acquired data and model parameters at station (1) are shown in (fig.3.). Data of the two-electrode configuration showing mainly the same trend of five layers are modeled with a descending trend in resistivity values. The maximum (a) for the Wenner array is 100 m. The model depth of Wenner data doesn't exceed 17 m. The maximum (AB/2) for the Schlumberger array is 200 m. The model depth of Schlumberger data doesn't exceed 32 m. The acquired data and model parameters at station (2) are shown in (fig.4.). Data of the two-electrode configuration shows mainly the same trend except for the last part of the curve of six layers. The maximum (a) for the Wenner array is 50 m. The model depth of Wenner doesn't exceed 26 m. The maximum (AB/2) for the Schlumberger array is 80 m. The model depth of Schlumberger data doesn't exceed 20 m. It is worth mentioning that although both VES have the same electrode spacing (AB=160) in the case of Schlumberger and a total space of (150m) in case of Wenner, it's found that the last layer has a higher resistivity than the surrounding in the case of Wenner data and lower resistivity than surrounding in case of Schlumberger data.

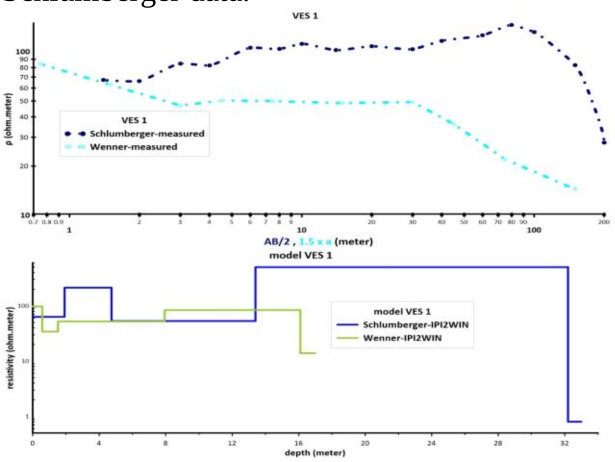

Fig. 3. Data of VES 1 and its model using IPI2WIN

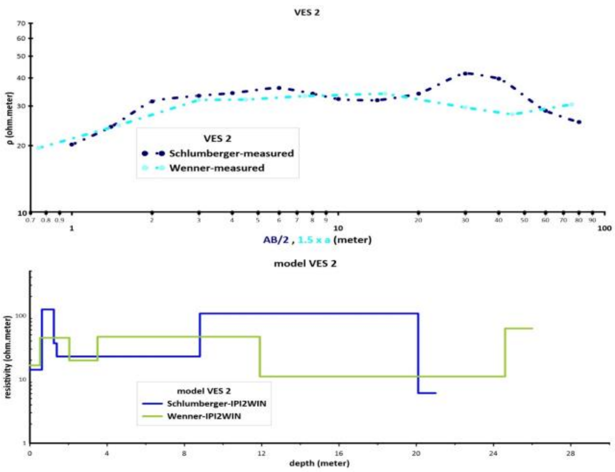

Fig. 4. Data of VES 2 and its model using IPI2WIN

The acquired data and model parameters at station (3) are shown in (fig.5.). Data of the two-electrode configuration shows different trends consisting of four layers. The maximum (a) for the Wenner array is 50 m. The model depth of Wenner data doesn't exceed 22 m. on the other hand, the maximum (AB/2) for the Schlumberger array is 80 m. The model of Schlumberger data depth doesn't exceed 18 m. The main difference in data is the third layer; it has low resistivity according to Wenner data and high resistivity according to Schlumberger data. It may be attributed to that the Schlumberger array is more accurate to vertical variation rather than the Wenner array.

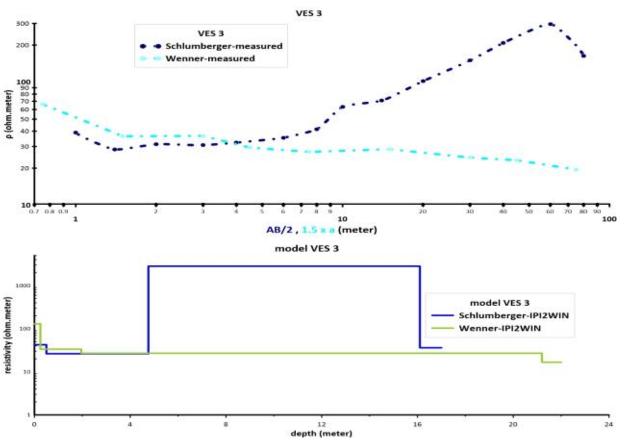

Fig. 5. Data of VES 3 and its model using IPI2WIN.

The acquired data and model parameters at station (4) are shown in (fig.6.). Data of the two-electrode configuration shows mainly the same trend of six layers. The maximum (a) for the Wenner array is 50 m. The model depth of Wenner data doesn't exceed 34 m. The maximum (AB/2) for the Schlumberger array is 80 m. The model of Schlumberger data depth doesn't exceed 38 m. One of the most different data is the last layer; it has higher resistivity according to Wenner data and lower resistivity according to Schlumberger data.

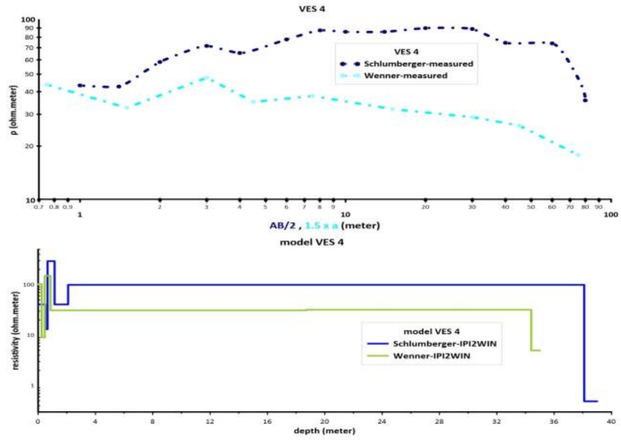

Fig. 6. Data of VES 4 and its model using IPI2WIN.

The acquired data and model parameters at station (5) are shown in (fig.7.). Data of the two-electrode configuration shows mainly the same trend of five layers with decreasing resistivity values with depth. The maximum (a) for the Wenner array is 30 m. The model depth of Wenner data doesn't exceed 30 m. The maximum (AB/2) for the Schlumberger array is 60 m. The model depth of Schlumberger data doesn't exceed 29 m. It is noticed a slight difference between both arrays; the last layer has higher resistivity in the case of Wenner data and lower resistivity in the case of Schlumberger data.

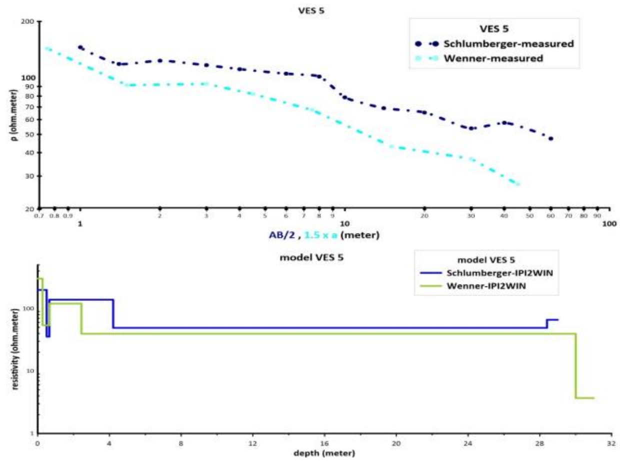

Fig. 7. Data of VES 5 and its model using IPI2WIN

The acquired data and model parameters at station (6) are shown in (fig.8.). Data of the two-electrode configuration shows mainly the same trend of mainly five layers. The maximum (a) for the Wenner array is 50 m.

The model depth of Wenner data doesn't exceed 5 m. The maximum (AB/2) for the Schlumberger array is 80 m. The model depth of Schlumberger data doesn't exceed 45 m.

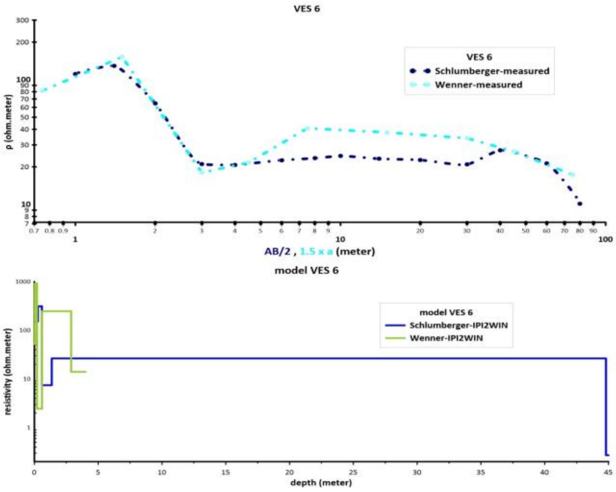

Fig. 8. Data of VES 6 and its model using IPI2WIN

The acquired data and model parameters at station (7) are shown in (fig.9.). Data of the two-electrode configuration shows mainly five layers. The maximum (a) for the Wenner array is 50 m. The model depth of Wenner data doesn't exceed 7 m. The maximum (AB/2) for the Schlumberger array is 80 m. The model depth of Schlumberger data doesn't exceed 29 m. it is noticeable from the obtained models that the last layer has higher resistivity in the case of Wenner data and lower resistivity in the case of Schlumberger data. It may be attributed to the depth of investigations of both arrays as the top of the last layer in the Schlumberger array is at 29 m, while the top of the last layer in the Wenner array is at 7 m.

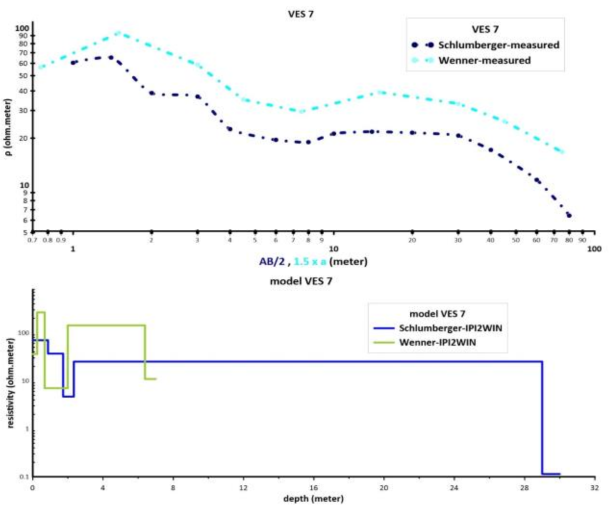

Fig. 9. Data of VES 7 and its model using IPI2WIN

The acquired data and model parameters at station (8) are shown in (fig.10.). Data of the two-electrode configuration shows mainly the same trend of mainly five layers. The maximum (a) for the Wenner array is 50 m. The model depth of Wenner data doesn't exceed 8 m. The maximum (AB/2) for the Schlumberger array is 80 m. Schlumberger data shows more details than Wenner data, but both are in the same trend. The model depth of Schlumberger data doesn't exceed 32 m. Although the two models have the same trend, it is noticed that the second layer has higher resistivity in the case of Wenner data and lower resistivity in the case of Schlumberger data. This may be attributed to near-surface heterogeneity.

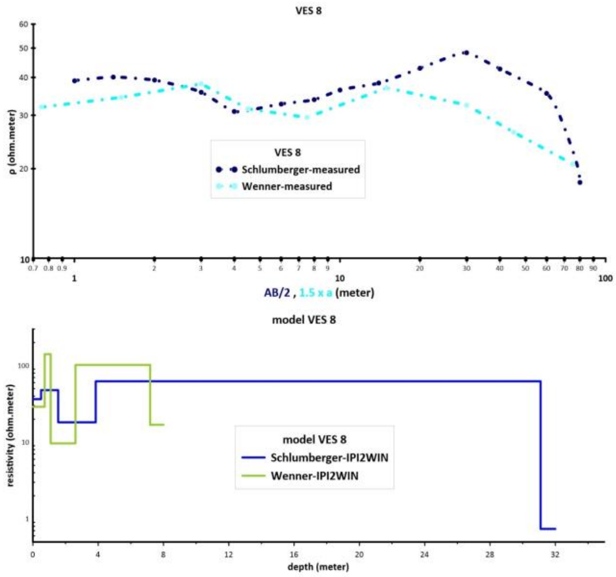

Fig. 10. Data of VES 8 and its model using IPI2WIN

The acquired data and model parameters at station (9) are shown in (fig.11.). Data of the two-electrode configuration shows the same trend except for the last part of the curve of mainly seven layers. The maximum (a) for the Wenner array is 100 m. The model depth of Wenner data doesn't exceed 21 m. The maximum (AB/2) for the Schlumberger array is 150 m. The model depth of Schlumberger data doesn't exceed 29 m. The main difference in data is the last layer; it has lower resistivity according to Wenner data and higher resistivity according to Schlumberger data. This is attributed to the achieved depth for both models (i.e. the last layer of the model of Wenner has a little bit resistivity than of fifth layer of Schlumberger).

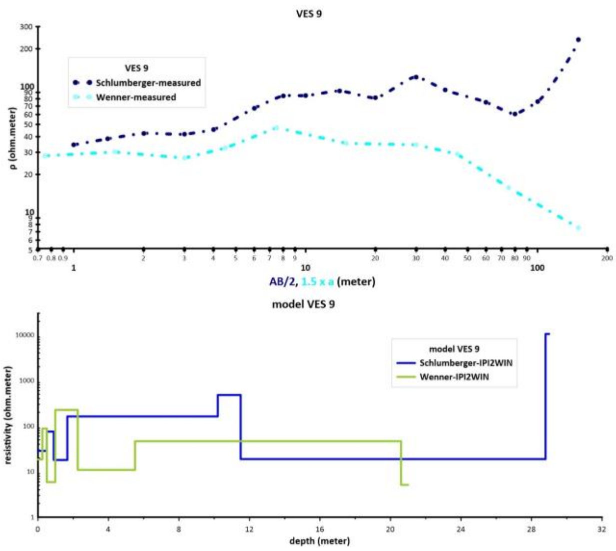

Fig. 11. Data of VES 9 and its model using IPI2WIN

The acquired data and model parameters at station (10) are shown in (fig.12.). Data of the two-electrode configuration shows mainly the same trend except for the last part of the curve of mainly seven layers. The maximum (a) for the Wenner array is 100 m. The model depth of Wenner data doesn't exceed 47 m. The maximum (AB/2) for the Schlumberger array is 150 m. The model depth of Schlumberger data doesn't exceed 49 m. However, comparing the models obtained for this VES and although the acquired data for the two VESes have the same trend, it is noticed that at greater depths there is a difference in resistivity magnitude and as well for the model parameters. This may confirm the differences in vertical resolutions for both techniques.

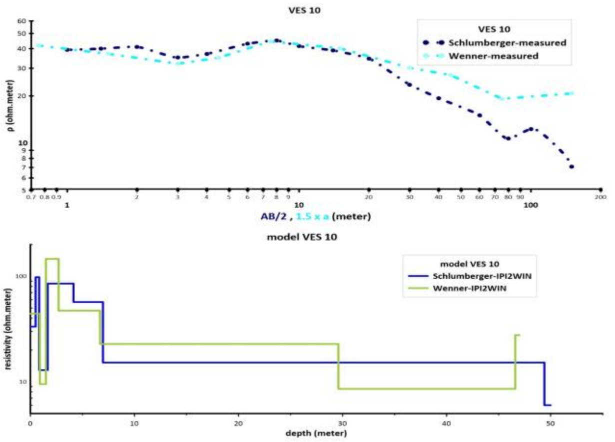

Fig. 12. Data of VES 10 and its model using IPI2WIN.

Moreover, and from the geological point of view, the data of the ten measured VES shows high resistivities at shallow depths which reflect dryness conditions and aeration zones, while at greater depths, there are decreasing of resistivities with depth and is attributed to water content and lithological changes with depth. This is in good match with the available sounding data south-east about 5 km away from the study area as shown in (fig.13. and fig.14.), **(**Ez El Din 2023, pers. comm., 25 August**)**.

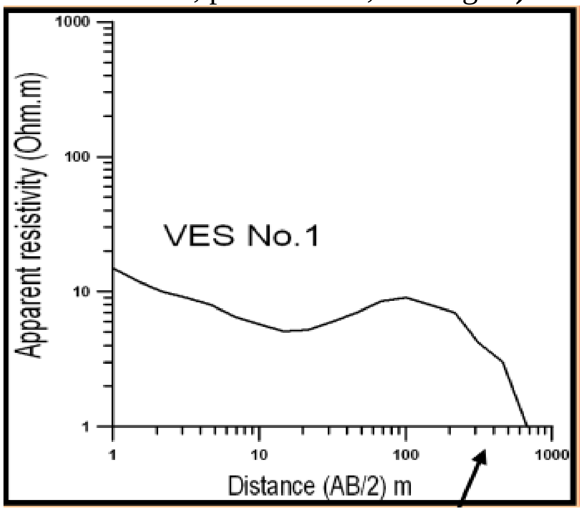

Fig. 13. Available data of VES near the study area (After, Ez El Din 2023, pers. comm.).

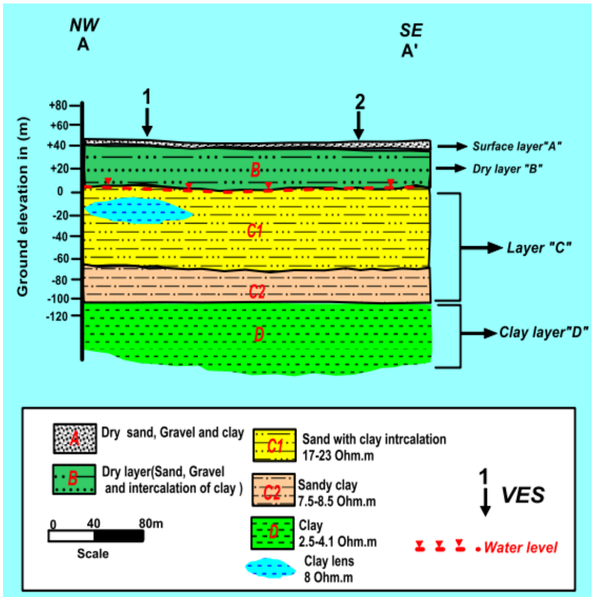

Fig. 14. Subsurface cross section near the study area (After, Ez El Din 2023, pers. comm.).

4. Conclusion

Ten VES have been carried out at Triple M Farm at the Abu Suwayer area, Ismailia governorate. For each VES, both Schlumberger and Wenner electrode arrays are deployed the number of data sets for each array are the same for the purpose of comparison. All the ten VES data are inverted using IPI2WIN software. The comparison of each VES is discussed in detail. Generally, most of the trend of the measured ten VES are in a good match. However, in some VES, the curve trends are not in match. This may be attributed to the degree of sensitivity to the lateral homogeneity for Schlumberger and Wenner arrays. Also, it is worth to mention that the depth of investigations achieved by Schlumberger is greater than that achieved by Wenner. Inverted data using Schlumberger shows more depth investigations compared with data of Wenner array.

4. References

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