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Research Article **GEOLOGY**

Site investigation for engineering purposes using geophysical techniques at Al-Madabigh area, Cairo, Egypt

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Leakage water,
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ABSTRACT

Engineering site investigation is fundamental to delineate the subsurface conditions of proposed building sites. Application of 1D and 2D geophysical resistivity techniques give useful data about the layering and condition of the subsurface along measured VESs and profiles. A contaminated area that has some caves, in addition to some near-surface contaminated water from an unknown source, was investigated at Al-Madabigh area, Cairo, Egypt. The objectives of this study are to identify the rock sequence, delineate the groundwater and source of contaminated surface water, and confirm the site's suitability for engineering construction using the electrical resistivity method. Twelve 1D VESs, consisting of seven VESs with the Wenner array and five VESs with the Schlumberger array, were conducted on the study site. In addition to a grid of thirteen 2D resistivity measurements using a Wenner array, were made along the research site: seven perpendicular to the major road and six parallel to it. The observed 1D and 2D resistivity field data were processed using ipi2win and Res2Dinv software. The correlation between geoelectrical results and those available from holes in the area and piezometric data gives an updated view of the groundwater table. It also helped in delineating the contact between contaminated leakage water and groundwater, and obtaining 2D images of the contaminated area, in addition to decelerating the site's suitability for engineering construction.

Introduction

Al-Madabegh area is an industrial area that contains the historic Magra Eloyoun wall that is located in the Old Cairo district (Fig. 1). The research area suffers from the deterioration of the sewage and electricity networks and the high levels of pollution caused by tanneries and the factories attached to them that harm its residents (Fig. 2a). The Egyptian government therefore started to take measures by demolishing tanneries as a part of its plan to develop unauthorized areas, eliminate pollution, and transform them into tourist attractions in addition to developing the Magra Eloyoun wall (Fig. 2b). Engineering site investigation is very important to provide a valuable geotechnical and geo-environmental assessment of the planned building sites **(Mondelli et al., 2012)**. It contains comprehensive studies of the surface and subsurface soil conditions to assess the aptness of the area for construction. Application of Electrical Resistivity Tomography (ERT) survey for engineering site investigation and geo-environmental conditions is valuable to delineate the subsurface soil layering types and condition of the needed area **(Hassan et al., 2018; Ebraheem et al., 2016; Kotb et al.,2021)**. Recently, the ERT geophysical method has been widely combined with geotechnical site tests **(Elawadi, et al., 2006; Al-Ebdaa, 2015)** to provide non-destroyed, time-saving, and costly effective data for delineating the subsurface layering conditions and the best location for drilling test boreholes required for other engineering investigations **(Youssef et al., 2012)**. The existence of natural caverns and sinkholes, as well as man-made caverns and sinkholes, pipes, channels, and structures, causes substantial geotechnical problems at engineering construction sites and geo-environmental problems. Locating these structures must be determined in order to assist the proposed construction site in terms of near surface and deep foundations. Conventional boring tests are often used for geotechnical site examinations. However, the boring methods are expensive and limited to the drilled point **(Al-Ebdaa, 2015).** In contrast, 2D ERT surveys are less expensive and could easily be carried out along lines to acquire 2D ERT sections **(Loke et al., 2013)**. Many authors have used the 2D ERT technique to investigate subsurface features such as fractures, sinkholes, cavities, faults, tunnels, walls, cracks, and buried utilities during engineering site investigations **(Metwaly and AlFouzan,**

2013; Amini and Ramazi, 2017; Thabit and Abed, 2014; Zayed and Nasr, 2023). The main aims of the current study are examination of the near-surface features and geo-environmental conditions to delineate the relationship between the surface leaking contaminated water and groundwater and confirmation of site suitability for engineering construction.

Materials and methods

History of the study site

The study site lies south of Cairo, in Misr al Kadima district, between 30° 1'6.00"N and 30° 1'16.00"N and 31°14'13.91"E to 31°14'30.00"E (Fig. 1). Geologically, it consists of marle, and marly limestone of the Middle Eocene **(Conoco, 1987),** covered by silt, sandstone, and gravel (Fig. 3). El Madabgh area includes workshops and factories for tanning leather, glue, and gelatin. In addition to the very poor status of their infrastructure, the tanneries in this area are subjected to a cycle of pollution (Fig. 2a). Furthermore, the tanneries employ antiquated machinery and lack nearly all clean technology in their buildings, as well as their electrical and hydraulic facilities. The Egyptian tanneries do not measure these polluting sources or apply preventative measures **(Leather, 2008).**

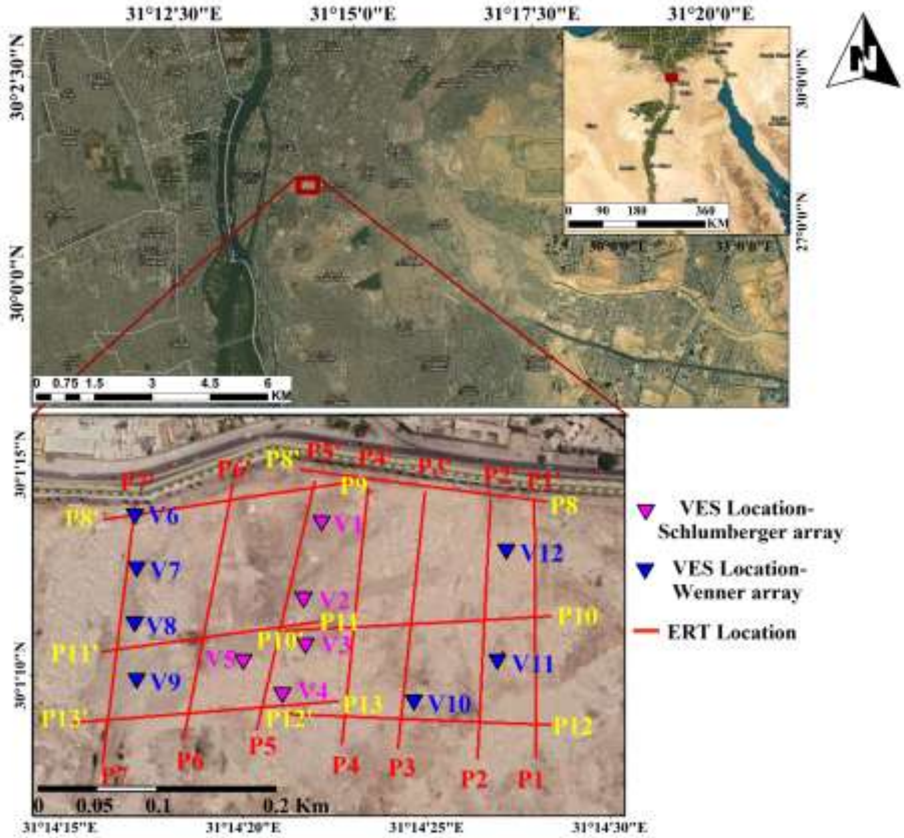

Fig. (1): A Google Earth map displays the location of the study site, along with a satellite image labeled with the positions of VESs and 2D ERT profiles

It is noteworthy that among the problems caused by the region was the problem of industrial drainage, which is one of the largest sources of pollution because it contains many toxic chemicals, and most factories, including tanneries, were involved in throwing a lot of materials such as acids, bases, detergents, dyes, and some phosphorous compounds and heavy minerals such as lead and mercury (Fig. 4). Nowadays, the government demolished tanneries to develop these areas, eliminate pollution, and replace them with new buildings, as planned in Fig. (2b).

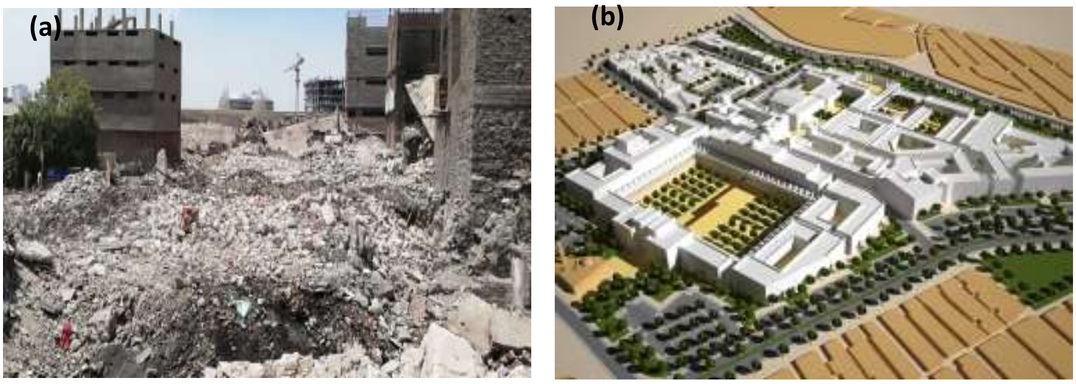

Fig. (2): (a) Shows the pollution at the study area; (b) shows the future development plan for the study site.

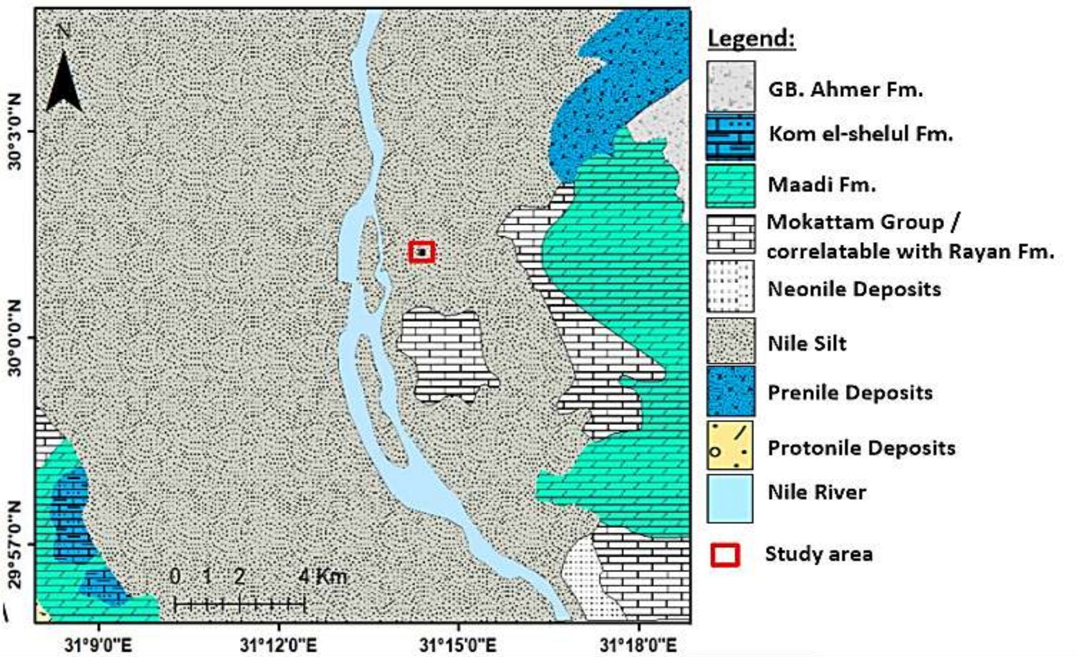

Fig. (3): Shows the geological map of the study site and its vicinities **(after CONCO, 1988)**

Field measurements

An exploratory study of VESs and 2D imaging were carried out in the El Madabgh area using the ABEM SAS 1000 device. This study includes twelve VES measurements that were carried out at the study site, which consisted of five VESs using the Schlumberger array and seven VESs using the Wenner array (Fig. 5). The VESs data is processed using ipi2 software. Also, thirteen 2D imaging profiles were conducted along the study area, which consists of seven profiles in the S-N direction and the other six profiles in the E-W direction (Fig. 1) using a Wenner array. The length of each profile was 190 meters, and the initial distance between the electrodes was five meters in order to reach the depth to be studied in precise detail. The Res2Dinv software has been used for processing the 2D apparent resistivity measurements and determining a geoelectric model.

Fig. (4): Shows the surface unclosited and contaminated water-bearing layer along the study area.

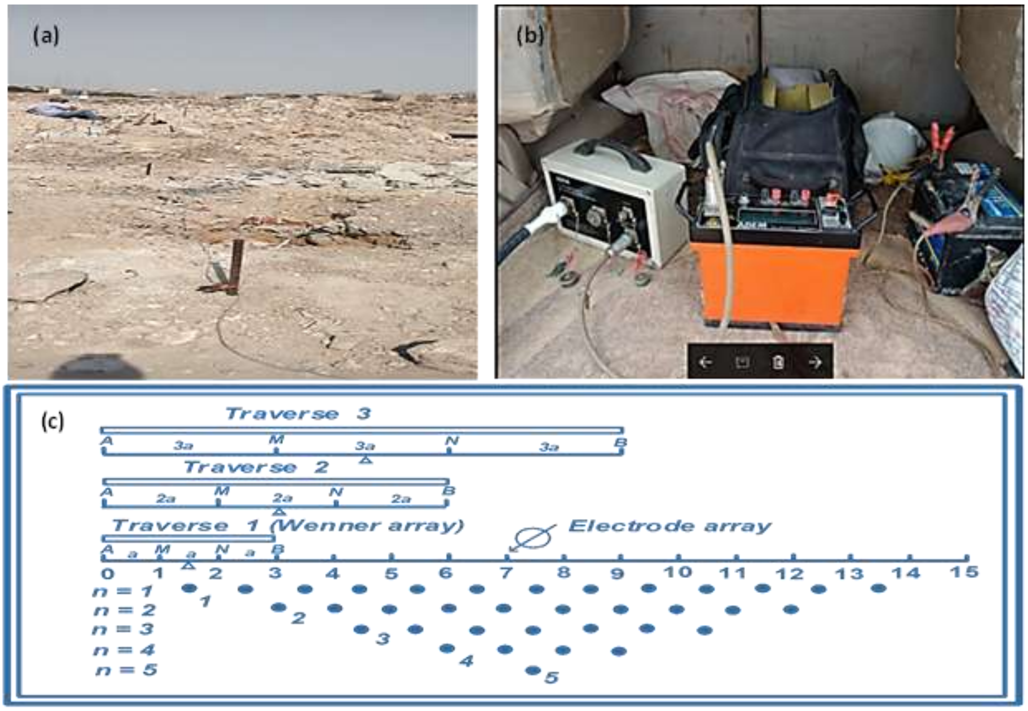

Fig. (5): (a) Field photo of a 2D ERT survey; (b) ABEM SAS 1000 with a multi-electrode system; (C) schematic model of the Wenner array electrode configuration.

Result and Discussion

VESs

The distribution of twelve VESs used for the study is given in Fig. (1), and the results are presented in Table 1. The results are analyzed in light of the available geological and hydrogeological information in order to investigate the layer sequences, the water-bearing layer, and its connection with the upper leakage of contaminated water. The apparent resistivity values are presented in the form of apparent resistivity curves using ipi2win software (Fig. 6). Also, this software was used to calculate the VES model and determine the true resistivity and thickness of each geoelectric layer, through which a geoelectrical section was drawn with a depth of approximately 40 meters. The results of the interpreted cross-section indicate that there are four geoelectrical layers. The first one is the surface layer, which is labeled by letters A and B (Figs. 7 and 8) and consists of rock fragments and sands that have surface water leakage, in addition to the presence of dry consolidated rock or concrete. The second observed layer, labeled by letter C consists of sand with clay intercalation and has an intermediate resistivity value. The third geoelectric layer that is labeled by the letter D consists of limestone with clay intercalation and has a relatively high resistivity value. The last layer reached at the depth of exploration is the fourth layer, which is labeled on the geoelectrical section by the letter E. It consists of water-bearing limestone with clay intercalation. The interpreted cross-section results are connected with geological features exposed around the sounding sites. Based on field observations, it is present in different geoelectrical water-saturated, fractured, and hard rock zones, with depth varying from place to place, as shown in figures 7 and 8.

Table (1): Shows the variations of the resistivity values and thickness for all the geoelectrical layers.

*		ρ1	h1	ρ2	h2	ρ3	h3	ρ4	h4	ρ5	h5	ρ6
Schlumberger array	**VES 1**	7867	0.4	1	1.4	84	1.6	11	7	73	6.5	11.6
	VES 2	5.27	1.7	1.7	1.13	8.5	5.5	67	9.4	25	-	
	VES 3	1.09	1.41	96	1.5	2.61	6.72	75	11.3	10.5	-	
	VES 4	7	1.18	1.63	0.8	6.7	9.17	94	6.6	33	-	
	VES 5	1.25	1.61	75.7	1.69	4.84	9.66	97	8.77	7.72	21.6	4.49
Wenner array	**VES 6**	45.5	2.8	6.68	5.13	61.6	10.4	15	-			
	VES 7	2.61	3.9	22	4.6	60	7.8	9.2	-			
	VES 8	5.7	0.5	119	1.33	3.5	5.6	72	8.7	9.11	-	
	VES 9	20	1.45	7.11	7.2	64.2	9.36	11	-			
	VES 10	17	0.5	31.6	1.3	4.8	4.7	51	11	10.5	-	
	VES 11	35	2	5	7	67	8.7	13.5	-			
	VES 12	15	0.5	22	1.3	6.4	7	81	8.7	15	-	

*(ρ) is a true resistivity & (h) is a thickness.

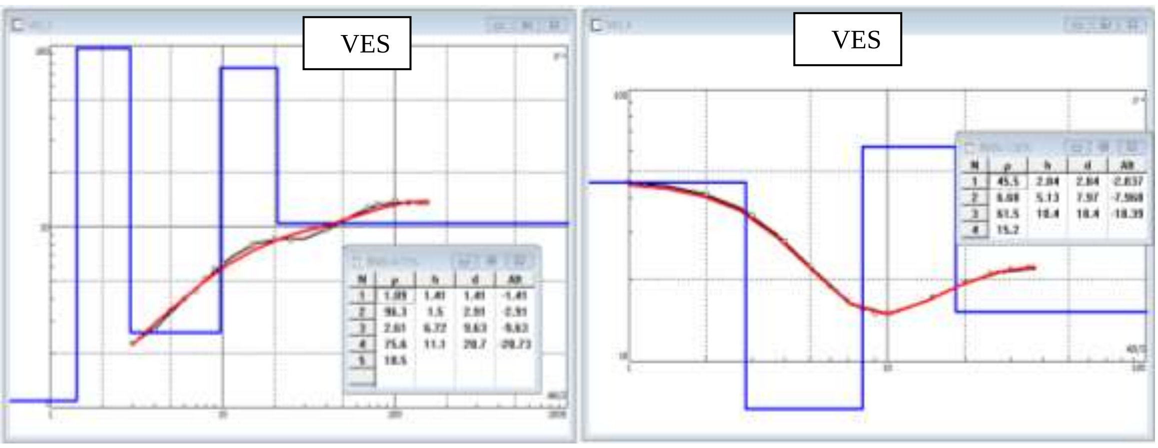

Fig. (6): Shows an example of the interpreted VESs using the IPI2win program, VES 3 of the Schlumberger array, and VES 6 of the Wenner array.

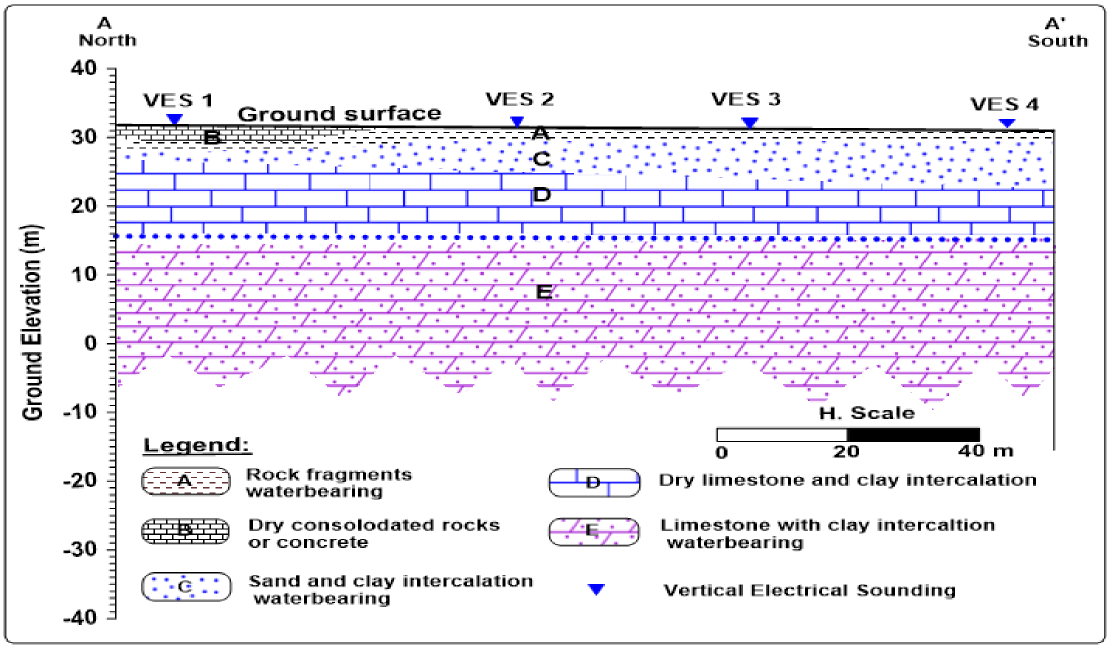

Fig. (7): Shows the 2D geoelectrical cross-section passing through the sites of VESs No. 1–4 using the Schlumberger array.

2D ERT

Thirteen 2D ERT profiles were inverted to generate a model for the subsurface distribution of electrical resistivity using Res2Dinv software, where the exploration depth reached approximately 20 meters (Figs. 9 and 10). The interpretation of these profiles is as follows:

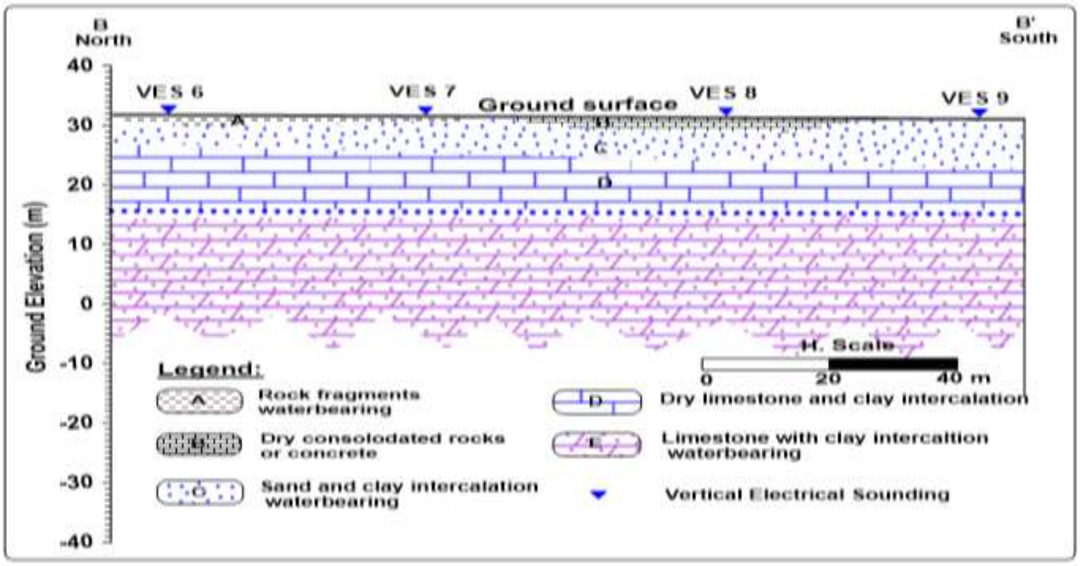

Fig. (8): Shows the 2D geoelectrical cross-section passing through the sites of VESs No. 6-9 using the Wenner array

Profiles in S-N direction: Seven geophysical two-dimensional resistivity profiles from south to north show the presence of three zones (Fig. 9). The first zone has a low resistivity range of 2-10 ohm.m and represents the leakage water-bearing layer. It is clearly visible, as it extends for a long distance and seems to connect to the groundwater in the northern and southern parts. Also, it appears in separate areas as lenses linked to the groundwater. The second zone represents medium resistivity values ranging from 10 to 50 ohm.m which represents the layer of limestone bearing groundwater and appears in the first and second profiles in the form of a broken layer in some places where it water connects to groundwater at depths ranging from 15-20 meters. the third zone with high resistivity values > 80 ohm.m, represents dry limestone or concrete bases and appears in the form of patches in some profiles. It appears on the surface in profiles 1, 4, and 5 as concrete bases and foundations. While in profiles 2, 4, 5, 6, and 7 at a distance of 60 meters in the form of a widget.

Profiles in E-W direction: Six profiles from east to west are perpendicular to the profiles from north to south (Fig. 1), and they also present three zones, with the first zone having a small resistivity with a range of 2–10 ohm.m. that represents the upper wastewater with a large extension in profiles 8 and 9 (Fig. 10). Profiles in this zone also show patches that are connected to the groundwater in some locations. The second zone has a medium resistivity with a range of 11–80 ohm.m. that may be related to the limestone bearing water; it appears in profile 8 and even larger in profiles 10-13 and disappears in profile 9. The third zone has high resistivity values >80 ohm.m., which represents the dry limestone and concrete bases. It appears in profiles No. 9, 10, 11, and 13 at the surface, representing some of the concrete bases and rooms. It also appears at the bottom of profiles 8-12 as that could be the dry limestone layer.

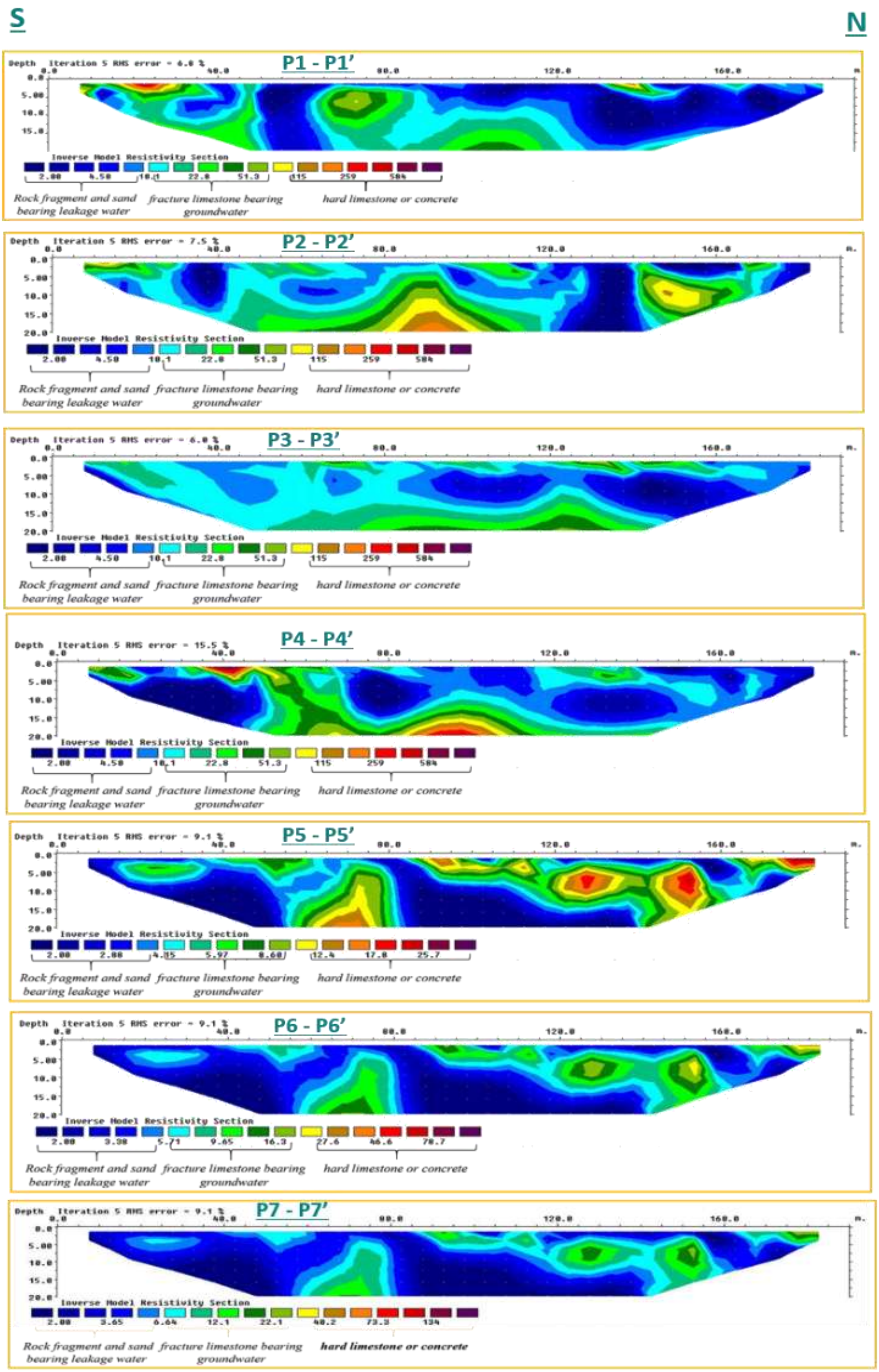

Fig. (9): Model resistivity section of the seven ERT profiles from P1 to P7 in the S-N direction.

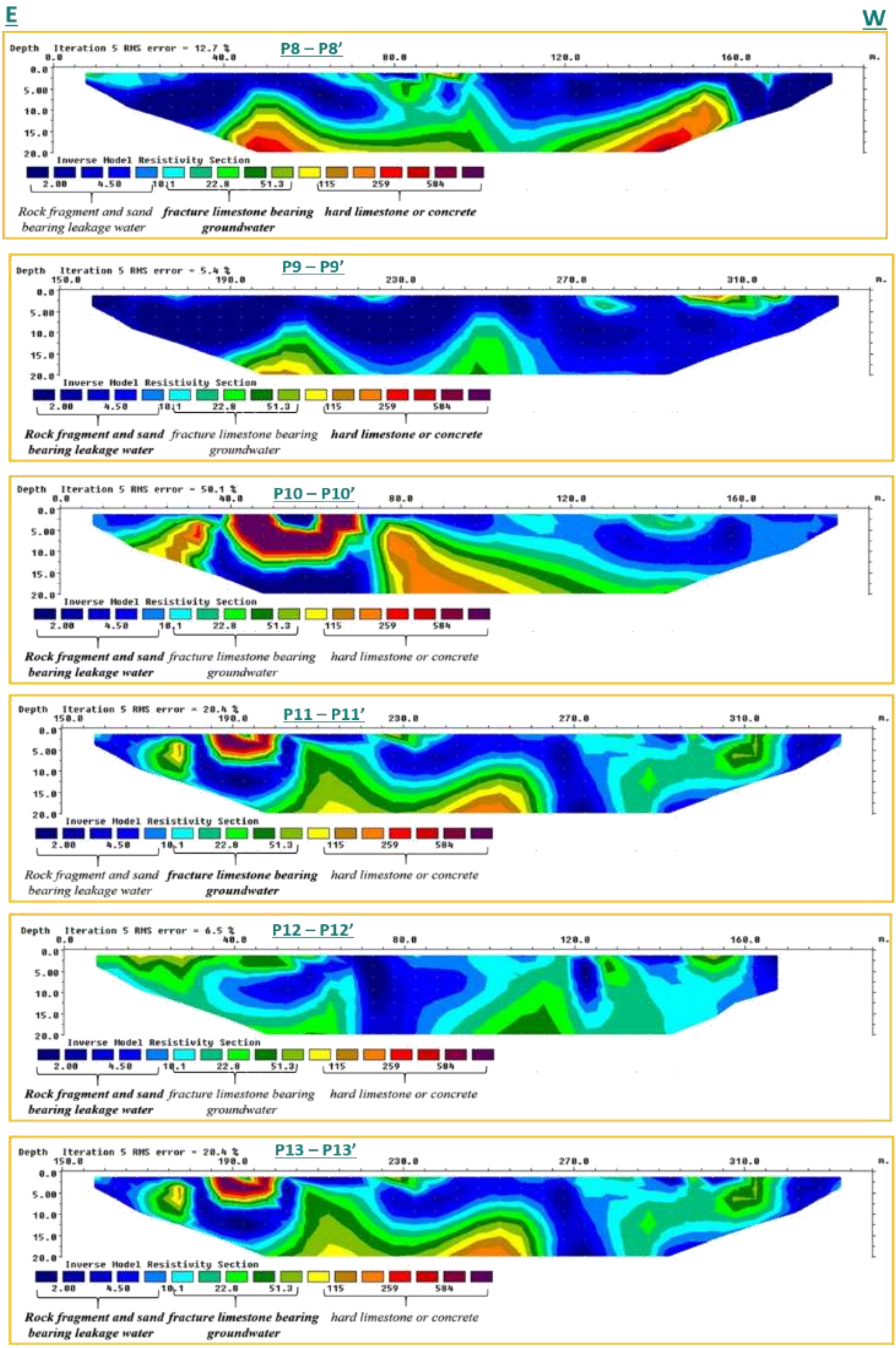

Fig. (10): Model resistivity section of the six ERT profiles from P8 to P13 in the E-W direction

Conclusion

Twelve VESs and thirteen 2D electrical resistivity tomography profiles carried out along the El Madabigh area to investigate the suitability of the area for engineering construction purposes, and the relation between the upper leakage contaminated water and groundwater have revealed the pattern of resistivity variations within the study area. Each profile represents the true subsurface resistivity distribution with depth as cross sections in the inverse models' results. The models display a variety of resistivity zones with both relatively low and high resistivity. That could be distinguished into four zones, as the first zone has a wide resistivity range and is interpreted as rock fragments and sand-bearing leakage water, in addition to dry consolidated rocks or concrete. The second zone has intermediate resistivity values that could be sand with clay intercalation. The third zone shows high resistivity values that could be hard limestone with clay intercalation. The fourth zone shows low to moderate resistivity values that may represent fractured limestone-bearing groundwater intercalated by clay. It was observed that the resistivity changes randomly in both horizontal and vertical directions, which is explained as due to high infiltration transports of contaminated materials downward along the inhomogeneity formed by human activity in the studied area. The nature of the non-cohesive surface soil and fractured subsurface layers help in direct or indirect contact between contaminated water seeping from the surface to groundwater.

Recommendations

The authors recommended a redistribution of the reinforced concrete columns according to thickness and the existence of the fractured layer revealed by this geoelectric study. It is also proposed to carry out an extensive experimental measurement of the water pollution type in the area.

Statements and Declarations

Data availability: This manuscript has no associated data.

Competing interests: The authors report there are no competing interests to declare.

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فحص الموقع للأغراض الهندسية باستخدام التقنيات الجيوفيزيائية بمنطقة المدابغ، القاهرة، مصر

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يعد فحص المواقع للأغراض الهندسية أمرًا أساسيًا لتحديد الظروف تحت السطحية لمواقع البناء المقترحة. توفر تطبيق تقنيات المقاومة الجيوفيزيائية أحادية وثنائية الأبعاد بيانات مفيدة حول حالة الطبقات التحت سطحية. جدير بالذكر أن منطقة الدراسة هى منطقة تحتوي على ملوثات سطحية و بعض الكهوف، بالإضافة إلى بعض المياه القريبة من السطح الملوثة من مصدر غير معروف. تهدف هذه الدراسة إلى التعرف على التتابع الصخري وتحديد المياه الجوفية والمياه الملوثة المتسربة من السطح والتأكد من ملائمة الموقع للإنشاءات الهندسية باستخدام طريقة المقاومة الكهربائية. تم إجراء اثني عشر جسة جيوكهربية رأسية، تشمل سبعة جسات باستخدام طريقة فينر والخمسة الأخرى باستخدام طريقة شلمبرجير. كما تم إجراء شبكة مكونة من ثلاثة عشر قطاعاً للمقاومة ثنائية الأبعاد تشمل ستة قطاعات موازية لسور مجرى العيون وسبعة متعامدة عليها، على طول موقع الدراسة باستخدام توزيع فينر. تمت معالجة بيانات المقاومة الأحادية والثنائية الابعاد باستخدام برنامج ipi2win و Res2Dinv. كما لوحظ أن هناك ارتباط بين النتائج الجيوكهربائية والحفر المتوفرة والبيانات البيزومترية ، الأمر الذي يعطي رؤية محدثة لمنسوب المياه الجوفية، ويحدد الاتصال بين المياه المتسربة الملوثة والمياه الجوفية من خلال قطاعات المقاومة ثنائية الأبعاد للمنطقة الملوثة، بالإضافة إلى عدم ملائمة الموقع للإنشاءات الهندسية بهذه الحاله.