ISSN: 1687-1251

Egyptian Society of Applied Petrophysics

Journal of Applied Geophysics (Cairo)

Journal home page: https://jag.journals.ekb.eg/

Original Article

# Study the Impact of Structural Geology on the Groundwater Aquifers Using Electromagnetic Survey - Wadi El Saieda - Western Desert - Egypt

Ahmed Nasr [1*]

[1] *Geophysical Exploration Department, Desert Research Center, Cairo, Egypt.*

ARTICLE INFO

*Keywords*:

*Groundwater,*
*Wadi El Saieda,*
*Transient Electromagnetic,*
*Geoelectric*

This study investigates the groundwater potential in Wadi El Saieda, Egypt, using geoelectric techniques to identify aquifer zones and assess water quality. Located in Egypt's Western Desert, the region is crucial for agricultural expansion due to its significant water and land resources. A transient electromagnetic method was used to measure nineteen geoelectric soundings, revealing the presence of multiple geoelectric layers, including two primary water-bearing strata. The identified water-bearing zones exhibit varying resistivity values, which correlate to subsurface lithological structures such as sand, silt, and clay layers. The results provide credence to the idea that this potential area can benefit from sustainable management of water resources and agricultural growth. The study highlights two significant aquifers, characterized by good groundwater quality, especially in the eastern regions of the study area. The geoelectric data, combined with geological interpretations, suggest potential sites for groundwater extraction, thereby supporting sustainable agricultural development in the region. Furthermore, the identification of fault structures impacting groundwater flow provided insights into the hydrogeological framework of the area.

*Corresponding author: Ahmed Nasr, e-mail: dr_a_nasr86@yahoo.com*

## 1. Introduction:

Egypt spans approximately one million square kilometers, the majority of which consists of desert, with only 4% of its area cultivated in the Nile Valley and Delta. With limited natural resources and a rapidly growing population, there is an urgent need to expand agricultural land to address food security challenges. To meet this demand, Egyptian authorities have developed a strategy to enhance agricultural productivity both horizontally and vertically. Supported by national and international agencies, significant efforts and investments are currently underway to bring new lands under cultivation **(Kouider et al., 2023).**

One area identified for agricultural expansion is the Wadi El Saieda region in the Western Desert, known for its water and land potential. Wadi El Saieda is located between longitudes 32° 10’ and 33° 00’ E and latitudes 24° 50’ and 25° 25’ N, covering approximately 500,000 feddan, with the study area itself encompassing about 370,000 feddan. The region is bordered by El-Besaliya village to the north, El Galaba Blain to the south, Idfu and the Nile to the east, and the Sin El-Kaddab plateau to the west (Figure 1). A variety of scientific techniques is necessary to assess the groundwater resources and their controlled structures without the use of costly excavation **(Mohamed et al., 2023).** For instance, geophysics serves as a device for assessing the condition of water and mapping the groundwater resource. Some geophysical methods, when applied to groundwater, have demonstrated greater success than others. Gravity, magnetics, seismic, electrical, and electromagnetic methods are among the methods listed **(Reynolds, 2011).**

Researchers have successfully used potential methods such as magnetics and gravity to map the large-scale basin features and their structures **(Wiederhold et al., 2021).** Seismic techniques have been employed to map both bedrock and fractured systems **(Gonzales et al., 2016).** Electrical and electromagnetic technologies are the most effective for groundwater studies and structure-controlled recharge **(George et al., 2017).** This is because the hydrogeological characteristics of a formation, including rock porosity and permeability, could be associated with electrical resistivity signatures **(Eke and Igboekwe, 2011).** Several of these geophysical methods have since been employed for groundwater characterization; however, the electrical and electromagnetic (EM) methods have once again yielded the most favorable results **(Mohallel et al., 2024)**.

This research aims to utilize the EM method to identify potential groundwater zones within the study area. In this study, the EM method is used to find and map aquifers by finding differences in electrical resistivity between formations that hold water and those that do not. It helps in determining the depth, extent, and quality of groundwater. It also aids in locating faults and fractures that affect groundwater flow, supporting optimal borehole drilling, and monitoring groundwater recharge. It provides critical insights into subsurface conditions for effective groundwater exploration and management.

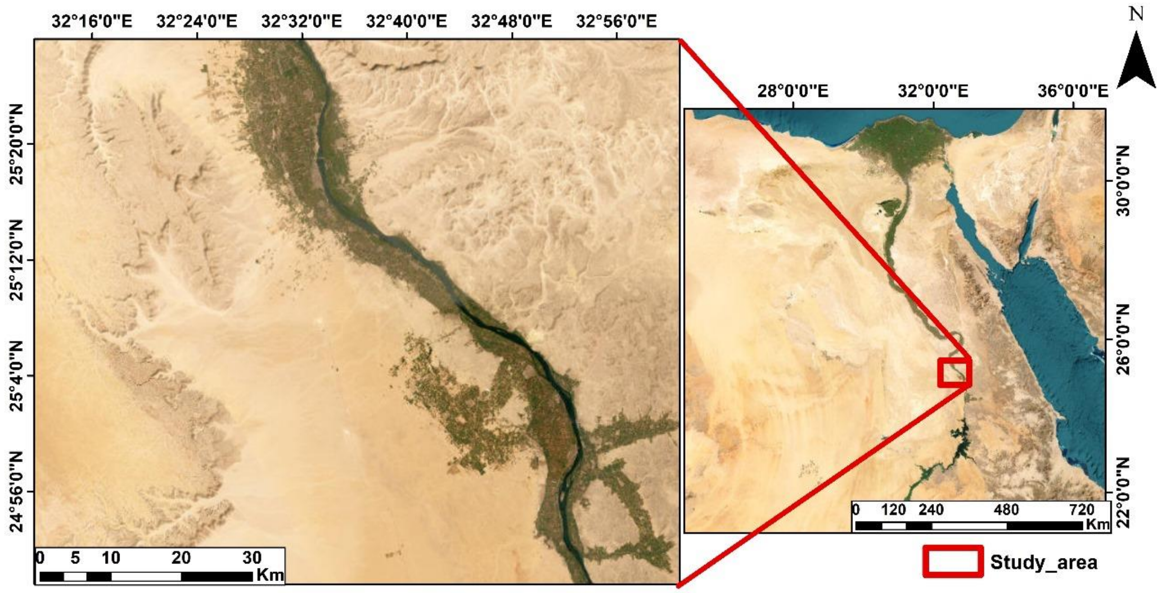


**Figure 1:** Satellite image-based location map for the Wadi El Saieda area.

## 2. Geologic Setting

### 2.1. Geomorphology

The interpretation of a satellite image considers one of the most common, versatile, and economical forms of advanced techniques, and can be used to identify geomorphic units in the Wadi El Saieda area. **UNDP/UNESCO/NARSS/EGSMA (2002)** used a geomorphological map of Aswan to identify and delineate the geomorphic units, while **Mohallel (2024)** conducted field investigations. The results delineated the primary geomorphic components and subunits of the examined region, organized from west to east (Figure 2): the structural plateau, the Bajada plain, the eroded Nubian ancient surface (peneplain), and the Nile alluvial plain.

The structural plateau is situated in the western section of the mapped region and ascends to over four hundred meters above sea level (ASL). Hard limestone constitutes the substratum of the plateau's surface. An escarpment facing the Nile Valley forms the eastern boundary of this plateau. Numerous Wadis, oriented eastward towards the Nile Valley, sever the escarpment face. Young deposits cover the channels of these Wadis almost entirely. Wadi deposits are thus usually poorly sorted gravel and sand. Eolian processes often rework these sediments, according to **Mohamed and Sylvain (2007).** Wadis specifically refers to Wadi El-Rimidin in this context.

The Bajada plain starts on the foot slopes of the escarpment face, i.e., at the base of the waxing slope. Two distinct types of the Bajada plain exist: a higher colluvial plain and a lower pavement plain. The coarse texture of the higher colluvial plain originates from the plateau and the escarpment. It has elevations ranging between 266 and 337 meters ASL. Locally, shifting sand covers the surface. One hypothesis regarding fragipan formation posits that soil smearing occurs during the colluvial process, resulting in materials sealing the interface between the mobile soil and the immobile substrate beneath it. Subsequent alterations in the landscape may facilitate the downward movement of material, allowing colluvium to safeguard ancient sites **(Thomas, 2007).** A lower plain comprised of medium-textured material is also derived from the plateau. The elevation varies from 209 to 272 meters ASL. Additionally, shifting sand covers part of the surface. The prevailing idea posits that they are created through the progressive erosion of sand, dust, and other fine-grained materials by wind and sporadic rainfall, resulting in the retention of only bigger fragments. However, once the pavement forms, it can act as a barrier to further erosion **(Grotzinger et al., 2007),** so this process does not continue indefinitely.

The term "Peneplain" denotes the eroded ancient Nubian surface. Water and wind erosion contribute to its formation. The creation of the peneplain erodes the upper surface, resulting in the exposure of underlying hard rocks **(Planation Surface, 2008).** This terrain encompasses a sizable portion of the elevated plateaus next to the Nile Valley. The Nubian sequence's moist brown sandstone strata underlying it. The wind significantly erodes the surface, while shifting sand obscures it. The elevation is approximately 288 meters ASL. This terrain creates local cliffs that overlook the Nile floodplain.

The Nile alluvial plain is characterized by the ancient Nile terraces and the contemporary Nile floodplain, with the former extending far to the west of the latter. The area is underlain by ancient Nile alluvial sediments, rising to 196 meters ASL and sloping from west to east. The current Nile floodplain is underlain by deposits of Nile silt, situated in the lowest section of the plotted region. The elevation is ninety-five meters ASL (Figure 2).

### 2.2. Geology

The region under study lies on Nubian sandstone, a formation researched by **Said (1962)** and others, such as **Shukri and Ayouty (1953).** The thickness of this formation ranges from 20 to 83 m, primarily consisting of false-bedded sandstone and quartzite beds at the plateau's surface. The area also features river terraces covered by fluvial sediments, sloping towards the Nile, with these terraces dating back to the late Tertiary and early Quaternary. The lower part of the Nubian sandstone, resistant to weathering, forms large plains, and likely belongs to the Upper Cretaceous. Additionally, the formation is capped by a thin layer of lower Eocene limestone.

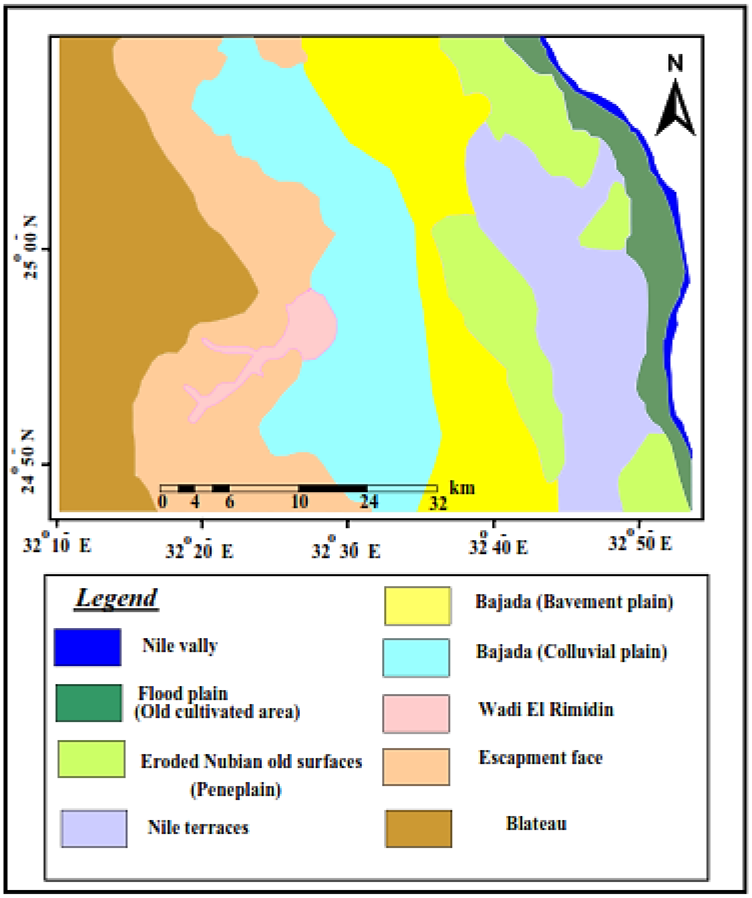


**Figure 2:** Figure 2: The study area's geomorphologic map, after Mohallel 2024.

**USAID's Aswan geological map (1978)** (Figure 3) shows a geological succession of Quaternary and Tertiary rocks from the Cenozoic Era and Cretaceous rocks from the Mesozoic Era (Table 1). The area primarily consists of Quaternary and Tertiary deposits, with lithostratigraphic units descending from the Quaternary to the Cretaceous, as the following: Pleistocene Unit: Composed of older Nile deposits (Qena Formation), predominantly quartz sand and gravel, with a thickness of 32 m (exposed) to 120 m. This represents the primary Quaternary aquifer in the Nile Valley. The Pliocene Unit (Tertiary) comprises marine deposits and sand layers over 50 m thick, lying above Eocene carbonates and acting as an aquiclude above the Quaternary aquifer. The Lower Eocene Unit (Thebes Formation) consists of karstified limestone, marl, and flint nodules, with a carbonate layer reaching 2000 m in thickness in the subsurface and optimally exposed to the west. The Paleocene Unit, primarily shale with interbeds of chalk and phosphate (Dakhla Formation), serves as an aquiclude separating the Eocene carbonate aquifer from the Nubian aquifer and is about 400 m thick. The Cretaceous Unit includes Upper Cretaceous chalk, limestone, and dolomite, with

Lower Cretaceous Nubian sandstone layers reaching 300 m in exposed areas and over 1000 m in the subsurface.

**Table (1): Stratigraphy of Wadi El Saieda area.**

| Era | Age | | Formation |
|---|---|---|---|
| Cenozoic | Quaternary | Pleistocene | Older Nile deposits:<br>Qena formation |
| | Tertiary | Pliocene | Marine deposits |
| | | Lower Eocene | Thebes formation |
| | | Paleocene | Dakhla formation |
| Mesozoic | Cretaceous | Upper Cretaceous | Dakhla formation |
| | | Lower Cretaceous | Nubia group |

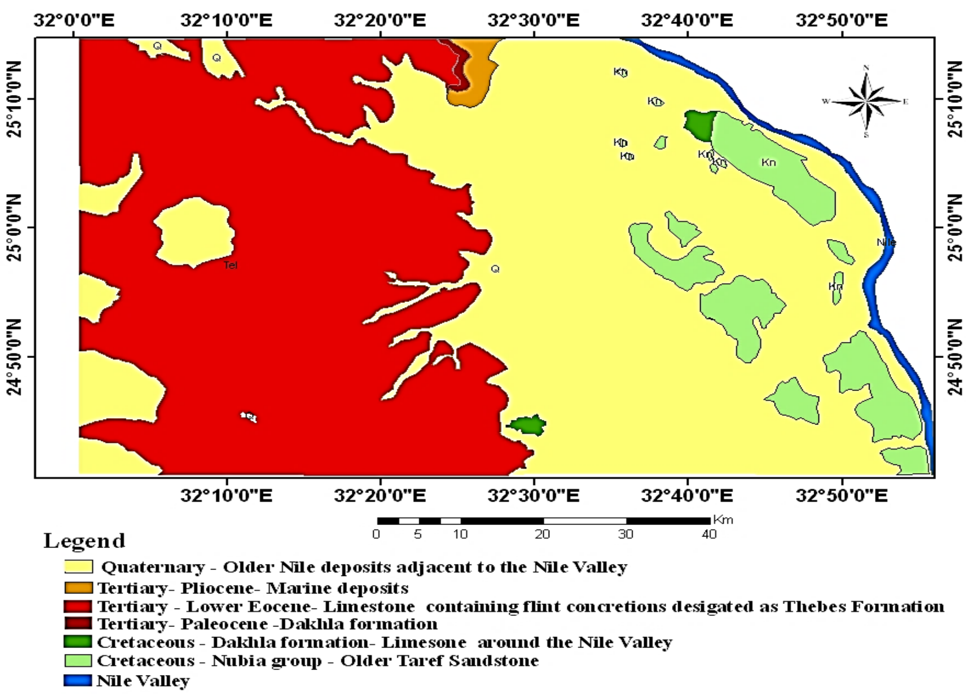


**Figure 3:** A detailed geologic map of the study area and its vicinities, after USAID 1978.

## 3. Materials and methods

The Transient Electromagnetic Method (TDEM) was employed to investigate groundwater potential in the study area due to its capability for deep subsurface exploration. TDEM operates on the principle of electromagnetic induction, where a primary magnetic field, generated by passing current through a loop of wire on the surface, induces secondary currents in the subsurface. These secondary currents, in turn, produce magnetic fields that decay over time, which are recorded by a receiver coil. The rate of decay of these fields provides information about the resistivity of subsurface layers **(Fitterman & Stewart, 1986).**

We employed the TDEM method for reconnaissance surveys to identify the geoelectric strata, particularly the deep layer. The current investigation performed 19 TDEM measurements (Figure 4). A straightforward coincident loop arrangement, wherein the identical loop transmits and receives signals, was utilized **(Nabighian, 1979).** A transmitter loop was laid out on the ground and connected to a power source to generate the primary electromagnetic field. The receiver coil was positioned to measure the decaying secondary fields once the primary field was switched off. Multiple measurement points were selected across the study area to ensure adequate coverage.

At certain stations, the field procedures were conducted two or three times utilizing a TEM-FAST 48 instrument, employing a single square loop configuration (functioning as both transmitter and receiver) measuring 200 by 200 m, with a current strength varying from 1 to 4 A. This acquisition strategy delivers numerous quantified data sets at each location. Data sets with the optimal signal-to-noise ratio are selected for subsequent processing and analysis. The collected data was processed to produce resistivity profiles, which were interpreted to delineate the subsurface geological structure. In particular, resistivity contrasts between dry formations and water-bearing layers were used to identify potential aquifers **(Baawaain et al., 2018).** The method's deep penetration enabled the identification of deeper aquifers that might be missed by shallow surveys **(El-Kaliouby & Abdalla, 2015).**

We initially performed an iterative inversion of the individual TDEM data sets using Zond TDEM 1D software (version 5.2, 2001-2016). The correlation between the measured and theoretical data computed during the forward calculations determines the selection of a suitable initial model for each measured dataset. The existing geological data was utilized to create preliminary models for a one-dimensional inversion of the TDEM data (**Ohwoghere et al., 2020**). Subsequently, trial modeling was employed on the analogous data sets to produce a unified model that accommodates both TDEM and borehole data sets. The rather dense collections of geological and well data govern the superficial aspects of the models. Geological, aeromagnetic, and TDEM data, especially the TDEM data, delineate the deeper aspects of these models, offering the most precise information **(Mohamed & El-Qady, 2023).**

TDEM's non-invasiveness, ability to penetrate deep layers, and sensitivity to resistivity contrasts made it suitable for the area's complex geological conditions. It also proved effective in minimizing noise from cultural interference and surface variations **(Farquharson et al., 2023).** This methodology allowed for a detailed understanding of the subsurface, identifying the depth and extent of aquifers and other geological features influencing groundwater distribution **(US EPA, 2023).**

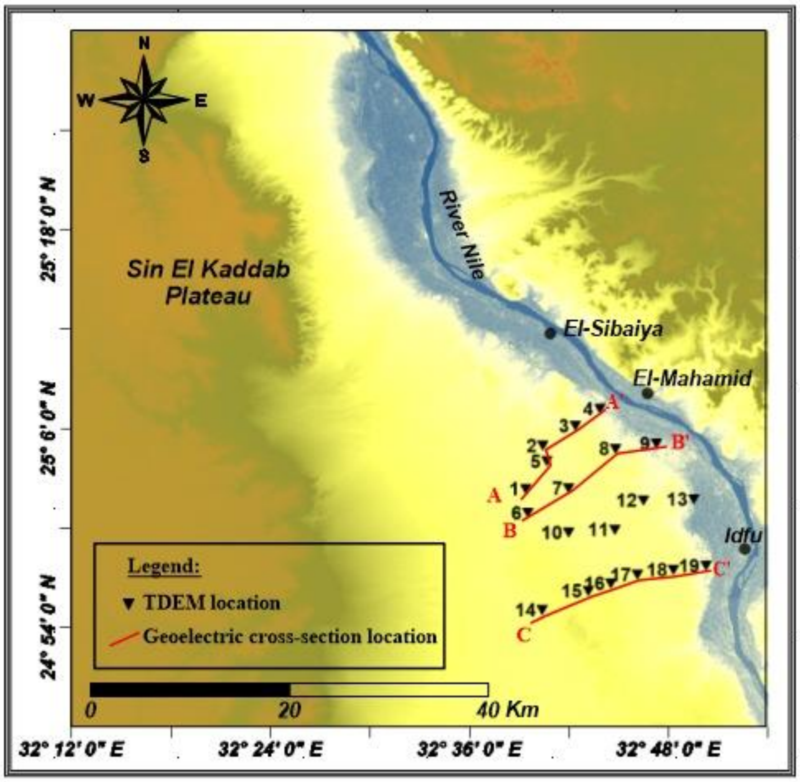


**Figure 4**: Show the locations of TDEMs and geoelectric cross sections.

## 4. Results and discussions

The initial phase in interpreting transient electromagnetic sounding data involves addressing the inverse problem. The inversion of 1D TDEM data entails forecasting measurement outcomes (the actual resistivity of layers and their respective thicknesses) derived from a preliminary model. The preliminary model can be developed based on regional geology and the lithological descriptions and well data from existing wells in the study area and its vicinity. The geological data aids in correlating the anticipated resistivity characteristic with its associated lithology. The software, Zoned TDEM1, inverted the TDEM sounds. The geological data obtained from wells was utilized to parameterize the initial model required for the inversion procedure. The root mean square error (RMS) between the observed and estimated parameters is recorded as being below 10% for all TDEM soundings in the research region.

**Geoelectrical successions**

The one-dimensional modeling approach is insufficient to capture the complex lateral and vertical resistivity variations needed for a detailed lithologic characterization of the area. Therefore, the results from the TDEM and VES inversion, including resistivities and layer thicknesses, have been presented as two-dimensional cross-sections for better visualization. These include three cross-sections (Figures 5-7), provide a clearer understanding of the lateral and vertical extent of the subsurface layers along the west-east direction, correlated with the corresponding geological rock units. The geoelectric cross-sections clearly depict the primary geological features of the study area and highlight the structural relationships between two distinct groups of stratigraphic layers. The cross-sections also reveal the presence of two normal faults (F1-F2), oriented NW-SE and NE-SW, which influence the region's subsurface structure. These faults form the framework for the basin that hosts river sediments. The TDEM data inversion identified a total of six distinct geoelectric layers within the study area, further refining the geological understanding of the region.

The first geoelectrical layer (A), correlated with geological and nearby borehole data, signifies the arid Quaternary composed of silt and fine sand. It achieves resistivity values between 54 and 70 Ohm.m and thicknesses from 20 to 45 m. The second geoelectrical layer (B) attains resistivity values that range from 60 to 200 Ohm.m. and it represents the dry quaternary of gravels and sand and thicknesses from 10 to 30 m. The third geoelectrical layer (C), represents lower resistivity values than the above layers, which attain resistivity values ranging from 15 to 35 Ohm.m. Water-bearing gravels, sand, and silt from Quaternary deposits compose this zone, representing the first waterbearing layer. The thickness of this layer ranges from 10 to 35 m. The fourth geoelectrical layer (D) was observed at the surface of the western part of the research area. It represents dry sandstone with clay intercalation. It attains resistivity values that range from 44 to 66 Ohm.m. and thicknesses from 11 to 25 m. The fifth geoelectrical layer (E) represents a second waterbearing layer that has low resistivity values ranging from 25 to 35 Ohm.m. This layer is composed of sandstone that has been intercalated with clay. The thickness of this layer ranges from 15 to 65 m. The six geoelectrical layer (F) is the final layer of the geoelectric layers that were observed. It has a low resistivity value ranging from 3 to 10 Ohm.m. and is composed of clay.

**Table (2): Resistivity ranges (Ohm.m), thickness ranges (m), and suggested geological interpretation (lithology) for each geoelectric layer of Wadi El Saieda area.**

| Layer | Res. ranges (Ohm/m) | Thickness ranges (m) | Suggested geological interpretation (Lithology) |
|---|---|---|---|
| A | 54-70 | 20-45 | Dry Nile silt and fine sand |
| B | 60-200 | 10-30 | Dry gravels, sand, and silt of Quaternary deposits |
| C | 15-35 | 10-35 | Waterbearing gravels, sand, and silt of Quaternary deposits |
| D | 44-66 | 11-25 | Dry sandstone with clay intercalation |
| E | 25-35 | 15-65 | Waterbearing sandstone with clay intercalation |
| F | 3-10 | - | Clay |

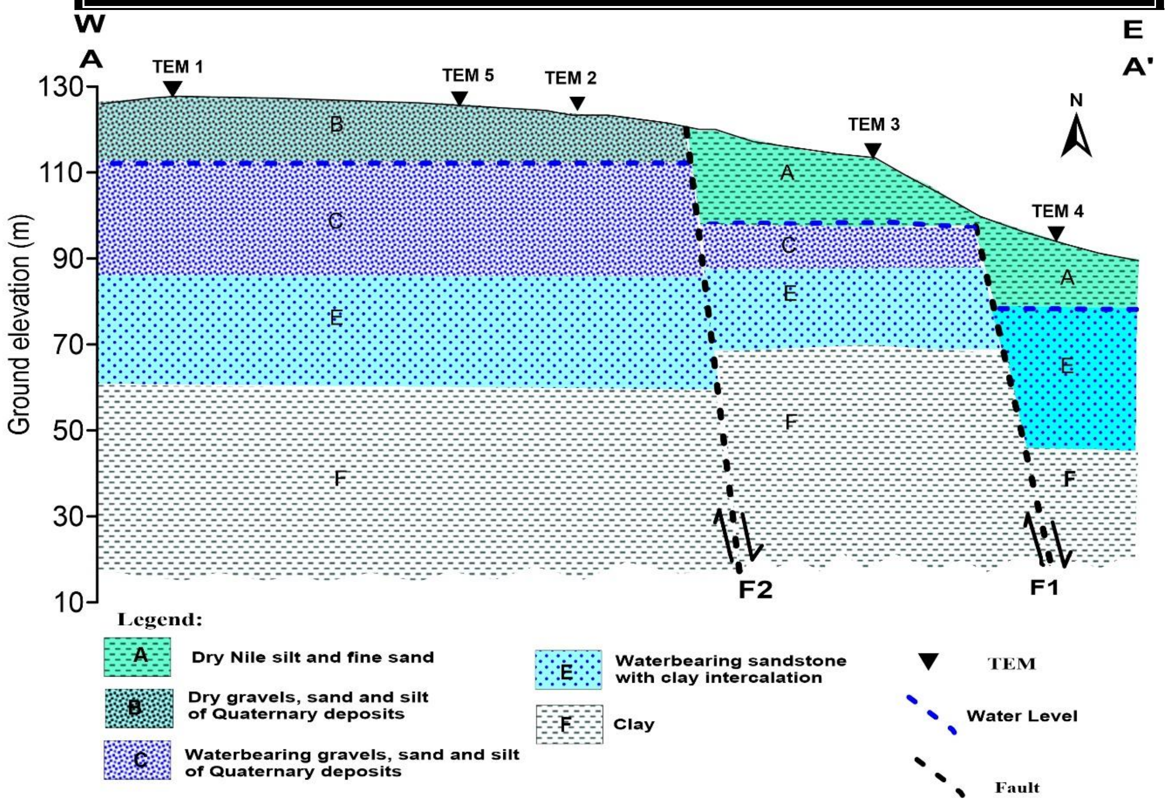


**Figure 5:** Geoelectrical cross-section A-A'.

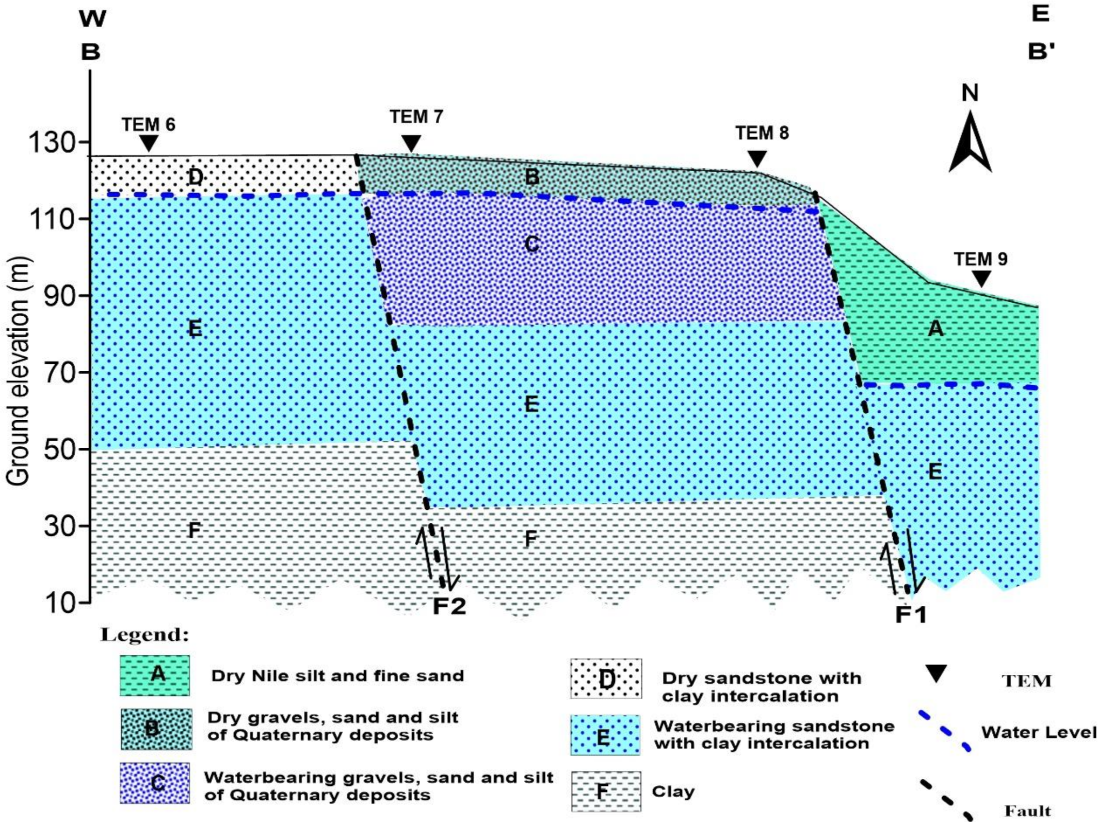


**Figure 6:** Geoelectrical cross-section B-B'.

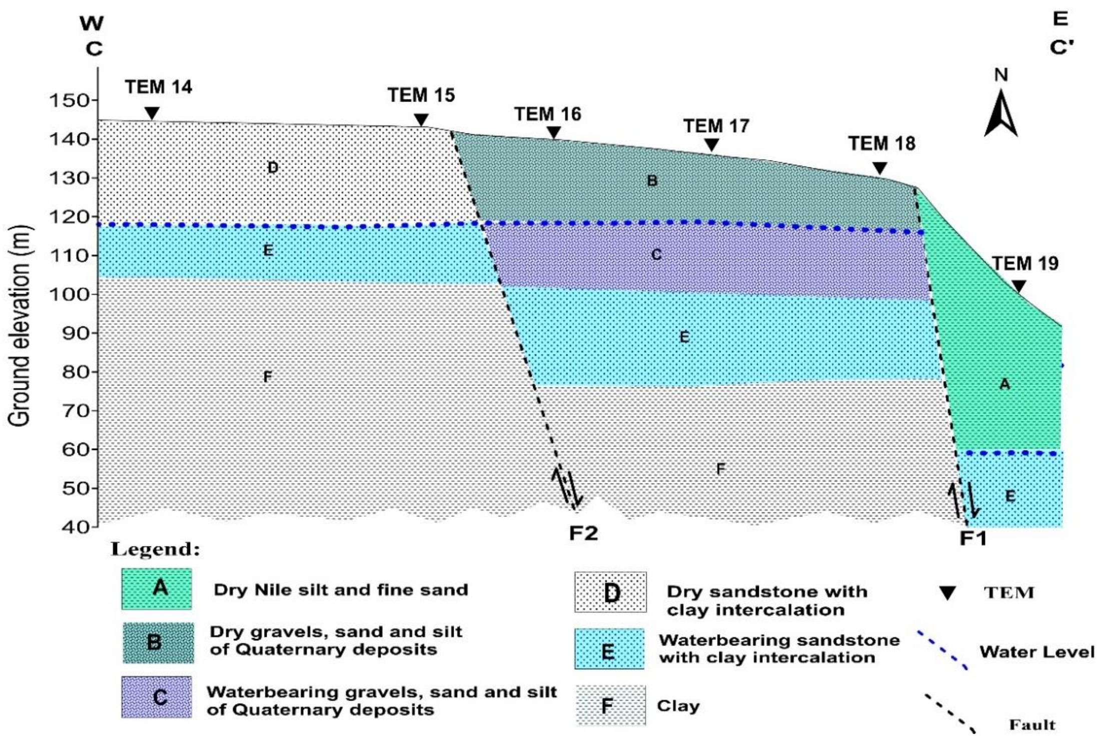


**Figure 7:** Geoelectrical cross-section C-C'.

The water-bearing geoelectric zones (C and E): The first detected geoelectrical water bearing zone (C) is not observed at all geoelectrical sounding stations, especially at the southwestern part of the study area. The interpreted resistivity values of this zone at different sounding stations (15–35 Ohm.m) with decreasing value towards southwestern direction. All geoelectrical sounding stations in the study area observe the second detected geoelectrical water bearing zone (E). The interpreted resistivity values of this zone at different sounding stations (25–35 ohms) are also decreasing in the southwestern direction. The high relative resistivity values of the second waterbearing layer are attributed to the coarse sand and lower clay content, which exhibit good groundwater conditions in terms of both quality and quantity. As a result, this zone is considered optimal for drilling wells and tapping.

## 5. Conclusion

This study assesses groundwater potential in Wadi El Saieda, Egypt, using geoelectric techniques to identify aquifers. Located in Egypt's Western Desert, the region is crucial for agricultural expansion. Nineteen TDEM soundings were conducted, revealing multiple geoelectric layers, including two primary water-bearing strata. The resistivity data, combined with geological information, identified two significant aquifers, with better groundwater quality in the eastern part of the study area. The first aquifer is localized, while the second is more extensive, making it suitable for groundwater extraction. The spatial variation in resistivity reflects differences in subsurface lithology, particularly sand, gravel, and clay content, which influence groundwater storage and quality. The study also identified two major infrared fault systems that control groundwater flow and recharge. These faults impact the structural framework of the area, emphasizing the importance of considering geological structures in groundwater management. The findings support sustainable water resource management and agricultural development in this promising region. By pinpointing optimal locations for groundwater extraction, particularly in the eastern zone, the study aids in Egypt's efforts to expand cultivable land. The geoelectric methods used offer a non-invasive, effective approach to explore groundwater resources in arid environments.

Overall, the study provides crucial insights into the hydrogeological framework of Wadi El Saieda and offers practical solutions for groundwater exploration, contributing to Egypt's food security and agricultural growth goals.

## References

**Baawaain, M. S., Al-Futaisi, A. M., Ebrahimi, A., & Omidvarborna, H. (2018).** Characterizing leachate contamination in a landfill site using Time Domain Electromagnetic (TDEM) imaging. Journal of Applied Geophysics, 151, 73-81.

**Eke, K. T., and Igboekwe, M. U. (2011).** Geoelectrical Investigation of Groundwater in Some Villages in Ohafia Locality, Abia State, Nigeria. British Journal of Applied Science & Technology 1(4), pp. 190-203.

**El-Kaliouby, H., & Abdalla, O. (2015).** Application of time-domain electromagnetic method in mapping saltwater intrusion of a coastal alluvial aquifer, North Oman. Journal of Applied Geophysics, 115, 59-64.

**Farquharson, C. G., Hu, X., Huang, Q., Li, X., Li, J., Xue, G., & Yin, C. (2023).** Advances in transient electromagnetic methods. Journal of Geophysics and Engineering, 20(6), 1305-1307.

**Fitterman, D.V. and Stewart, M.T., (1986)**. Transient Electromagnetic Sounding for Groundwater. Geophysics, 51, 955-1005.

**George, N.J., Atat, J.G., Umoren, E.B., Etebong, Isong, (2017).** Geophysical exploration to estimate the surface conductivity of residual argillaceous bands in the groundwater repositories of coastal sediments of EOLGA, Nigeria, NRIAG Journal of Astronomy and Geophysics, vo. 1174- 183

**Gonzales, A., Dahlin, T., Barmen, G., Rosberg, J., E., (2016).** Electrical resistivity tomography and induced polarization for mapping the subsurface of alluvial fans: a case study in Punata (Bolivia). Geosciences 6:51.

**Grotzinger, *et al.* (2007).** Understanding Earth, fifth edition. Freeman and Company. NY, NY. 458-460 *http:// www.sciencedirect.com/science.*

**Kouider, M. H., Dahou, M. E. A., Nezli, I. E., Dehmani, S., Touahri, A., Séverin, P., & Antonio, P. B. (2023).** Fractures and lineaments mapping and hydrodynamic impacts on surface and groundwater occurrence and quality in an arid region, Oued M'ya basin–Southern Sahara, Algeria. *Environmental Earth Sciences*, *82*(22), 538.

**Mohallel, S. A. (2024).** Hydrogeochemical tracers to assess the groundwater in El Saieda Basin, western desert, Aswan, Egypt. Applied Water Science, 14(7), 157.

**Mohamed Achitea and Sylvain Ouillonb (2007).** Suspended sediment transport in a semiarid watershed, Wadi Abd, Algeria (1973–1995). Journal of Hydrology Volume 343, Issues 3-4, 187-202.

**Mohamed, A. A., & El-Qady, G. (2023).** Hydrogeophysical and structural investigation using VES and TDEM data: A case study at El-Nubariya–Wadi El-Natrun area, west Nile Delta, Egypt. NRIAG Journal of Astronomy and Geophysics, 6(2), 209-220.

**Mohamed, A., Alarifi, S. S., & Abdelrady, A. (2023).** Sedimentary cover and structural trends affecting the groundwater flow in the Nubian Sandstone Aquifer System: inferences from geophysical, field and geochemical data. Frontiers in earth science, 11, 1173569.

**Nabighian, M. N. (1979).** Quasi-static transient response of a conducting half-space—An approximate representation. Geophysics, 44(10), 1700-1705.

**Ohwoghere-Asuma, O., Chinyem, I. F., Aweto, K. E., & Iserhien-Emekeme, R. (2020).** The use of very low-frequency electromagnetic survey in the mapping of groundwater condition in oporoza-gbamaratu area of the Niger Delta. *Applied Water Science*, *10*(7), 1-14.

**Planation surface (2008).** In Encyclopædia Britannica. Retrieved October 11, 2008, from Encyclopædia Britannica Online: http://www.britannica.com/ EBchecked/topic/ 462878/ planation-surface.

**Reynolds, J. M. (2011).** An introduction to applied and environmental geophysics. John Wiley & Sons.

**Said, R. (1962).** "The geology of Egypt.", Elsevier, Amsterdam, New York U.S., 377p. Publishing Co., the Netherlands.

**Shukri, N. M. and Ayouty, M. K. (1953).** The mineralogy of the Nubian sandstone in Aswan. Bull. Inst. Desert Egypt, 3 (2): 65-88.

**Thomas Madigan (2007).** "The Geology of the MNRRA Corridor", p. 26, National Park Service, Retrieved July 23, 2007, Retrieved from *"http://en.wikipedia.org/wiki/Colluvium"*

**UNDP/UNESCO/NARSS/EGSMA (2002).** Joint Project for Capacity Building of The Egyptian Geological Survey & Mining Authority and For the Sustainable Development of The South Valley and Sinai, Egy/97/011.

**US EPA. (2023).** Electromagnetic Methods: Time-Domain. Retrieved from EPA website.

**USAID (1978).** Geological Map of the Aswan Quadrangle, Ministry of Industry and Mineral Resources, The Egyptian Geological Survey and Mining Authority, Egypt.

**Wiederhold, H., Kallesøe, A. J., Kirsch, R., Mecking, R., Pechnig, R., & Skowronek, F. (2021).** Geophysical methods help to assess potential groundwater extraction sites. *Grundwasser*, *26*(4), 367-378.