Geoelectrical analysis for evaluating the groundwater characteristics of wadi El Madamud Area, Southeast Luxor, Egypt

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ABSTRACT
In this work, the totally 31 Vertical Electric Soundings (VESes) were carried out at wadi El Madamud, Southeastern Luxor city. These are processed and interpreted the forms of geologic models composed of five geoelectric layers of varying resistivities, lithologies, depths and thicknesses. They are surfacial unconsolidated dry silts, sands and gravels, consolidated silts, sandy gravels, sandstone and clays saturated with water, clay with unsaturated sand intercalations and chalky limestone with chert bands. The surficial layer, dry silts, sands and gravels layer (Quaternary) is cropped out on the surface of the whole area with a very small thickness range (0.5-2.2 meter (m.)) and average thickness 1.1 meters. The surficial layer, Unconsolidated wadi deposits composed of silts, sands and gravels which show the highest resistivity range (3073-90,581Ω.m.) with average value 27,968Ω.m. throughout the whole study area. The consolidated silt, sandy and gravels is the second geoelectric layer, which has decreasing resistivity values than the first layer. Thickness of the second geoelectric layer ranges from 1–14 meter. The third geoelectric layer is sandstone and clay saturated with groundwater, which has resistivity range from 4 to 1887 Ω.m. and average value 234Ω.m. and thickness range from 18 to 41 meters with average 21.3 meters. The main target is the shallow aquifer which represented in third geoelectric layer. The clay with unsaturated sandstone intercalation is forth geoelectric layer and has resistivity range from 11 to 10,700Ω.m. and thickness ranges from 44 to 83 m. The last geoelectric layer is the chalky limestone with chert band, having a wide resistivity range (264–37,045Ω.m.) with non-defined thickness. The thickness and true resistivity maps of the different layers and 2D geoelectric cross sections are generated for the represented layers to delineate their spatial distribution. The aquifer hydraulic characteristics; such as hydraulic conductivity and transmissivity within the salty aquifer, as well as the groundwater quality (salinity) are estimated, utilizing the true resistivity values acquired on the surface through the geoelectric resistivity survey.

1. Introduction
Geoelectrical resistivity is a vital tool of the geophysical investigations, which is significant at a large scale, mostly for reconnaissance phase of the feasibility procedure [1,3–6,8,9,11,12,16,21,23]. The vertical electrical sounding (VES) technique is applied to investigate nature, types lithostratigraphy (facies), civil engineering, geoenvironmental investigations and geometry of a shallow and deep aquifers.

In addition to interpreting the data specifically, the knowledge of the geological setting of the area is significant. The ability of geoelectrical investigation is to refer to the changes in the subsurface layers conditions by means of varying resistivities candidate then to be significant tools for the pre-investigation and production procedures [2,3]. However, it is not constantly potential to relate a resistivity variation to a specific rock condition or property. Evaluating the aquifer hydraulic characteristics is significant to solve several hydrogeological problems, while the electric anisotropy, hydraulic conductivity and transmissivity are playing a vital role in assessing the hydrogeological conditions.

The present study is objected to evaluate such aquifer hydraulic parameters, as, hydraulic conductivity and transmissivity of the studied section, as well as estimating the groundwater quality (salinity) from the acquired true resistivity values. Before performing the mentioned parameters, quantitative interpretation was carried out to determine the true resistivity and thickness of each layer, and represented them as 2D geoelectric cross sections and areal distribution maps.

2. Geology of the area
The study area is located on the alluvial plains of the Nile Valley (Figures. 1 and 2), which are surrounded by elevated structural plateaus capped by Eocene limestone (Thebes Formation) and underlain by Paleocene
shale (Esna Formation). The alluvial plains in the study area slope gently to the north, south and east Figure 3A (elevation range from 110 m. to 160 m. above sea level (a.s.l.)). These alluvial plains can be differentiated into a densely cultivated younger plain occupying the central part of the Nile valley and covered by Holocene silt and clay, and an older reclaimed plain covered by Pleistocene sand and gravel as shown in Figure 3B [10,20,26].
El Hossary [10] said that two aquifers of groundwa-
ter are distinguished within the Plio-Pleistocene units
beneath Luxor town; the shallow Quaternary aquifer
and the underlying Plio-Pleistocene aquifer. The Qua-
ternary aquifer is composed of graded sand and gravel
with some clay and has a local thickness ranging from
5 to 95 m. This aquifer is semi confined by upper silty
clay in the central part of the Nile valley. However,
the aquifer is phreatic where the silty clay layer thins,
then terminates near the River Valley. The regional flow
direction of groundwater is from east to west towards
the River Nile channel. The underlying Plio-Pleistocene
aquifer comprised of sand, clay and gravel represents
the secondary aquifer in the study area. The salinity
of this aquifer is significantly higher than that of the
Quaternary aquifer.

From Esna to Luxor the beds dip generally towards
the north. In this area a more complete section of
lower Eocene rocks is exposed above the Esna shale
[22]. The composite stratigraphic column of Luxor study
area described by [10] and shown in (Figure 3B). This
section described from top to bottom as Quaternary
age included Holocene (Arkin Formation (Fm.)) and
Pleistocene (Abbassia, Dandara, Qena, Issawia, Armant
and Idfu Formations (Fms)). In generally, these forma-
tions of Quaternary age are composed mainly of clastic
sediments varied in grain sizes; Tertiary age is repre-
sented Dakhla, Duwi and Nubian Fms.

3. Geoelectrical investigation

3.1. Geoelectrical measurements

The Vertical Electrical Sounding (VES) method is carried
out in the mentioned study for the purpose of subdi-
viding the shallow section into layers of varying litholo-
gies and water contents in the subsurface of Wadi El
Madamud area, and also for determining the geoelec-
tric Dar-Zarrouk parameters for evaluating the aquifer
hydraulic characteristics. In the present study, 31 ver-
tical electrical soundings (VESes), using Schlumberger
array, are conducted to investigate the vertical distri-
bution of the examined resistivity layers (Figure 4). The
spacing between the VESes locations are controlled by
the topographic and geologic conditions of the site. The
used resistivity meter is SYSCAL-R2, of IRIS Instruments,
French, with a microprocessor, digital display and RS-
232C interface for PC data dump. SYSCAL-R2 has a trans-
mitter and receiver in the same unit with high power sig-
als. The apparent resistivity values measured by using
Schlumberger arrangement were plotted on a log–log
graph paper to obtain the field resistivity curves. The
used minimum AB/2 is one meter while the maximum
AB/2 is 500 meters.

3.2. Geoelectrical analysis

Schlumberger configuration was applied to inject cur-
cent and the produced potential difference, to calculate
the apparent resistivity values (ρa), which are plotted
versus AB/2 on a log–log graph paper, to perform the
field resistivity curves. The utilities of the log-log plot are that, it confirms the near-surface resistivity differences and inhibits the differences at greater depths. This is significant, because the interpretation of the results depends mainly on the differences in resistivities, taking place at shallow depths. Due to the theoretical curves are generally smooth, the field curves should be smoothed, before carrying out their interpretation, to neglect the obvious errors and effects of lateral variability. Isolated one-point spike in the resistivity is neglected instead of interpolated. The resistivity curves should be investigated for the apparent deformation, because of the effects of lateral differences.

Comparing with the theoretical multi-layer curves (Figure 4A) is helpful in detecting the layered geologic model. The field data were processed, using special software, to reduce the different segments of the sounding curve into a continuous curve, to remove the noises from the curve and to plot the corrected sounding curve. So, the data analysis was carried out, using two appropriate geoelectric softwares, which allow the analyst to achieve the equivalent true resistivity ($\rho$) model for each sounding. Subsequently, the data were interpreted quantitatively via the Ato program of Zohdy and Bisdrof [27] to achieve the multi-layer model, and the Resist of Velpen [25] to perform the layering model.
where the automatic curve appropriate computer program results in a geoelectric model, the calculated apparent resistivity, of which meets the given field curve roughly exactly (Figure 4), in addition to the regional background on the geology of the area, are used to construct a preliminary model, that would fairly fit the observed field curves. This is after a minimum number of non-automatic iterations, which in turns represent the input model for Resist program (Figure 4b). Zohdy and Bisdorf program [27] process is adjusted to adapt the values of \((AB/2)\) and \((\rho_a)\) into a multi-layer model. It is an entirely automated and fast refined method, depended on obtaining the interpreted depths and true formation resistivities from the shifted electrode spacings and the modified apparent resistivities. Based on Sadek et al. [29], an additional information, about the subsurface variations within any selected geoelectric layer, can be provided via constructing the n-layer model by Ato program [27], (Figure 4A). This is after a minimum number of non-automatic iterations, which contribute to perform the input model of the Resist of Velpen, [25], (Figure 4B). This program was generated for 1D automated and interactive semi-automated interpretation of vertical electrical sounding.

3.3. Geoelectrical results

A. Spatial distribution of the model parameters

The spatial distribution of the model involves the lateral and vertical variations of the true resistivities and thicknesses through the study area. To represent the areal distribution of the resulting data, two colored images are generated for each resistivity layer; resistivity colored image and thickness colored image. Table 1 summarized resistivities, thicknesses and depths layers in the study area.

| T (m²/day) | Aquifer potential | Groundwater yielding capacity |
|-----------|-------------------|------------------------------|
| > 1000    | Very High         | Very high Withdrawal of great regional importance |
| 100 - 1000| High              | Withdrawal of lesser regional importance |
| 10 - 100  | Moderate          | Withdrawal of local water supply (eg. small community) |
| 1 - 10    | Very low          | Smaller withdrawal for local water supply (private consumption) |
| 0.1 - 1   | low               | Withdrawal of local water supply with limited consumption |
| < 0.1     | Negligible        | Impermeable sources for local water supply are difficult |

3.3. A. Areal distribution maps of the model parameters

3.3. A.1. Unconsolidated wadi deposits (dry silts, sands and gravels layer). Figures (5A and 5B) show the true resistivities and thickness colored images, with the localities of the first layer (dry silts, sands and gravels layer), which has a wide range of true resistivities from 3073 to 90,581 Ω.m. and a maximum thickness about 2.2 m. The resistivities of this layer reach their highest values at the northwestern and southeastern parts of the area, which might be classified as highly dry sand. The thickness colored image map of the first layer. (Figure 5B) shows that, the minimum thickness (less than 0.7 m) is recorded at the northeastern, southwestern and southeastern parts of the study area.

Figure 5. (A): True resistivity colored image of dry silts, sands and gravels. (B): Thickness colored image of dry silts, sands and gravels.

Table 1. Classification of the transmissivity magnitude [13] and [18].
### 3.3. A.2. Consolidated wadi deposits (silts, sands and gravels)

Figure (6A) exhibits the resistivity colored image and the localities of the saturated sands and gravels layer, the highly resistive zones (more than 1500 Ω.m.) are noticed at the northwestern part of the study area. The south-central part has moderate to low resistivity values (300 < ρ < 1500 Ω.m.). The lowest resistivity values (less than 300 Ω.m.) are shown at some parts of the central, northeastern and southern parts of the study area. This layer is found to be thicker of more than 8m (Figure 6B) at the central part of the study area, at VES 19. On the other hand, the thickness decreases to be less than 3m at the western parts of the study area.

### 3.3. A.3. Sandstone and clay saturated with groundwater (Plio-Pleistocene aquifer)

Figure (7A) reveals the true resistivity colored image and the localities of the sandstone and clay saturated with groundwater. The southern part possesses the lowest resistivity values (less than 100 Ω.m.). The highest resistivity values (more than 200 Ω.m.) are recorded at the central part and some parts in the northern area, reflecting the abundance of groundwater aquifer at southern part of the study area. Thickness colored image of this layer (Figure 7B) shows that, the thickness values are ranging from about 18m at the northern parts of the area and decreasing to the central part, then increase to the southern of the study area. The values of computed electric resistivity values, thickness and depth to the top of this layer are listed in table 4 for each VESes.

### 3.3. A.4. Clay with unsaturated sandstone

Figures (8A and 8B) show the resistivity and thickness colored images with the localities of VESes within the fourth layer (Clay with unsaturated sandstone), which has a range of true resistivities ranging (from 11 to 10,700 Ω.m.) and a maximum thickness of about 83 m at VES 6. The resistivities of this layer reach their highest values at the northwestern part of the area, which might be classified as highly compacted sandstone. Meanwhile, the low resistivity values at the southern and central parts reached to less than 1000 Ω.m., which may be described as richer clay than sandstone. The thickness colored image map of the fourth geoelectric layer. (Figure 8B) shows that, the minimum thickness (less than 60 m.) is recorded at the central and southern parts of the study area.

### 3.3. A.5. Checkley limestone with chert band (Thebes Fm.)

Figure (9) exhibits the resistivity colored image and the localities of the massive limestone layer, the highly resistive zones (more than 6000 Ω.m.) are noticed at the northwestern, southcentral parts of the study area. The other parts of the northcentral and southcentral parts have moderate to low resistivity values (6000 > ρ > 3000 Ω.m.), which decrease to less than 3000 Ω.m. at some parts of the southeastern, northeastern, southwestern and extremely eastern parts of the study area.

### 3.3. B. Vertical distribution of the model parameters

The established resistivity modeling contributes for constructing four 2-D reliable geoelectric cross sections,
which show three geoelectric layers (Figs. 10A to 10D). It is worth mentioning that, the first geoelectric layer (dry silts, sands and gravels) is thin and of high resistivity. So, it is not recognizable in some parts of the 2D geoelectric cross section, causing mis-interpretation for the first layer (dry silts, sands and gravels); the second (sands and gravels saturated with fresh water in some sites at VESes 19 and 20); the third geoelectric layer is sandstone and clay saturated with groundwater; the forth geoelectric layer is clay with unsaturated sandstone and the last geoelectric layer is represented by Checkley limestone with chert band (Thebes Fm.). Therefore, the four generated geoelectric sections are built and discussed in view of their directions, lengths and included soundings.
Figure 9. True resistivity colored image of checkley limestone with chert band.

3.3. B.1. Geoelectric cross section A-A’. This section (Figure 10A) extends for about 5.5 km. and passes through VESes 30, 27, 25, 23, 21 and 19, respectively, across the southern part, from the south to the north directions, of the area. The resistivity values of the aquifer are range from 4 to 99 Ω.m. increase relatively toward the central parts of this section (towards VESes 21 and 25), as compared with the values recorded at the rest of the section, for the same layer. In this section, there are normal fault nearly trending E-W, which tend to increase the thickness of aquifer for more than 35 meters.

3.3. B.2. Geoelectric cross section B-B’. The second geoelectric cross section (Figure 10B) is approximately parallel to the first one and extends also from the South to the North directions. It passes through VESes 31, 28, 26, 24 and 22, respectively and extends for about 4.5 km. The sandstone and clay saturated with groundwater (The Plio-Pleistocene aquifer) recorded the lowest resistivity value of 35 Ω.m. at VES 26 and VES 28. The thickness of this layer increase, toward the southern part of this section, which may result from normal fault formed a graben at the southern part of this section.

3.3. B.3. Geoelectric cross section C–C’. The third geoelectric section C–C’ extends for about 2.4 km., from west to the east directions. It is represented by VES stations 12, 13, 14 and 18, respectively (Figure 10C). The lowest resistivity and thickness value at the central part of this section are noticed under VES 14 but the thicknesses and resistivities are increased for the both side of the section. The Plio-Pleistocene aquifer layer along the whole section has thickness range 8-18 m.

3.3. B.4. Geoelectric cross section D-D’. The fourth geoelectric cross section has length 5.3 km., (Figure 10D) passes through VESes 1, 2, 3, 11, 4, 5 and 6, respectively. It extends from the western to the eastern directions and approximately perpendicular to the sections A – A’ and B – B’ and parallel to the geoelectric section C – C’ at the northern part of the study area. The Plio-Pleistocene aquifer recorded the lowest resistivity values at the eastern part of this section, with thin thickness along section.

4. Aquifer hydraulic parameters

The geoelectric resistivity method is primarily used to measure the potential differences on the surface caused by the current flow within the ground. However, the mechanism judging the electric current, conductance and fluid flow are mainly controlled by the same physical parameters and lithological conditions. Therefore, the hydraulic and electric conductivities are generally dependent upon each other. These parameters are depended on the consideration of a column of unit square cross-sectional area (m²) cut out of layers group of infinite lateral extent [19] and [3].

4.1. Electric hydraulic conductivity (K)

Due to the lack of hydraulic conductivity values from boreholes in the study area, the estimated hydraulic conductivity is assumed from Singh’s equation (2005) to be relatively equal to the resistivity values of the aquifer through alternating layers of sandstone and clay saturated with groundwater (The Plio-Pleistocene aquifer). Singh [24] postulated an empirical relation to calculate the hydraulic conductivity in a fractured hard rock aquifer, as shown:

$$K = 8 \times 10^{-6}e^{-0.0013\rho}$$

where: $\rho$ is resistivity of the aquifer.

Figure (11) shows a range of hydraulic conductivity values, from 0.06 m/day to 0.68 m/day. It is noticed that, the northwestern and central parts have lower hydraulic conductivities as less than 0.5 m/day. Meanwhile, the highest values are recorded at the west central, north eastern and southern parts of the study area. Values of the computed electric hydraulic conductivity are listed in Table (4) for each VES.

4.2. Electric transmissivity (T)

Henriet [15] described the aquifer transmissivity (the product of aquifer thickness and hydraulic conductivity)
Figure 10. (A): Geoelectric cross section A-A of the VESes 30, 27, 25, 23, 21 and 19. (B): Geoelectric cross section B-B of the VESes 31, 28, 26, 24 and 22. (C): Geoelectric cross section C-C of the VESes 12, 13, 14 and 18. (D): Geoelectric cross section D-D of the VESes 1, 2, 3, 11, 4, 5 and 6.
Figure 11. Hydraulic conductivity map of Plio-Pleistocene aquifer of the study area.

Figure 12. Transmissivity map of Plio-Pleistocene aquifer of the study area.

for all the sounding locations in the study area, including those parts due to there are no boreholes in the investigated area. The transmissivity computed from the relation: 

\[ T = K \times h \]

where \( T \) is the transmissivity in \( \text{m}^2/\text{day} \) and \( h \) is the aquifer thickness in meter.

Transmissivity across the study area varies between 1 and 25 \( \text{m}^2/\text{day} \) with average 12.1 \( \text{m}^2/\text{day} \). Figure (12) shows the aerial distribution of the transmissivity obtained for the study area, showing parts of high transmissivity (more than 15 \( \text{m}^2/\text{day} \)) at southern and west central while, low transmissivity values (less than 8 \( \text{m}^2/\text{day} \)) at northwestern and central parts of the study area. Therefore, the productive potential of the aquifer indicates that, this location has the moderately potential for production, due to its moderate hydraulic conductivities and transmissivities. Values of the computed electric transmissivity of the saline aquifer is listed in Table 4 for each VES. Table (2) shows the classification of transmissivity magnitudes [13] and [18].

### 4.3. Salinity

To detect the expected salinity, there is a function of its measured electrical conductivity, according to the relation:

\[ \rho_w = \frac{1}{EC} \]

where \( \rho_w \) is the electrical resistivity of groundwater (\( \Omega \text{m} \)), \( EC \) is the electrical conductivity of groundwater (siemens/m (S/m) = 10^\text{desi-siemens/m} (dS/m)).

In this study, the groundwater resistivity (\( \rho_w \)) have been estimated from the geoelectric resistivity measurements via assuming that, the least resistivity value (high saturation zone) is relatively equal to the groundwater resistivity, and according to Hem [14] and Iyasele and David [17], the relation between the electrical

| Salinity Hazard Class | EC (dS/m) | TDS (ppm) | Description and use | Management Requirements |
|----------------------|-----------|-----------|---------------------|------------------------|
| Low (Fresh)          | < 0.75    | < 500     | Drinking and all irrigation | No detrimental effects expected. |
| Medium (Marginal)    | 0.75 - 1.5| 500 - 1,000| Most irrigation, adverse effects on ecosystems become apparent | Moderate leaching to prevent salt accumulation. |
| High (Brackish)      | 1.5 - 3.0 | 1,000 - 2,000| Irrigation certain crops only; useful for most stock | Turf species/ cultivar selection, good irrigation, leaching, drainage. |
| Very high (Saline)   | > 3.00    | > 2,000   | Useful for most livestock | Most salt-tolerant cultivars, excellent drainage, frequent leaching, intensive management. |
Figure 13. (A): Electric conductivity map of Plio-Pleistocene aquifer of the study area. (B): Salinity map of Plio-Pleistocene aquifer of the study area.

Table 3. Summary of results of aquifer properties of VES points.

| VES No. | a.s.l (m) | Aquifer thickness (m) | EC (dS/m) | Aquifer conductivity (m/d) | Transmissivity (m²/day) | Groundwater yielding capacity/salinity hazard | Salinity (ppm) |
|---------|-----------|----------------------|----------|----------------------------|------------------------|----------------------------------------------|---------------|
| 1       | 160       | 277                  | 0.04     | 18                         | 0.48                   | 8.68                                         | Low (Fresh)   |
| 2       | 120       | 419                  | 0.02     | 20                         | 0.40                   | 8.02                                         | Low (Fresh)   |
| 3       | 140       | 291                  | 0.03     | 25                         | 0.47                   | 11.84                                        | Low (Fresh)   |
| 4       | 125       | 173                  | 0.06     | 18.7                       | 0.55                   | 10.32                                        | Low (Fresh)   |
| 5       | 134       | 42                   | 0.24     | 20                         | 0.65                   | 13.09                                        | Low (Fresh)   |
| 6       | 142       | 72                   | 0.14     | 10.6                       | 0.63                   | 6.67                                         | Low (Fresh)   |
| 7       | 130       | 979                  | 0.01     | 16.4                       | 0.19                   | 3.17                                         | Low (Fresh)   |
| 8       | 122       | 905                  | 0.01     | 15.5                       | 0.21                   | 3.30                                         | Low (Fresh)   |
| 9       | 127       | 150                  | 0.07     | 30                         | 0.57                   | 17.06                                        | Low (Fresh)   |
| 10      | 135       | 14                   | 0.71     | 22                         | 0.68                   | 14.93                                        | Low (Fresh)   |
| 11      | 142       | 106                  | 0.09     | 17.6                       | 0.60                   | 10.60                                        | Low (Fresh)   |
| 12      | 124       | 289                  | 0.03     | 8.7                        | 0.47                   | 4.13                                         | Low (Fresh)   |
| 13      | 130       | 56                   | 0.18     | 23                         | 0.64                   | 14.78                                        | Low (Fresh)   |
| 14      | 133       | 35                   | 0.29     | 16                         | 0.66                   | 10.57                                        | Low (Fresh)   |
| 15      | 130       | 514                  | 0.02     | 16                         | 0.35                   | 5.67                                         | Low (Fresh)   |
| 16      | 131       | 91                   | 0.11     | 30                         | 0.61                   | 18.42                                        | Low (Fresh)   |
| 17      | 122       | 1887                 | 0.01     | 16.5                       | 0.06                   | 0.98                                         | Low (Fresh)   |
| 18      | 133       | 114                  | 0.09     | 18.5                       | 0.60                   | 11.03                                        | Low (Fresh)   |
| 19      | 122       | 35                   | 0.29     | 17                         | 0.66                   | 11.23                                        | Low (Fresh)   |
| 20      | 151       | 139.75               | 0.63     | 19.2                       | 0.68                   | 13.00                                        | Low (Fresh)   |
| 21      | 120       | 111.4                | 0.1      | 14                         | 0.61                   | 8.51                                         | Low (Fresh)   |
| 22      | 120       | 70                   | 0.14     | 22                         | 0.63                   | 13.88                                        | Low (Fresh)   |
| 23      | 169       | 151.5                | 0.17     | 25                         | 0.64                   | 15.98                                        | Low (Fresh)   |
| 24      | 121       | 289                  | 0.03     | 13                         | 0.47                   | 6.17                                         | Low (Fresh)   |
| 25      | 120       | 89                   | 0.11     | 20                         | 0.62                   | 12.31                                        | Low (Fresh)   |
| 26      | 174       | 38                   | 0.26     | 18.6                       | 0.66                   | 12.24                                        | Low (Fresh)   |
| 27      | 120       | 4                    | 2.5      | 24                         | 0.69                   | 16.50                                        | Medium (Marginal) |
| 28      | 120       | 32                   | 0.31     | 33                         | 0.66                   | 21.88                                        | Low (Fresh)   |
| 29      | 120       | 12                   | 0.83     | 31.5                       | 0.68                   | 21.44                                        | Low (Fresh)   |
| 30      | 121       | 34                   | 0.29     | 39                         | 0.66                   | 25.79                                        | Low (Fresh)   |
| 31      | 135       | 77                   | 0.13     | 41                         | 0.63                   | 25.64                                        | Low (Fresh)   |

Conductivity and total dissolved solids (TDS):

\[
\text{TDS (ppm or mg/l)} = 640 \times \text{EC (dS/m)}
\]

Figure (13A) shows distribution of electric conductivity within Plio-Pleistocene aquifer. It high electric conductivity (more than 0.5 dS/m) at southern and west central while, lower electric conductivity values (less than 0.1 dS/m) at northwestern and central parts of the study area.

Figure (13B) shows the areal distribution map of the salinity (water quality) throughout the study area. The rough estimation for groundwater salinity ranges of less
than 500 ppm in all VESes, except VESes 27 and 29. The lowest value of salinity recorded (less than 100 ppm) of VESes 1, 2, 3, 4, 7, 8, 9, 10, and 24 at the northwestern and east central parts of the study area. Values of the computed salinity aquifer and evaluated salinity hazard class, according to the EC and TDS [7] and [17] are listed in table 3 for each VES. So, the aquifer is characterized by fresh, marginal to slightly brackish water.

### Summary and conclusions

This work discusses the qualitative and quantitative interpretations, of the surface geoelectric data of Wadi El Madamud area, Southeast Luxor, Egypt. The final resistivity model is consisted of five geoelectric resistivity layers distributed to be appropriate to represent the subsurface geologic layering of the study area. Lithologies, resistivities, depths and thicknesses of these layers are: surficial unconsolidated dry silts, sands and gravels; consolidated sands and gravels; saturated sandstone and clay intercalation (Plio-Pleistocene aquifer); clay with unconsolidated sandstone and Checkley limestone with chert band (Thebes Fm.).

The areal distribution of the resistivity and thickness maps and 2D geoelectric cross section are illustrated in the form of spatial distribution, both vertical and horizontal for each layer. As well as, presented inferred fault has nearly trending E-W, which tend to increase the thickness of Plio-Pleistocene aquifer for more than 35 meters in southern of the study area.

Through the application of the evaluation of the hydraulic conductivity and the transmissivity for the VES locations along the study area. The lowest hydraulic conductivity (less than 0.5 m/day) and the lowest transmissivity value (less than 10 m²/day) were obtained at the VESes No 1, 2, 3, 4, 7, 8, 9, 15, 1710 and 24 to be Smaller withdrawal for local water supply (private consumption) where very small aquifer potential. According to the computed salinity, the highest salinity within the aquifer tends to be at the southern part of the study area, which recorded maximum salinities of 533 and 1600 ppm under VESes 29 and 27, respectively. The aquifer is thus characterized by fresh, marginal to slightly brackish water.

### Disclosure statement

No potential conflict of interest was reported by the author(s).

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