Hydrogeochemistry of groundwater at El Moghra area, north Western Desert, Egypt

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ABSTRACT
Thirty-three groundwater samples were collected from recent drillings conducted as a part of the 1.5 million feddan (Acres) national reclamation project at El Moghra area. These samples were analysed for the concentrations of the major ions (Na, K, Ca, Mg, Cl, SO4, HCO3 and CO3) along with different physicochemical parameters (pH, TDS and EC). The assessment of these groundwater samples was obtained to evaluate groundwater suitability for different purposes (drinking, irrigation, and domestic purposes). The investigated aquifer has slightly acidic to alkaline water with pH value ranged from 6.71 to 8.7. The salinity (as TDS) value varies from 2236 mg/l (Brackish water) to 7830 mg/l (saline water). In the study area, the concentrations of major ions are generally higher than the maximum standard limits for drinking and domestic purposes. The main chemical water type according to the hydrochemistry composition is NaCl. The groundwater of the study area is unsuitable for drinking and domestic purposes; however, it can be used for irrigation as the cultivation of salt-tolerant crops (Jojoba and Olives) especially in the western part of the study area. Five VES stations were measured to identify by the subsurface section which consists of different alternated layers of sand intercalated with clay.

1. Introduction
Western Desert represents about 68% of the total area of Egypt. It is characterised by an arid to hyper-arid climate. Groundwater in the Western Desert represents the main source of water supply. Few parts in north-western Desert have been selected by the Egyptian government to establish new agricultural projects aiming to achieve food self-sufficiency. Moghra Oasis and its vicinities are characterised by vast areas of good soil which are favourable for agricultural development. This encourages some companies and farmers to reclaim more areas based on groundwater in the next few years. In this respect, ambitious plans and successful programs are urgently required.

The present work aims to investigate the hydrochemical characteristics of groundwater through the determination of cations and anions concentrations, some toxic metals, and physicochemical parameters. These hydrochemical items were used to evaluate the groundwater quality for different purposes. El Moghra Oasis and its vicinities are located in the northeast part of El Qattara mega delta in north western Desert of Egypt, about 40 kilometres south of El Alamein city (Figure 1(a)). It extends between latitudes 30°00′ – 30°25′ N and longitudes 28°20′ – 29°20′. Authors such as Aly et al. (1988), Yousef (2013), and El Sabri et al. (2016) are applied hydrochemical analysis on groundwater samples in and around the study area. Arafia (2013) and Sultan et al. (2009) applied hydrochemical analysis for some water samples on east greater Cairo and south Sinai areas.

Thirty-three groundwater samples were collected from El Moghra aquifer (Figure 1(b)). The chemical analyses were carried out in REGWA, The Arab Contractors, El Arabia Co and Desert Research Center laboratories, according to the standard methods, to show the physical and chemical properties of the groundwater samples. These hydrochemical properties are used to classify different types of groundwater. Also, the water quality of El Moghra aquifer is evaluated for different purposes.

2. Geologic setting
Geomorphologically, the area is subdivided into three main units namely; structural plateau, sand dune belt, and Moghra depression (Figure 2(a)). Structural Plateau occupies the northern part of the study area. It stretches in an E – W direction. It declines gradually northward from about (+200 m) to about (+60 m) above sea level while drops off sharply southward to (−40 m) below sea level creating cliff (Misak, 1979). It is mostly composed of massive and cavernous
limestone and it is partially covered by sand sheets belonging to the Quaternary age. Sand dune belt constitutes the main portion of Moghra Oasis and differentiated into; Sand sheets which widespread on the floor of the oasis and gravely plain constitutes the main portion of Moghra Oasis, On the other hand, the longitudinal sand dunes are located to the south of Moghra Oasis forming the northern part of Ghard Abu El Mahariq which extends in NNW-SSE direction. Moghra-Qattara Depression had been originated from morpho-tectonic processes involving structural and erosional conditions. Moghra-Qattara Depression elevations are below zero level. Geomorphologically, Moghra-Qattara Depression is distinguished into three units which are low lands, sabkhas, and Moghra Lake.

Geologically, the surface geology has been described through a geological map of El Moghra Oasis and its vicinities, which was constructed by CONOCO, (1987) (Figure 2(b)). El Moghra Oasis and its vicinities are covered by rocks ranging in age from Lower Miocene to Recent. In the study area, the composite stratigraphic succession can be subdivided into the following rock units from base to top:–

Moghra Formation of Lower Miocene (Said, 1962) which consists of fluvimarine sediments which grades northwards and westward to more marine facies called Mamura Formation. Moghra Formation is the main aquifer in the study area; that is why it is intensively studied, where it can be distinguished from base to top into three members according to Omara and Sanad (1975), El Raml, Bait Owian and Monquar El Dowi members. Marmarrica Formation covers almost the northern stretch of the Western Desert. It is made up of white limestone in the upper part and grey calc-arenites with some shale intercalations in the

Figure 1. A) Location of the study area, b) VES and samples location map.
lower part. The Pliocene sediments are represented by El Hagif Formation (Late Pliocene). It is recorded in the northeast of Moghra Oasis. It is composed of whitish limestone with shale and evaporite layers (Omara and Sanad, 1975). The Quaternary sediments are represented by sand sheets, sand dunes and sabkhas. The sand sheet covers vast areas in Moghra Oasis and composed mostly of fine to coarse sand. Sand dunes occupied the southern part of the oasis that takes NW-SE direction.

Hydrogeologically, El Moghra aquifer is distinguished into three water-bearing units separated by clay beds. These units are called Monquar El Dowi (upper unit), Bait Owian (middle unit), and El Raml (lower unit). They are hydraulically connected. So, they act as one hydrogeological aquifer (Yousef, 2013; El Sabri et al., 2016). Monquar El Dowi water-bearing zone consists of gravel, sand, and sandstone interbedded with clay. Bait Owian water-bearing represents the middle zone which is overlain and underlain by clay layers i.e. confined aquifer. Generally, Bait Owian water-bearing zone consists of sandstone with minor claystone. El Raml water-bearing represents the lower zone which is underlain by the huge thickness of the Oligocene shale (Dabaa Formation) and is overlain by clay beds of Bait Owian i.e. confined aquifer. It has a thickness reaching 400 m composed of sandstone intercalated with claystone and represents the main aquifer most of the boreholes penetrated and produce from this layer.

3. Methodology

Thirty-three groundwater samples were collected from El Moghra aquifer. These samples were analysed to determine the major cations (Na, Ca, Mg and K) and major anions (Cl, SO₄, HCO₃ and CO₃) along with different physicochemical parameters (pH, TDS and EC) (Appendix). The interpretation of the groundwater samples includes hydrochemical analysis and groundwater assessment for different purposes. The hydrochemical analysis of groundwater samples includes a representative of physicochemical parameters, cations and anions concentrations as well as the hydrogeochemical types using Piper’s and Schoeller diagram. Some parameters such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), and Sodium Adsorption Ratio (SAR) were used for evaluation of groundwater quality for irrigation and domestic purposes. Six VES stations are measured to represent the subsurface stratigraphy in the study area using
4. Results and discussion

4.1. Physicochemical parameters of groundwater

4.1.1. Hydrogen ion content (pH)

According to (WHO, 2011), EPA, and (FAO, 1985), the guideline for pH in the drinking and irrigated water ranges between 6.5 and 8.5 in pure natural water. According to the obtained results of the groundwater samples in the area of study, the pH value ranges from 6.71 to 8.70. The minimum values 6.71 and 6.8 were recorded in wells No. X-85, X-60, and X-115 in the southwestern part of the studied area, and the maximum value 8.70 was found in wells No. Mo-30 and Mo-33 in the northeastern part (Figure 3(a)), which indicates that the groundwater in the study area is a slightly moderate alkaline.

4.1.2. Electric conductivity (EC)

The electric conductance (EC) measures the water’s ability to conduct an electric current (μS/cm). It is directly related to the total dissolved salts (ions) in the water. There is a proportional relation between EC and TDS (Hem, 1970).

\[ \text{TDS (in ppm)} = 0.64 \times \text{EC (in μmhos/cm)} \]

The obtained values of EC in the groundwater samples range from 3420 (μmhos/cm) at Well No. Mo-26 to 11,800 (μmhos/cm) at Well No. R-140. The distribution of EC in groundwater (Figure 3(b)), indicates that the minimum values of EC are observed at the eastern and southeastern parts while these values increase towards the northwestern, southwestern, and northern parts. The conductivity is low in the east and southeastern direction due to the recharge from the Quaternary aquifer and due to seepage from Wadi El Natroun groundwater through subsurface channels.

4.1.3. Groundwater salinity (as TDS)

The term “Solids” is referred to dissolved materials in the water body and, TDS or salinity refers to several ions dissolved in water. The obtained TDS in groundwater varies from 2236 (mg/l) at sample number Mo-26 to 7830 (mg/l) at sample number R-140 and there is a strong similarity relationship between TDS and EC in terms of increasing and decreasing locations (Figure 3(c)). This relationship is explained by the cross plot (Figure 3(d)) which shows that the proportional relationship between TDS and EC with confidence value is 0.9 (\( r^2 = 0.981 \)). Total dissolved solids are useful for determining the general quality of groundwater (Chebotarev’s, 1955). The chemical classification of water according to salinity variation is shown in (Table 1).

Schlumberger configuration of AB-2 ranging from 1 to 500 m.

Figure 3. A) pH zonation map, b) Electric conductivity (EC) Zonation map, c) Total dissolved solids (TDS) zonation map, d) Cross plot showing the TDS & EC relationship.
According to the classification of Chebotarev’s, (1955) 31.25 % of samples fall within the brackish water category and 68.75% of samples within the saline category.

4.2. Chemical composition

According to the obtained results of the hydrochemical analyses data, the following could be deduced:

4.2.1. Major cations concentration

Major Cations Concentration includes Sodium (Na+), Potassium (K+), Calcium (Ca2+), and Magnesium (Mg2+).

4.2.1.1. Sodium (Na+). The recommended world Health Organization guideline for sodium is 200 mg/l (WHO, 2011). The concentration of sodium in groundwater of the investigation area is ranging from 573 to 2000 mg/l as shown in (Figure 4(a)). The lowest value is found in well no Mo-26 located on the Northeast side of the study area, while the highest value is recoded in well no. R-140, which is located on the northwest side of the study area.

The SAR value is defined by the following equation according to Richards (1954):

\[
SAR = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}
\]

Where, Na+, Ca2+ and Mg2+ concentrations are calculated in meq/L.

4.2.1.2. Potassium (K+). The concentration of Potassium in the studied samples is ranging from 15 to 44 mg/l as shown in (Figure 4(b)). The minimum content was recorded in well no GV-874 and the maximum value was recorded in wells no R-140 and R-134 in the northwestern side of the studied area. Right now, there is no confirmation that Potassium levels in municipally treated drinking-water, even water treated with Potassium permanganate, are probably going to represent any hazard for the health of consumers. It is not viewed as important to set up a health-based guideline value for Potassium in drinking-water (WHO, 2011).

4.2.1.3. Calcium (Ca2+). Calcium is the richest alkaline earth metals and constitutes a standout amongst the most common ions in subsurface water. Calcium may result from dissolving rocks rich with limestone, marble, calcite, dolomite, gypsum, fluorite and apatite. The concentration range of calcium in potable groundwater extends from 10 to 100 mg/l which doesn’t affect the human health or animals (Nag and Lahir, 2012). Calcium concentration in the studied samples is ranging from 139 to 345 mg/l as shown in (Figure 4(c)), the lowest value is found in well no Mo-26 that located in the northeastern side of the study area, while the highest value is recoded in well no. Mo-24 which is located on the southwest side of the study area.

4.2.1.4. Magnesium (Mg2+). If the concentration of Magnesium in drinking water exceeds the permissible limit, it will cause an unpleasant taste to water (Ramesh and Vennila, 2012). In the present study, the Magnesium content changes from 61 to 376.9 mg/l, with an average of 218.95 mg/l (Figure 4(d)). The minimum level (61 mg/l) was found in well no. Mo-26 on the northeastern side of the studied area due to the recharge from the irrigation water, while the maximum value (376.9 mg/l) was recorded in well no. R-140 on the northwestern side.
4.2.2. Major anions concentration

Detection of the major anions, for example, chloride (Cl⁻), sulphate (SO₄²⁻), carbonate (CO₃²⁻), and bicarbonate (HCO₃⁻) regularly is attractive to describe water properties or to survey the requirement for a particular treatment. The distribution of every cation is discussed as the following:

4.2.2.1. Chloride (Cl⁻). The chloride content of water is an indicator of pollution. There is a relationship between chloride and EC Where, the increase of chloride content leads to increasing of the EC of water and increases its corrosively in metal pipes, chloride reacts with metal ions to form soluble salts (WHO, 1978).

The high content of chloride gives a salty taste to water and refreshments. Taste edges of the chloride anion rely upon the related cation and are in the limit of 200–300 mg/l for sodium, Potassium, and Calcium chloride. Concentrations above 250 mg/l are progressive and could be identified by taste. No health-based guideline value is demonstrated for chloride in drinking-water (WHO, 2011). The concentration of chloride in groundwater of the investigation area is ranging from 1108 to 3300 mg/l as shown in (Figure 4(e)). Relatively, the chloride concentration values are higher than the other anions. The minimum values of chloride for samples are recorded in the southeastern part while its increase towards the northwestern parts.

Figure 4. A) Sodium concentration map, b) Potassium concentration map, c) Calcium concentration map, d) Magnesium concentration map, e) Chloride concentration map, f) Sulphate concentration map, g) Bicarbonate concentration map.
4.2.2.2. Sulphate\((SO_4^{2-})\). The sulphate concentration in the studied area ranges between 300 and 1198 mg/l with an average of 749 mg/l (Figure 4(f)). The minimum value (300 mg/l) is recorded in wells no. Mo–21 and Mo–26 in the eastern and northeastern parts of the area under study. The maximum (1198 mg/l) is recorded in well no. Mo–2 in the northern part of the studied area. The increment of sulphate in the north direction is most probably due to the intrusion of saline water. A low concentration of sulphate ions is recorded on the eastern side of the studied area due to the infiltration of irrigation water from Wadi El Natroun. No health-based guideline is proposed for sulphate. It is recommended that health authorities be notified of sources of drinking-water that contain sulphate concentrations over 500 mg/l. The presence of sulphate in drinking-water may also cause a noticeable taste and may contribute to the corrosion of distribution systems (WHO, 2011).

4.2.2.3. Bicarbonate \((HCO_3^-)\) and carbonate \((CO_3^{2-})\). The presence of carbonate-bicarbonate ions in the groundwater is related to the presence of carbon dioxide in the atmosphere, soils and the dissolution of carbonate rocks (Howari et al., 2005). Bicarbonate is responsible for the alkalinity of the groundwater at neutral pH (4.5–8.2). So, it is an important ion in the evaluation of irrigation water quality (Ramesh and Elango, 2006; Yammani et al., 2008; Poehls and Smith, 2009). The concentration of bicarbonate in groundwater of the investigation area is ranging from 79.3 to 884 mg/l as shown in (Figure 4(g)). The minimum value (79.3 mg/l) is recorded in well no. Mo–21 in the East area and the maximum value (884 mg/l) is recorded in well no. A–6 that located to the north of the studied area. The concentration of carbonate in groundwater of the investigated area is ranging from 4 to 43 mg/l.

4.3. Groundwater geochemical type

4.3.1. Piper’s diagram classification

Piper’s classification (Piper, 1944) is used as a useful tool in water analysis interpretation, and it’s widely used in water classification and determination of hydrochemical facies of mixed water samples. Specifically, used to detect the water type. Generally, all of the studied samples fall in the field 4 characterised by Na-Cl type, which reflects mixed water of marine and meteoric origin (Figure 5(a)).

4.3.2. Schoeller diagram

The relationship between different ions is represented by plotting the chemical data on the semilogarithmic paper, where the anions and cations are arranged according to their mobility’s. The Schoeller diagram relationship (Figure 5(b)) shows the following relationship: \(K < Na > Mg < Ca > CO_3 < HCO_3 < CI > SO_4\) (Reflecting Sodium-Chloride groundwater type)

4.4. Evaluation of groundwater for different purposes

4.4.1. Total hardness (TH)

Total hardness is one of the most important parameters, which control its use in drinking and domestic uses. Total hardness of water is defined as its content of metallic ions that react sodium soaps to produce solid soaps. Hardness makes it hard to obtain soap-suds with soap (Lantzke, 2004). It has no known adverse impacts on humans (WHO, 2008) and it is resulted due to the abundant presence of divalent cations like Ca\(^{2+}\) and Mg\(^{2+}\) (Tood, 1980). Hard water is unsuitable for domestic usage, as well as the hardness of water limits its use for industrial purposes; causing scaling of pots, boilers, and irrigation pipes (WHO, 2008). The following formula was used for detecting the hardness of water according to (Sawyer and Mccarthy, 1967):

\[
TH = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}
\]

Based on total hardness according to Sawyer and Mccarthy, (1967), all the studied groundwater samples (Figure 5(c)) are discriminated against as very hard water (Table 2).

4.4.2. Evaluation of groundwater for drinking purposes

In general, water used for drinking and domestic should be colourless, odourless, clean, soft, and free from excessive dissolved salts as well as harmful organisms. In the present study, the evaluation of groundwater quality for drinking and domestic uses is established based on some international quality standards like World Health Organization (WHO, 1984) (Table 3), and the United State Geological Survey (Hem, 1970). Also, water classification standard suggested by the (ECAFE & UNESCO, 1963). According to (Table 3), the chemical analysis of the collected water samples indicates that the total salinity in the studied area ranging from 2236 mg/l to 7830 mg/l is unsuitable for drinking according to WHO standard 1500 mg/l, also it’s not acceptable by ECAFE & UNESCO, (1963).

4.4.3. Evaluation of groundwater for livestock and poultry

Water that required for livestock and poultry Should be characterised by some special quality limitations (Table 4). A lot of schemes were developed as a guideline, from which that suggested by the National Academy of Science, (1972).

According to the chemical analysis of the water in the investigated area the following can be deduced;
No Water Sample in the investigated area is excellent water for all classes of livestock and poultry (TDS < 1000 mg/l).

(ii) 12.5% of Water Samples in the investigated area is Very Satisfactory water for livestock and poultry (TDS ranges from 1000 to 2999 mg/l).

(iii) 41% of Water Samples in the investigated area are satisfactory for all classes of livestock (TDS ranges from 3000 to 4999 mg/l).

(iv) 46.5% of Water Samples in the investigated area is unsuitable for livestock and poultry (TDS > 4999 mg/l).

Table 2. Suitability of groundwater for domestic purpose based on TH according to Sawyer and Mccarthy, (1967).

| TH   | Water class | Samples | Percentage |
|------|-------------|---------|------------|
| <75  | Soft        | –       | 0          |
| 75–150 | Moderately Hard | –       | 0          |
| 150–300 | Hard       | –       | 0          |
| >300 | Very Hard   | All studied samples | 100%       |

(i) No Water Sample in the investigated area is excellent water for all classes of livestock and poultry (TDS < 1000 mg/l).

(ii) 12.5% of Water Samples in the investigated area is Very Satisfactory water for livestock and poultry (TDS ranges from 1000 to 2999 mg/l).

(iii) 41% of Water Samples in the investigated area are satisfactory for all classes of livestock (TDS ranges from 3000 to 4999 mg/l).

(iv) 46.5% of Water Samples in the investigated area is unsuitable for livestock and poultry (TDS > 4999 mg/l).

Table 3. International standards for drinking-water (WHO, 1984).

| Property  | Acceptable Limit | Permissible Limit |
|-----------|------------------|-------------------|
| Colour    | 5.00             | 50.0              |
| Turbidity | 5.00             | 25.0              |
| pH        | 7–8.5            | 6.5–9.2           |
| Hardness  | 250              | 500               |
| TDS       | 500 mg/l         | 1500 mg/l         |
| Cl−       | 200 mg/l         | 600 mg/l          |
| SO42−     | 200 mg/l         | 400 mg/l          |
| HCO3−     | –                | –                 |
| Mg2+      | 50 mg/l          | 150 mg/l          |
| Ca2+      | 75 mg/l          | 200 mg/l          |
| Na+       | –                | 200 mg/l          |
| Fe3+      | 0.3 mg/l         | 1.00 mg/l         |
| Mn2+      | 0.1 mg/l         | 0.5 mg/l          |
| Pd2+      | –                | 0.5 mg/l          |
| Cu2+      | 1.0 mg/l         | 1.5 mg/l          |
| Cd2+      | –                | 0.01 mg/l         |
| Zn2+      | 5 mg/l           | 15 mg/l           |

4.4.4. Evaluation of groundwater for irrigation purposes

Classifications of groundwater for irrigation purposes are applied depending on several parameters including
Table 4. Guide to use saline water for livestock and poultry (after National Academy of Science, 1972).

| TDS mg/l | Remarks | Sample No. |
|----------|---------|------------|
| Less than 1000 | Relatively low level of salinity. Excellent for all classes of livestock and poultry. | – |
| 1000 to 2999 | Very Satisfactory for all classes of livestock and poultry. May cause temporal and mild diarrhoea in livestock not accustomed to them or water drop in poultry. | AC 2, Mo 23, Mo 26, Mo 21 |
| 3000 to 4999 | Satisfactory for livestock but may cause diarrhoea or be refused at first animals not accustomed to them. Poor water for poultry often causing water faces, increased mortality, and decreased growth especially in turkeys. | A 1, A 2, A 3, AC 7, AC 8, R 58, Mo 27, Mo 30, Mo 29, Mo 8, GV 874, Mo 13, Mo 1 |

Table 5. Suitability of groundwater for irrigation based on EC according to Fipps (2003).

| EC (µS/cm) | Water class | Samples | Percentage |
|-----------|-------------|---------|------------|
| <250      | Excellent   | –       | –          |
| 250–750   | Good        | –       | –          |
| 750–2000  | Permissible | –       | –          |
| 2000–3000 | Doubtful    | –       | –          |
| >3000     | Unsuitable  | All the studied samples | 100 % |

Table 6. Suitability of groundwater for irrigation based on TDS according to Fipps (2003).

| TDS (mg/l) | Water class | Samples | Percentage |
|-----------|-------------|---------|------------|
| <175      | Excellent   | –       | –          |
| 175–525   | Good        | –       | –          |
| 525–1400  | Permissible | –       | –          |
| 1400–2100 | Doubtful    | –       | –          |
| >2100     | Unsuitable  | All the studied samples | 100 % |

Table 7. Suitability of groundwater for irrigation based on SAR according to Tood, (1980).

| SAR        | Water class | Samples | Percentage |
|------------|-------------|---------|------------|
| S₁ < 10    | Excellent   | A1, A2, A3, A6, AC2, AC3 | 19.4 % |
| S₂ 10–18   | Good        | AC7, AC8, R134, X60, R58, R85, Mo 27, Mo 30, Mo 26, Mo 29, Mo 23, Mo 14, Mo 20, Mo 24, Mo 33, Mo 13, X85, X57, Mo 1, Mo 8 | 64.5 % |
| S₃ 18–26   | Doubtful    | X115, R90, R140, R113, Mo 2 | 16.1 % |
| S₄ > 26    | Unsuitable  | –       | –          |

Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Sodium Adsorption Ratio (SAR).

4.4.4.1. Electrical conductivity (EC). Groundwater is classified according to EC values proposed by Fipps (2003) into five classes (Table 5), all the studied samples belong to the Unsuitable group.

4.4.4.2. Total dissolved solids (TDS). The groundwater is classified according to TDS values proposed by Fipps (2003) into five classes (Table 6), all the studied samples belong to the Unsuitable groundwater group.

4.4.4.3. Sodium adsorption ratio (SAR). According to Toss’s classification (Tood, 1980) for the calculated values of SAR in the investigated water (Table 7), 19.4% of the studied samples of groundwater is classified as excellent irrigation water, 64.5% are classified as good irrigation water and 16.1% are classified as Doubtful irrigation water.

4.5. Geoelectrical data

4.5.1. Geoelectric data acquisition and interpretation

The quantitative interpretation of geoelectrical data is carried out through two techniques, the first technique is the manual interpretation using two layers master curves and the generalised Cagniard graphs, Koefoed (1960). The results of manual interpretation are used as initial model parameters for the second technique which is known as the analytical technique. The authors used IPI2WIN software (Bobachev et al., 2008) for the analytical technique to compute the inverted depths and resistivities for each VES curve. To verify the geoelectrical interpretation results one VES station (VES 3) is measured beside borehole number A4. The borehole data is used as constraints for our subsurface model. Figure 6(a) shows borehole A4 logging data, which reveals that El Moghra aquifer is associated with a sandstone layer at depth ~48 m from sea level representing the main aquifer in the El Moghra area. The results of the quantitative interpretation of VES’s data are used to construct a geoelectrical cross-section. (Figure 6(b)). The geoelectric cross-section shown that the subsurface section consists of six main geoelectrical units; the first unit is composed of gravel and sand of high resistivity values ranging from 102 to 2445 Ω.m and thickness of few metres. The second geoelectrical unit is characterised by varying resistivity values ranging from 19 to 1868 Ω.m and consists of sandstone intercalated with clay. The third one is composed of clay with low resistivity values ranging from 0.1 to 9 Ω.m. The fourth unit consists of sandstone and exhibits moderately to high resistivity values ranging from 21.7 to 1358 Ω.m, which represents the top of El Moghra aquifer. The fifth geoelectrical unit is composed of clay which reveals low resistivity values ranging from 0.7 to 8.8 Ω.m. The sixth geoelectrical layer represents the main aquifer in the area under study.
5. Conclusions

The TDS value is varied from 2236 mg/l (Brackish water) to 7830 mg/l (saline water). Brackish water is mainly found to be associated with the eastern part of the study area, close to Wadi El Natroun. It is suggested that the aquifer is recharged by the infiltration from the irrigation network. The groundwater salinity increases in the west and northwestern direction.

The groundwater is slightly alkaline with pH value ranged from 6.71 to 8.7. The concentrations of major ions are generally higher than the maximum-slantered limits, according to the World Health Organization (WHO, 2003 & 2011) and the Environmental Protection Agency (EPA, 2011). The hydrochemical composition reflects the NaCl water type. The investigated area can be used for the cultivation of salt-tolerant crops (Jojoba and Olives).
especially the western part of the study area and fish farming. The subsurface section consists of different alternating layers of sand intercalated with clay.

**Disclosure statement**

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

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### Appendix: Major Ion’s concentration (mg/l), EC (in µmos/cm) and TDS (mg/l)

| Long. | Lat. | Sample No. | Physiochemical Parameters | Major Cations | Major Anions |
|-------|------|------------|---------------------------|---------------|--------------|
| CE    | TDS  | pH | Ca | Mg | Na | K | CO3 | HCO3 | SO4 | Cl |
| 685725 | 3357963 | A1 | 8940 | 4950 | 305 | 287 | 864 | 35 | 43 | 839 | 760 | 1411 |
| 690742 | 3357972 | A2 | 9140 | 4520 | 292 | 240 | 795 | 34 | 42 | 840 | 789 | 1442 |
| 688270 | 3352975 | A3 | 8670 | 4340 | 291 | 242 | 792 | 32 | 40 | 841 | 785 | 1444 |
| 679235 | 3349933 | A6 | 8882 | 5240 | 309 | 352 | 887 | 41 | 43 | 884 | 762 | 1447 |
| 663562 | 3345265 | AC2 | 4240 | 2544 | 124 | 135 | 606 | 24 | 167 | 319 | 1417 |
| 659300 | 3351336 | AC3 | 3750 | 2250 | 109 | 119 | 536 | 22 | 147 | 283 | 1254 |
| 672796 | 3357303 | AC7 | 6967 | 4180 | 203 | 221 | 936 | 40 | 274 | 525 | 2329 |
| 662924 | 3355243 | AC8 | 6240 | 3744 | 182 | 198 | 892 | 36 | 245 | 470 | 2086 |
| 656364.9 | 3347790.7 | R134 | 11770 | 7500 | 7.28 | 280 | 328 | 1600 | 44 | 4 | 180 | 1000 | 3300 |
| 636390 | 3331697 | X60 | 9140 | 5880 | 6.8 | 180 | 243 | 1550 | 28 | 8 | 152 | 720 | 2700 |
| 637135 | 3335963 | X115 | 8780 | 5780 | 6.83 | 200 | 207 | 1700 | 27 | 12 | 180 | 750 | 2800 |
| 648812.2 | 3340753.4 | R90 | 10540 | 6800 | 7.5 | 200 | 292 | 1800 | 29 | 12 | 152 | 830 | 3200 |
| 654002 | 654002.04 | R58 | 6000 | 4250 | 7.6 | 160 | 146 | 1125 | 30 | 4 | 144 | 660 | 1950 |
| 653811.3 | 3340785.4 | R85 | 9890 | 6470 | 7.34 | 240 | 268 | 1700 | 21 | 12 | 156 | 670 | 3100 |
| 688444 | 3355770 | Mo27 | 6160 | 4384 | 7.6 | 275 | 158 | 1099 | 28 | 305 | 614 | 2057 |
| 689565.3 | 3351583 | Mo30 | 5620 | 3458 | 8.7 | 176 | 93 | 963 | 27 | 207 | 430 | 1665 |
| 697564.5 | 3349059.9 | Mo23 | 3620 | 2356 | 8.1 | 152 | 70 | 600 | 19 | 189 | 302 | 1119 |
| 698764.3 | 3347092.7 | Mo26 | 3420 | 2236 | 7.9 | 139 | 61 | 574 | 19 | 244 | 304 | 1018 |
| 693177.7 | 3338241 | Mo21 | 4360 | 2828 | 7.7 | 186 | 87 | 209 | 19 | 79 | 300 | 1488 |
| 688391.6 | 3334423.4 | Mo8 | 4940 | 3152 | 7.9 | 232 | 105 | 774 | 18 | 134 | 368 | 1589 |
| 686366 | 3337332 | Mo29 | 4820 | 3491 | 8.1 | 205 | 103 | 896 | 20 | 128 | 378 | 1823 |
| 654502.9 | 3328336.7 | Mo14 | 6120 | 5010 | 7.8 | 299 | 159 | 1310 | 28 | 164 | 613 | 2518 |
| 656878 | 3320740.8 | Mo20 | 7840 | 5508 | 8.1 | 327 | 173 | 1432 | 28 | 171 | 595 | 2868 |
| 650791.9 | 3321504.6 | Mo24 | 7760 | 5868 | 8.1 | 345 | 195 | 1511 | 29 | 201 | 551 | 3135 |
| 686380.1 | 3348787.0 | Mo33 | 9031 | 5870 | 8.7 | 183 | 67 | 701 | 20 | 116 | 442 | 1165 |
| 673762.1 | 3338324 | GV874 | 5584 | 3574 | 6.9 | 340 | 135 | 1279 | 15 | 100 | 610 | 1382 |
| 650366.5 | 3347752.2 | R140 | 11800 | 7830 | 7.52 | 200 | 377 | 2000 | 44 | 12 | 180 | 1000 | 3600 |
| 657205.8 | 3337809.9 | Mo13 | 5820 | 3842 | 7.7 | 212 | 134 | 1044 | 28 | 244 | 504 | 1797 |
| 656448.9 | 3344795.9 | R113 | 10290 | 6580 | 7.1 | 180 | 292 | 1700 | 30 | 12 | 160 | 900 | 2900 |
| 639261.1 | 333709.3 | X85 | 8390 | 5397 | 6.71 | 180 | 207 | 1400 | 31 | 12 | 144 | 520 | 2700 |
| 639388.1 | 3311705.7 | X57 | 9470 | 5900 | 7.1 | 180 | 243 | 1550 | 32 | 8 | 156 | 720 | 2700 |
| 671349 | 3345098 | Mo1 | 5770 | 4243 | 7.3 | 215 | 120 | 1032 | 42 | 189 | 718 | 2022 |
| 676112.2 | 3352333.5 | Mo2 | 8270 | 6480 | 8.2 | 303 | 151 | 1642 | 61 | 226 | 1198 | 3012 |

Average: 7334 4741 7.62 224 188 1136 30 19 259 618 2135