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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, SO_4, HCO_3 and CO_3) 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.

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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 hadrochemical analysis on groundwater samples in and around the study area. Araffa (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

Geomorphologicaly, 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

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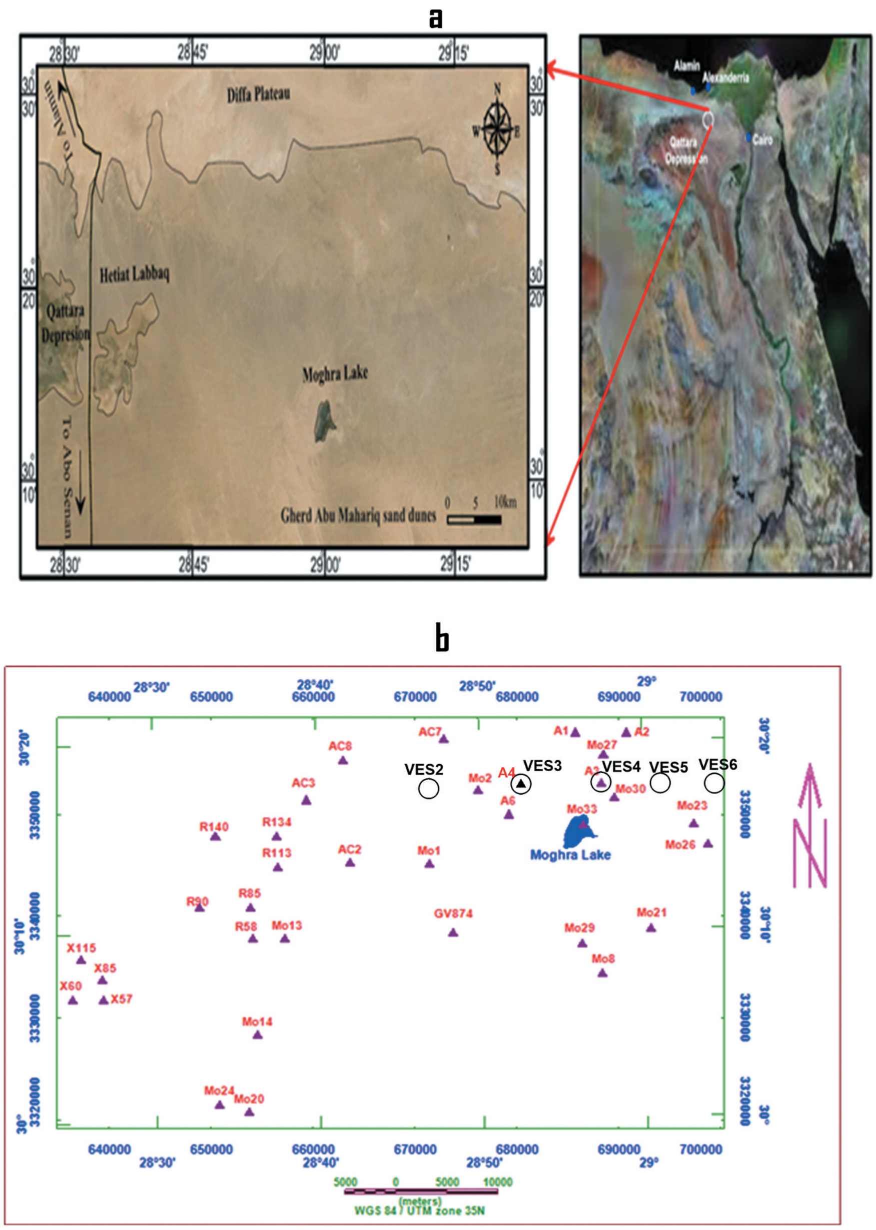

Figure 1. A) Location of the study area, b) VES and samples location map.

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 fluviomarine 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

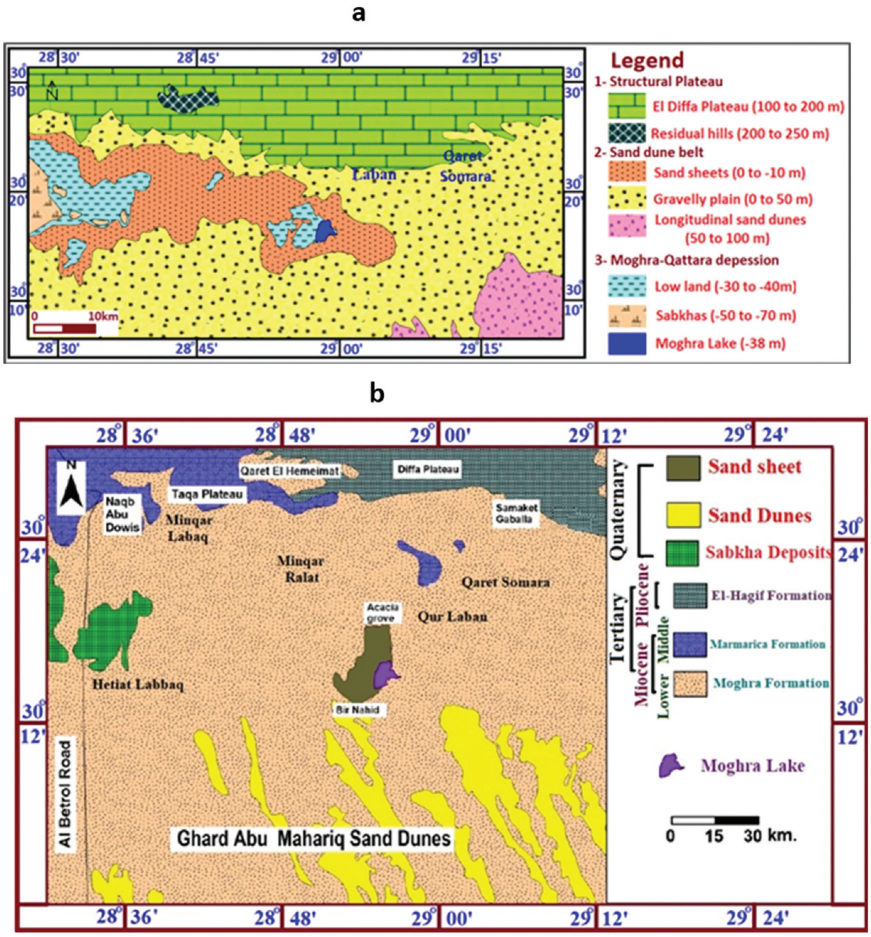

Figure 2. A) The main geomorphologic units of the study area (modified after Yousef 2013), b) Geological map of Moghra Oasis and its vicinities, modified after CONOCO (1987).

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, SO_4, HCO_3 and CO_3) 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

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

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).

TDS (in ppm) = 0.64 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).

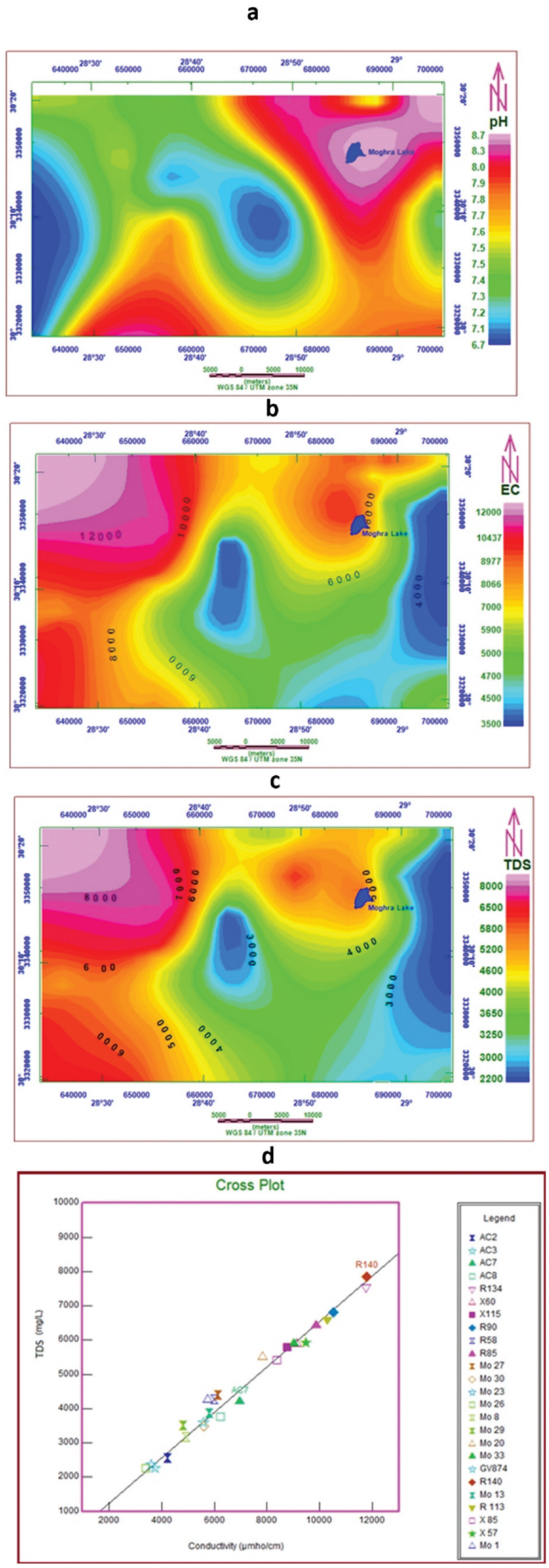

Figure 3. A) pH zonation map, b) Electric conductivity (EC) Zonation map, c) Total dissolved solids (TDS) zonation map, d) Cross plot showing the TDS & EC relationship.

Table 1. The chemical classification of groundwater according to (Chebotarev's, 1955) and the groundwater samples in each class.

Class		TDS (ppm)	groundwater samples
Fresh Water	Good Potable	<500	-----
	Fresh	500-700	-----
	Fairly Fresh	700-1500	-----
Brackish Water	Slightly Brackish	1500-2500	Mo23, Mo26
	Brackish	2500-3200	Mo21,AC2,Mo8
	Brackish	3200-4000	AC8,Mo30,Mo29, GV874,Mo13
Limits for Human Consumption			
Salt Water	Slightly Saline	4000-6500	A1,A2,A3,A6,AC7, X60,X115,R58,R85 ,Mo27,Mo14,Mo20, Mo24,Mo33,X85, X57,Mo1,Mo2
	Saline	6500-7000	R 90, R 113
	Very Saline	7000-10000	R 134, R 140
	Extremely Saline	>10000	0

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 (Ca^{2+}), and Magnesium (Mg^{2+}).

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):

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where, Na^+, Ca^{2+} and Mg^{2+} 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.

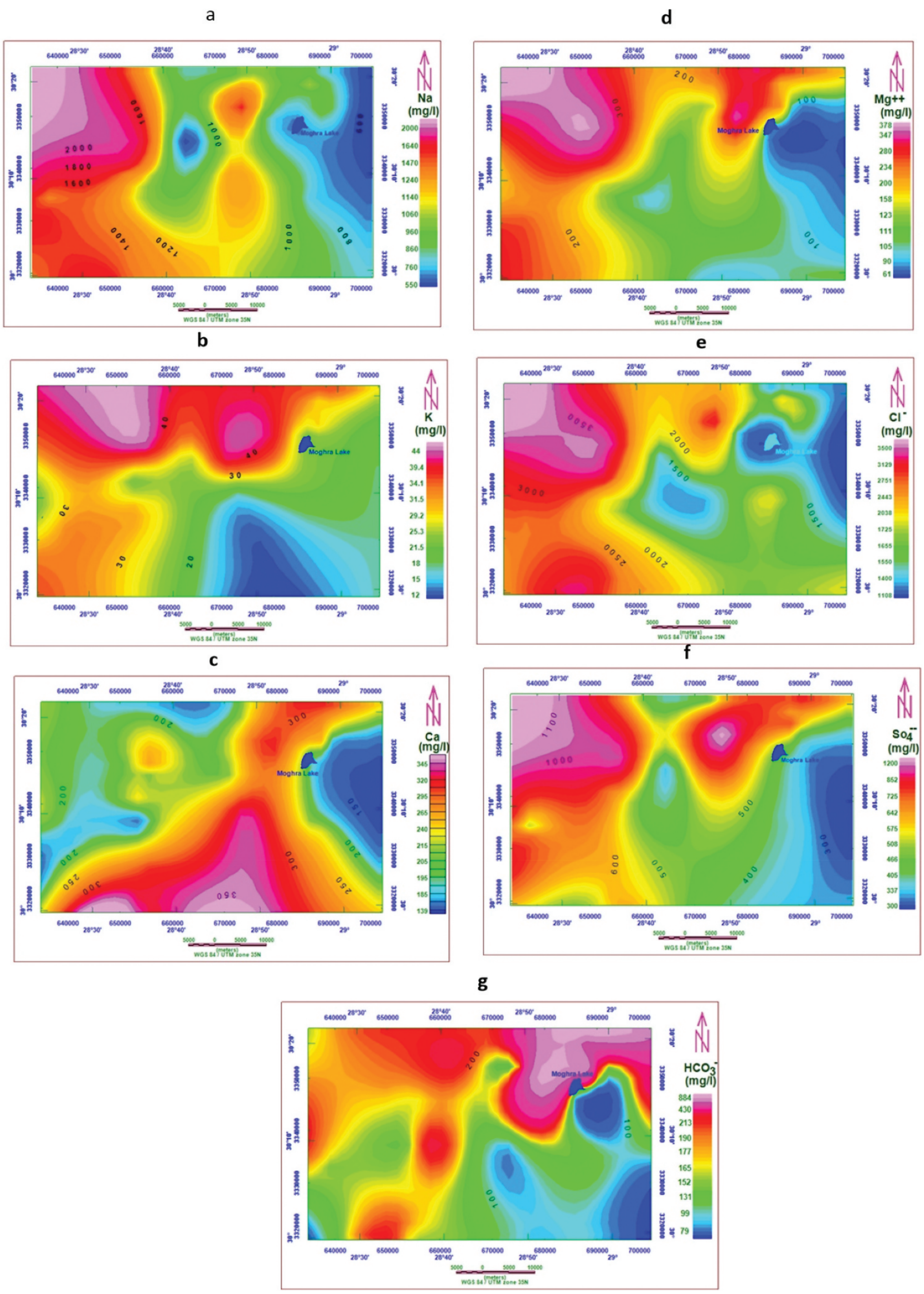

Figure 4. A) Sodium concentration map, b) Potassium concentration map, c) Calcium concentration map, d) Magnesium concentration map, e) Chloride concentration map, f) Sulphate concentration map, g) Bicarbonate concentration map.

4.2.2. Major anions concentration

Detection of the major anions, for example, chloride (Cl-), sulphate(SO_4^{2-}), carbonate (CO_3^{2-}), and bicarbonate (HCO^{3-}) 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.

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 of the 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 < Cl > 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 soapsuds 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 becharacterisedby 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;

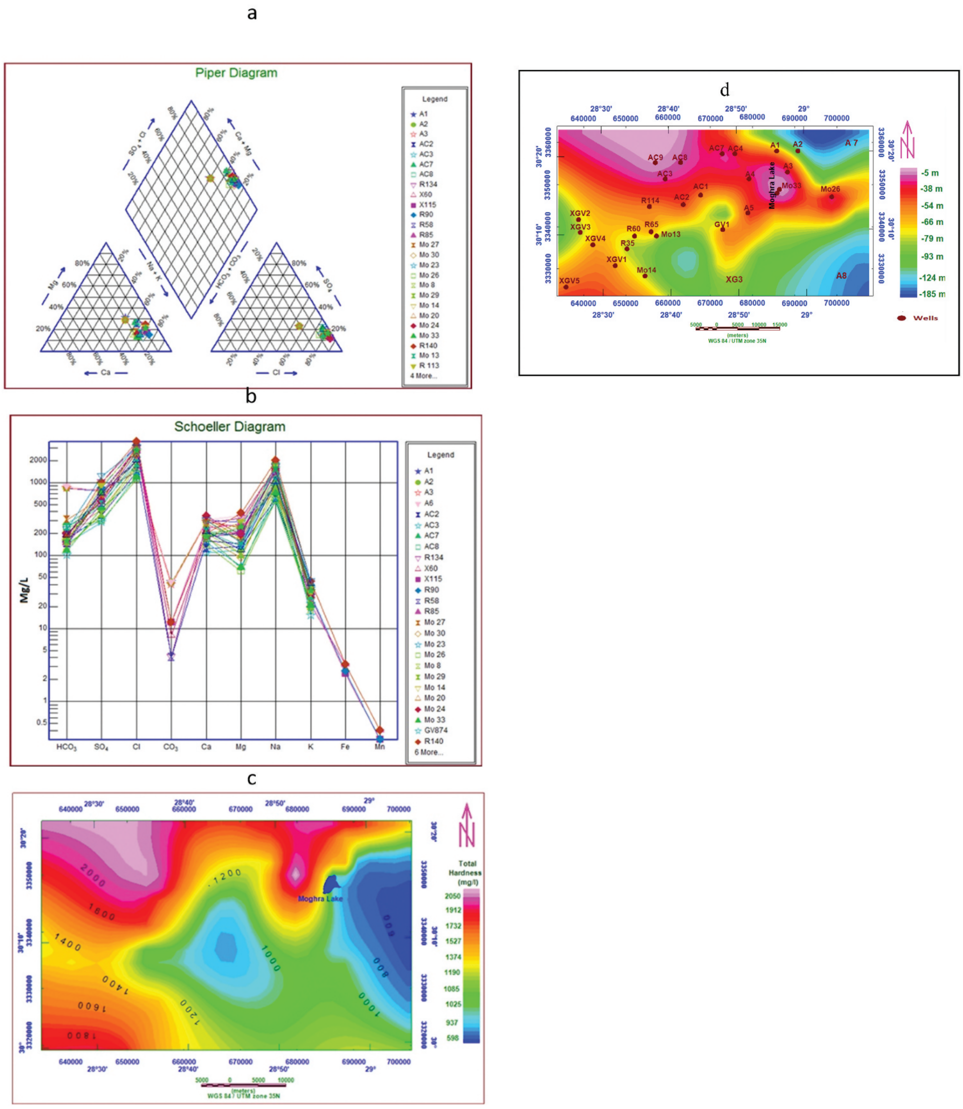

Figure 5. A) Piper classification diagram, b) Schoeller diagram, c) Total hardness distribution map, d) Water table map from borehole data.

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
SO_4^-	200 mg/l	400 mg/l
HCO_3^-	–	–
Mg^{++}	50 mg/l	150 mg/l
Ca^{++}	75 mg/l	200 mg/l
Na^+	–	200 mg/l
Fe^{++}	0.3 mg/l	1.00 mg/l
Mn^{++}	0.1 mg/l	0.5 mg/l
Pd^-	–	0.5 mg/l
Cu^{++}	1.0 mg/l	1.5 mg/l
Cd^{++}	–	0.01 mg/l
Zn^{++}	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 causes temporal and mild diarrhoea in livestock not accustom to them or watery dropping 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
S_1 < 10	Excellent	A1,A2,A3,A6,AC2, AC3	19.4 %
S_2 10–18	Good	AC7,AC8,R134, X60,R58,R85, Mo27,Mo30, Mo26,Mo29, Mo23,Mo14, Mo20,Mo24, Mo33,Mo13, X85,X57,Mo1, Mo8	64.5 %
S_3 18–26	Doubtful	X115,R90,R140, R113,Mo2	16.1 %
S_4 > 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 are 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 ffth 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.

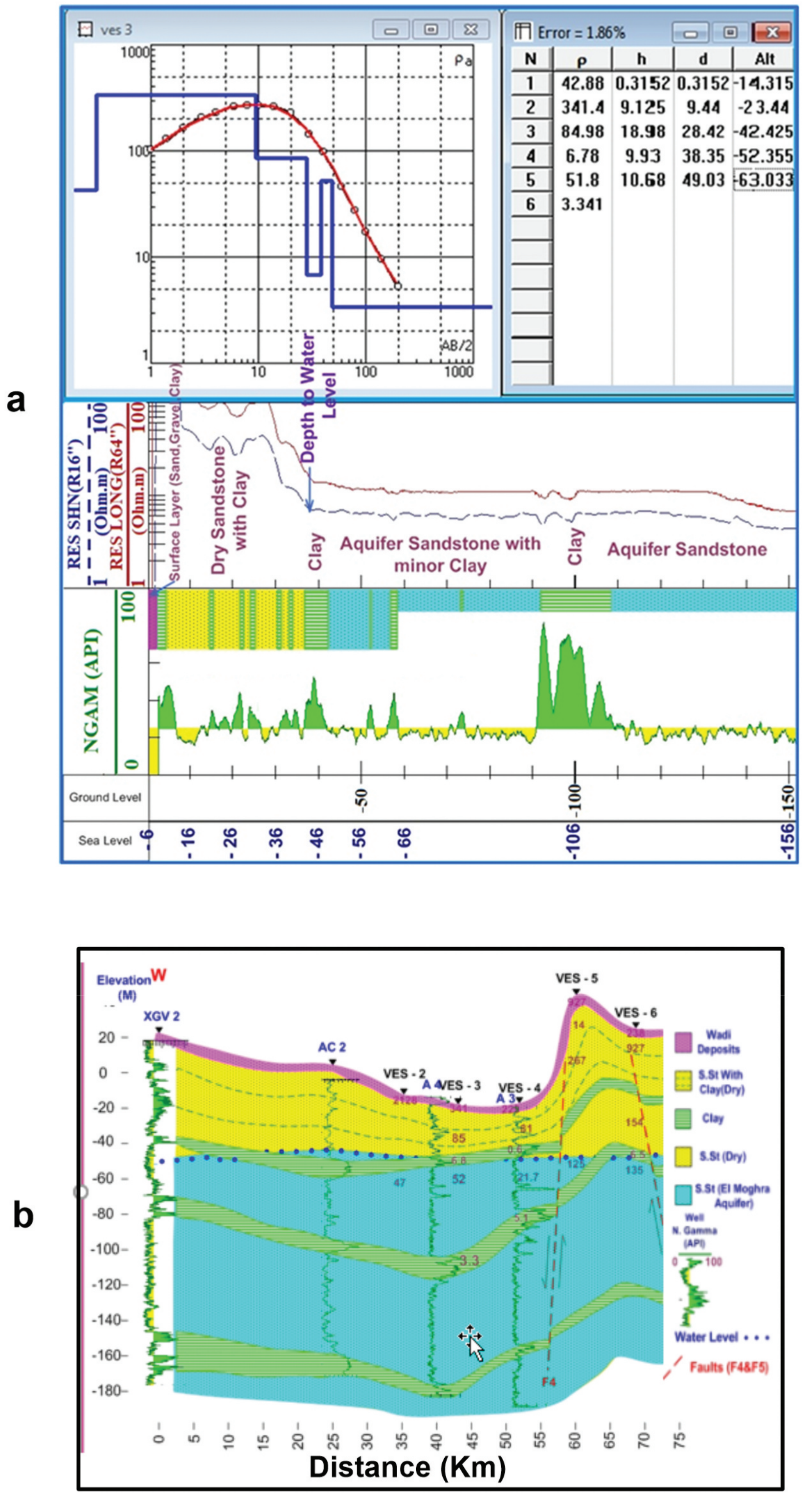

Figure 6. A) Correlation between VES No. 3 indicating resistivities, thickness, depths, elevations of different units complained with well A4. b) Geoelectric cross sections along profiles A – A\showing different geologic units, fault elements, borehole logs.

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-slandered 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 µmhos/cm) and TDS (mg/l)

Long.	Lat.	Sample No.	Physiochemical Parameters			Major Cations				Major Anions			
			EC	TDS	pH	Ca	Ma	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	3335693	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
688442	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
697365.5	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	3338824.1	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
653687	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	3348870.5	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		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	3333709.3	X85	8390	5397	6.71	180	207	1400	31	12	144	520	2700
639388.1	3331715.7	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
676113.2	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