

Quaternary aquifer hydrochemical assessment, El-Tur area, South Sinai, EgyptMohamed Shehata¹, Samy Aita² and Yara Abd El Azeem¹

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ABSTRACT: The main water supply source is the Quaternary aquifer in El-Tur area, southwest Sinai governorate, Egypt. The groundwater of the Quaternary aquifer is of meteoric origin, mainly recharged by surface runoffs and the outflow of subsurface from the Pre-Cambrian basement rock fractures. The groundwater flow direction is from east to west. Twenty one groundwater samples from several wells were collected and analyzed at El-Tur area. Several hydrochemical characteristics were determined including physicochemical parameters (pH, electrical conductivity, hardness, and total dissolved solids). Major anions (sulfate, chloride, and bicarbonate) and major cations (sodium, potassium, magnesium, and calcium) were also analyzed. Groundwater is an alkaline and salinity ranges from fresh water (363 mg/l) to saline water (24210 mg/l). The chloride and sodium content predominate in groundwater. The calcium is more than magnesium in terms of content. The results of the chemical analyses refer that the types of water are NaCl and MgCl₂ of marine genesis as well as CaCl₂ of old marine genesis. Na-Cl-SO₄ water dominates. According to Piper trilinear diagram, groundwater samples are NaCl and mixed Ca/MgCl type. The saturation indices for minerals were calculated and used to understand the rock-water interactions. The results indicate to the presence of 7 minerals that reflect the chemical properties of the shallow aquifer. The majority of groundwater samples is unsuitable for drinking and requires treatment for irrigation. The current study was conducted for qualitative analysis depending on groundwater physicochemical parameters.

KEYWORDS: Quaternary Aquifer; South Sinai; Groundwater quality; El-Qaa plain.

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I. INTRODUCTION

Sinai Peninsula represents the eastern-strategic part of Egypt. Nowadays, more attentions are paid by the officials and private sectors for the development of some parts of Sinai. El-Tur area is located in the west of South Sinai which is located on the eastern side of the Gulf of Suez Rift Valley (Fig. 1). The study area bordered to the east by the El-Qaa plain, on the northwest by Gabel Hammam Mousa and to the Gulf of Suez in west and lies between latitudes 28° 2' and 28°23' N and longitudes 33°33' and 33°47' E (Fig. 1). An arid climate with infrequent precipitation is dominated in the area. Sinai Peninsula is affected by intensive block fault structure and has a number of extended plains, one of these plains is El-Qaa Plain which is located in Sinai southwestern part where geomorphologic and geologic settings control the occurrence of groundwater. This Quaternary aquifer is low-cost fresh water source in this area which is shallow aquifer and composed of alluvial fans, terrace gravel deposits and wadi deposits. Several hydrogeological, geological and geophysical studies have been conducted in the study area (El-Tur area) parts and several workers studied the El-Qaa plain hydrogeology such as Issar and Gilad (1982); El-Refaei (1984); Shendy (1984); Dames and Moore (1985); Tealeb and Riad (1987); Meshref and El-Kattan (1989); Ibrahim and Ghoneimi (1992); WRI and JICA (1999); Gorski and Ghodeif (2000); Abdel-Lattif (2003); Leppard and Gawthorpe (2006); Sultan et al. (2009) and El-Sayed et al. (2011).

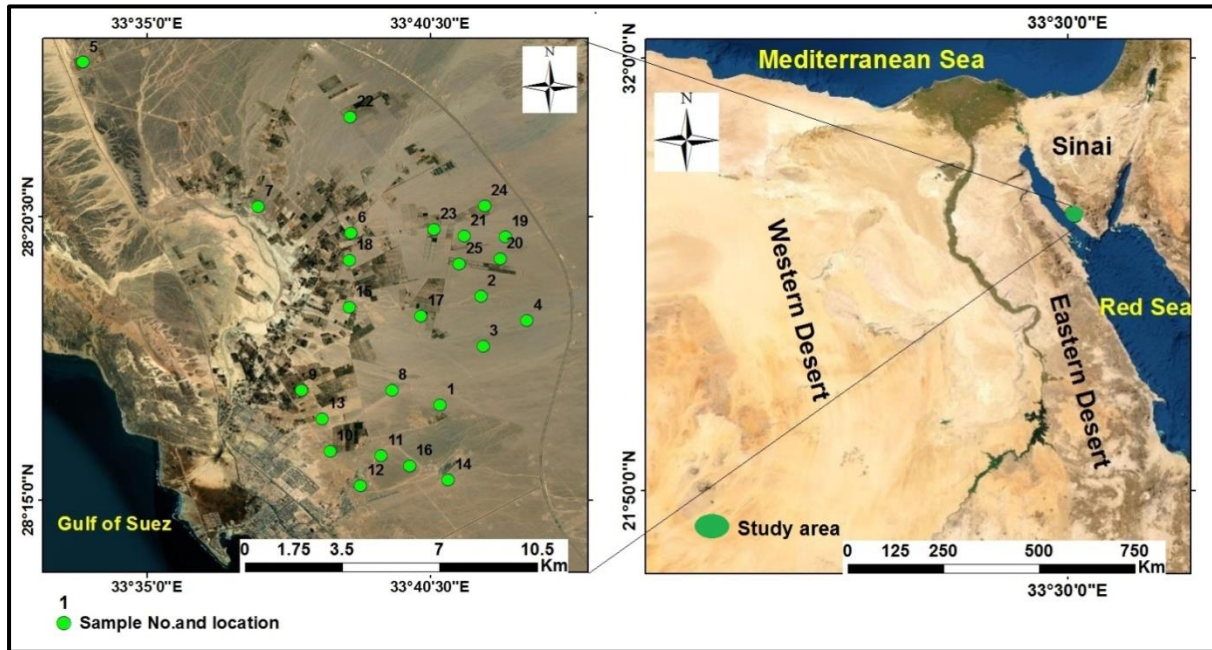


Fig. 1. Map of the study area showing groundwater samples locations.

The primary goals of this research the assessment the groundwater resources in El-Tur area, Southwest Sinai, Egypt and the future investments of the South Sinai area.

Geological Settings:

Different authors studied the geomorphological and geological characteristics of El-Tur area. Among of them; Gilboa (1980); CONOCO (1987); WRI (1995) and WRI and JICA (1999). Geologically, in El-Tur, the exposed rocks have a long geologic time range from Precambrian to Quaternary.

Geomorphologically, three main geomorphic units are divided the area into; the lowland unit, the northeastern high mountain unit and the northwestern relatively high mountain unit as the following (Fig. 2).

The northeastern high mountains are the Precambrian basement rocks and formed of crystalline rocks such as medium to high grade metamorphic rocks, alkaline to alkali feldspars granitic rocks, diorite and granodioritic rocks and gabbroic rocks. The geomorphic unit constitutes of topographic highs with sharp relief and the elevation up to about +2641m from mean sea level (G. Katherina). The surface is very tough with outcrop edges and peaks and dominated by fissures and fractures. It is dissected by a huge network of drainage basins, such as Abura, El Abyad, Imlaha, Isla, Mir, Shidiq, Wagan, Thiman and Mahash basins that terminate in the lowland unit.

The northwestern-relatively high mountains are sedimentary rocks belong to the geologic times of Paleozoic, Mesozoic, and Cenozoic. Elevated hills are dominated and recognized into series of elongated ridges arranged in a NW-SE direction. The maximum elevation reaches about +370 m (G. Abu Suwera). The surface is dissected by dense subsequent drainages of sub parallel type following the regional slope of the land towards the east.

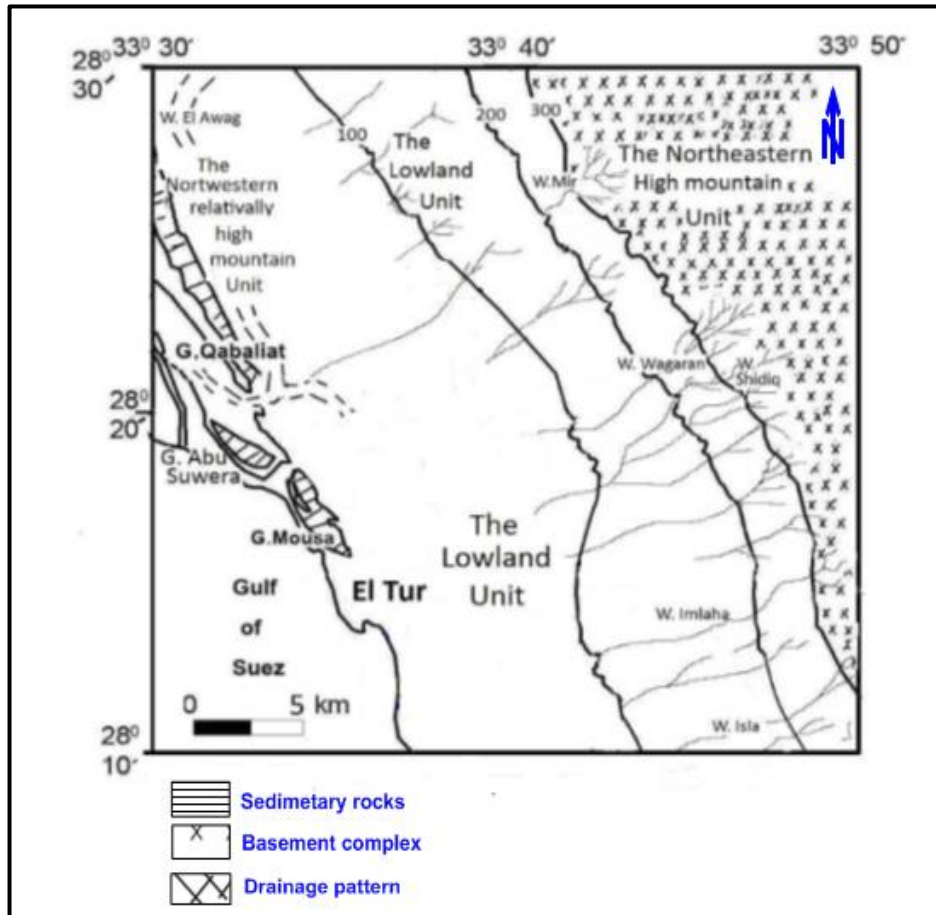


Fig. 2. Geomorphic units map of study area.

The lowlands surface is consisted of wadi deposits, sabkha deposits (clay, silt and evaporites) and undifferentiated Quaternary deposits (alluvial fans, gravel, sand, and recent coastal deposits). Northerly, the lowlands occupy the area between the preceding two geomorphic units while to the south it faces directly the Gulf of Suez. The surface is characterized by low elevations having a slope from east to west from about 300 m to 4 m close to the Gulf of Suez shore-line.

Structurally, El-Qaa Plain lies in the east of the Gulf of Suez. Several faults and tilted fault blocks were developed in the plain during the Neogene Suez rift opening (Moustafa and El-Raey, 1993).

In the plain, the major faulting is parallel to the Gulf of Suez rift direction, i.e., direction of NE-SW. Most of the major faults are normal and synthetic with the down-thrown towards the center of the rift (Robson, 1971). El-Qaa Plain is influenced by a NE-SW oriented fault which runs through Wadi Isla south El-Tur area and separates the plain into the northern and southern parts.

The subsurface lithostratigraphic succession in the area is highly influenced by faulting system (Fig. 3). The sedimentary sequence belonging to Pre-Miocene, Miocene and Quaternary times and its thickness generally increases from northeast to southwest directions. The maximum thickness reaches about 2500 m in the center of the area. The structural features were recognized through the vertical and lateral correlation such as horsts and grabens blocks.

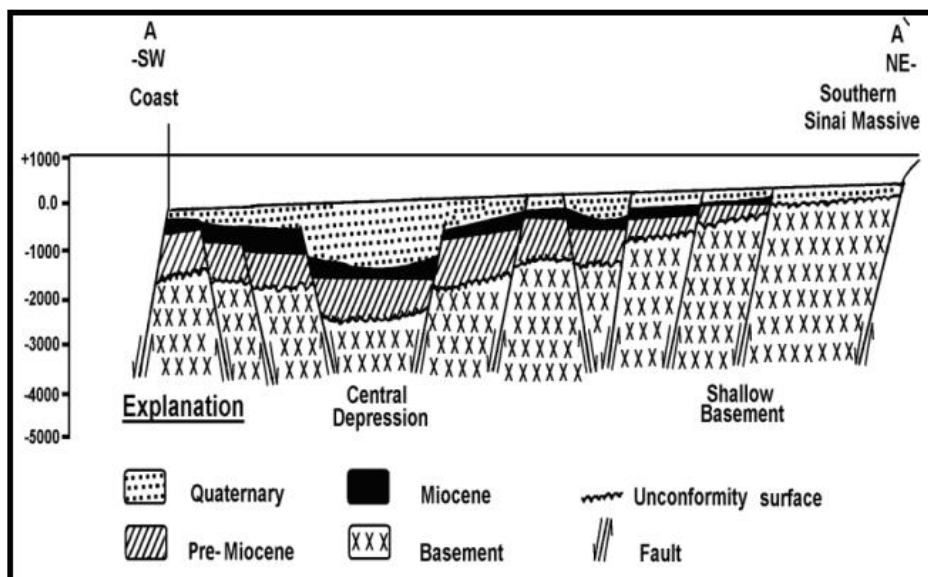


Fig. 3. Generalized geological cross section trending in a NW-SW direction of El-Tur area (Giloba, 1980).

Hydrogeological Conditions:

In the area, four water bearing formations are characterized by the following; the fractured Pre-Cambrian basement rocks, the lower Cretaceous Malha Formation (the Nubia sandstone aquifer system), the Lower Miocene clastic deposits and the Quaternary deposits.

El-Qaa plain rises up to 200 m (above sea level); sloping gently to the south-east direction which is characterized by young Quaternary and Tertiary alluvial sediments, gypsum, sandstone, and limestone. More of the alluvial sediments originated from the hills to the eastward (Monier and Amer, 2003).

WRRI, (1995) and Gorski and Ghodeif (2000) recorded that the lower Miocene aquifer was saturated by saline water due to the dissolution of evaporites. The Quaternary aquifer represents the available aquifer with great potential. The Quaternary aquifer is formed of sedimentary facies that change laterally and vertically in thickness and lithologic characters. The aquifer is composed mainly of gravel and coarse sand with fragments of weathered basement, the aquifer lithology consists mainly of marine sandstone, limestone, coral reefs, and clay alternating with continental sabkha and alluvial deposits. The thickness ranged between 50m close to northwestern sedimentary hills to 400m east El-Tur City to 1000 m in the study area center (WRRI, 1995).

Sands and coarse materials increase eastwards. They are mixed with boulders and cobbles of weathered Pre-Cambrian rocks. Limestone, clay, coral reefs and evaporite increase westwards due the shoreline and G. Mousa. The Quaternary aquifer is bordered from the east and northeast directions by the fractured Pre-Cambrian mountains which represent the surface collected areas and the recharge boundary while from south; it is bounded by the subsurface sealed fault passing through W. Isla. It is bounded from the southwest by the Gulf of Suez representing a discharge outlet and salt water intrusion and from the northwest by G. Qabaliat which acts as a no flow boundary (Gorski and Ghodeif, 2000).

The Quaternary aquifer is mainly recharged by winter rains which fall on the area. The groundwater exists under free water table conditions. Rains was recorded and ranged from 10 mm / year on the Quaternary of exposed sediments and reach to 60 mm / year on the eastward Precambrian mountains representing the main collected areas (Gorski and Ghodeif, 2000). Occasionally, the eastern high areas exposed to heavy rains about 76 mm / day for few hours and causing flash flood (WRRI, 1995). The Quaternary aquifer has hydraulic conductivity (K) values range from 3 m/day to 136 m/day and transmissivity (T) values ranging from 81 m² / day to 3407 m² / day with an average value of 600 m² / day (WRRI, 1995).

Study wells tapping the Quaternary aquifer are classified into deep wells (depths range between 65m and 140m) with diameters from 8 to 12 inches. The depth to water levels changes from east direction to west direction of the area according to topographic elevation (El-Sayed et al., 2011). The flow of groundwater system changes have resulted in salinization, with the salts dissolution and stagnant saline water leaching from deposits of coral reef. A fresh water

aquifer exists in the east of the area of study, but a salt-water aquifer overlies in the southern part hence the abstraction from that aquifer part must be limited (Sultan et al., 2009)

II. MATERIALS AND METHODS

Geological and hydrological data were collected from the previous works. Sampling is carried out for 21 groundwater sample from the study area as for chemical analysis (Fig. 1) during 2019. The coordinate and altitudes of samples were determined by Global Positioning System device (GPS). The depth ranges from 65–140m. The electrical conductivity (EC, $\mu\text{S}/\text{cm}$), the hydrogen ion concentration (pH), the water temperature (T °C) were measured in situ using a mobile meter of EC and pH (HANNA). Total dissolved solids are the measurement of overall minerals dissolved amount in water. It is a very useful for assessment water quality. The water samples were analyzed chemically for major ions according to the following methods; potassium (K^+) and sodium (Na^+) were analyzed by using digital Flam Analyzer. While magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), nitrate (NO_3^-) and bicarbonate (HCO_3^-) were analyzed using the conventional titration methods, but sulfate (SO_4^{2-}) was analyzed by Spectrophotometer. The geochemical results are displayed on piper trilinear plot using Aqua Chem (4.0) software is used to evaluate the quality control procedure and predominated study area hydrogeochemical facies. Saturation indices were calculated for some minerals in groundwater samples.

III. RESULTS AND DISCUSSION

Hydro-chemical properties:

Chemical analyses as well as SAR for Quaternary aquifer groundwater samples are presented in table (1). The groundwater samples are nearly neutral to slightly alkaline water wherever the pH value ranges between 6.76 and 8.33. The groundwater is characterized by significant heterogeneity. The total dissolved solids (TDS) range between 363 mg/l (well No. 19) and 24210 mg/l (well No. 10). The electrical conductivities (EC) at 25 °C vary from 542 $\mu\text{S}/\text{cm}$ (well No. 19) to 36134 $\mu\text{S}/\text{cm}$ (well No. 10) for groundwater samples. Groundwater conductivity shows lateral variability. A continual increase in salinity is observed to be from the east to west with groundwater flow direction (Fig. 4). A wide variation of salinity and major ions in the Quaternary aquifer (Table 1) reflects the different geochemical processes effect and the large variation in the hydrochemical facies.

Water classification used different methods according to the total dissolved salts. Todd (1980) classified the water according to the value of TDS into four classes: fresh (less than 1000 mg/l), brackish (1000 - 10000 mg/l), saline (10000 -1000000 mg/l), brine (more than 1000000 mg/l). In the current study area, the groundwater is classified as fresh to saline.

The results of cations Na^+ , Mg^{2+} , Ca^{2+} and K^+ and anions SO_4^{2-} , Cl^- and HCO_3^- for groundwater samples are tabulated in table (1). Na^+ is a major cation and Cl^- is a major anion in the most samples.

One of the major ions dissolved in natural waters is sodium ion when react with chloride ions produces rock salt (NaCl). Frequently, sodium ion is considered as an important parameter in deciding the irrigation water suitability. The Na^+ concentrations range from 38 mg/l to 6230 mg/l.

The Ca^{2+} concentration ranges from 29 to 1490 mg/l in groundwater samples. The Mg^{2+} concentration in groundwater samples range from 13 to 1114.3 mg/l. The K^+ presence is very important in the natural water and vital nutrient component for plants (EEAA, 2002). In the groundwater samples K^+ concentrations are reaches up to 53 mg/l.

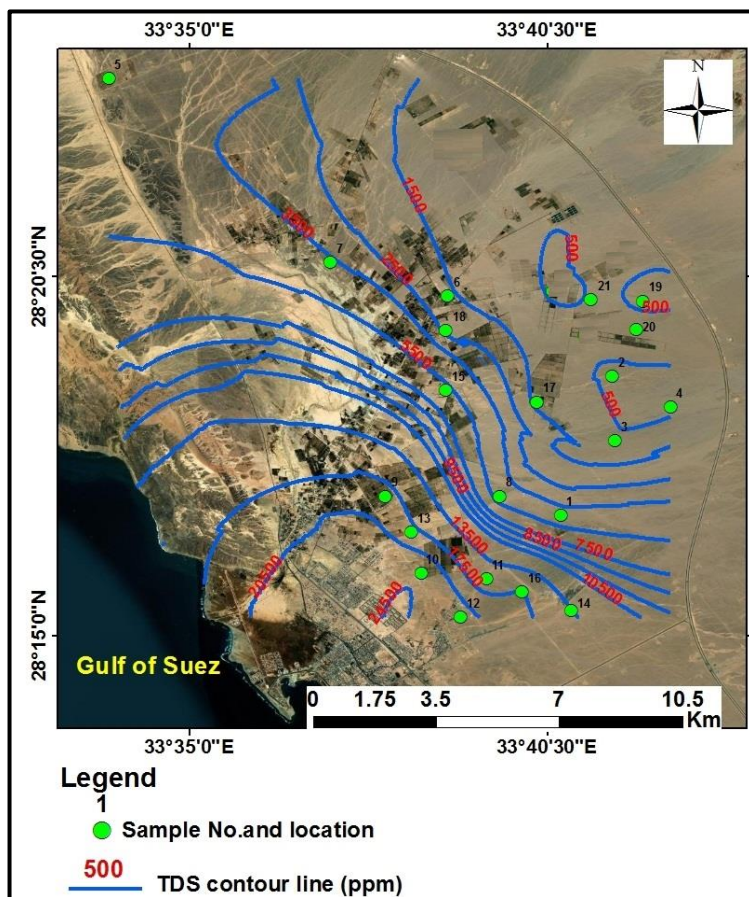


Fig. 4. Study area salinity distribution map of groundwater.

Table 1. Chemical analysis of studied groundwater samples, El-Tur area.

Sample No.	pH	EC μ S/cm	TDS ppm	TH ppm	SAR epm	K ppm	Na ppm	Mg ppm	Ca ppm	Cl ppm	SO ₄ ppm	HCO ₃ ppm
1	6.76	8220	4150	6116.3	3.89	7	700	850	1050	3143	1200	1596.3
2	7.77	820	410	334.8	0.90	2	38	45	60	177	50	103.1
3	7.63	1180	590	669.6	0.76	2	45	90	120	313	150	126.2
4	7.65	990	440	768.2	1.41	3	90	80	176	464.6	60	196
5	7.01	7700	3860	6613.9	3.96	10	740	880	1200	3129.2	1296.3	1800
6	7.48	3280	1650	5147.2	2.39	4	395	760	810	1909.6	1600	1327.1
7	6.78	7320	3680	8301.3	3.58	50	750	1114.3	1490	3108	4500	916.4
8	8.08	6892.5	4618	336.7	36.98	12	1560	40	69	1430	1310	179
9	8.22	28736	19253	3623.4	38.37	7	5310	506	618	4300	8312	187
10	8.29	36134	24210	4750.3	39.32	30	6230	783	613	7350	9000	104
11	8	22691	15203	4362.8	25.42	53	3860	690	611	8920	820	236
12	7.99	33043	22139	5278.1	36.04	50	6020	790	813	9380	4950	125
13	8.2	27143	18186	5287.7	24.23	36	4050	503	1290	7150	5000	141
14	8.33	20315	13611	4213.9	20.10	10	3000	783	398	4890	4400	113
15	7.98	9119.4	6110	3215.4	3.32	32	433	163	1020	2200	1350	153
16	8.23	26567	17800	442.4	109.60	42	5300	56	85	5220	3900	183
17	8.01	1882	1260.8	476.7	4.58	3	230	51.6	106	550.25	8.5	2.44
18	8.3	3381	2265	934.7	5.38	8	378	21	340	1020	31	350
19	7.96	542	363	125.8	2.91	3	75	13	29	126	11	100
20	8	1209	810	269.1	4.51	4	170	26	65	280	6	230
21	7.9	776	520	181.3	3.42	3	106	18	43	180	7	160
EHCW	9.2	-	1200	500	-	-	200	150	200	500	400	-
WHO	9.5	1500	1000	500	-	12	250	100	75	250	250	-

*EHCW: Egyptian Higher Committee for Water

*WHO: World Health Organization

The Cl⁻ concentrations of the studied groundwater samples reaches 9380 mg/l. The SO₄²⁻ concentration in the studied samples ranges from 6 to 9000 mg/l. The content of bicarbonate varies between 2.44 and 1800 mg/l in groundwater samples.

Hardness of water is caused by the cations presence like calcium and magnesium for total hardness and anions like carbonate and bicarbonate for hardness of carbonate. Hard water isn't a health risks but it may not be suitable for domestic usage especially laundry. TH in the area of study varies from 125.8 to 8301 mg/L (Table 1) which reflects high calcium and magnesium contents in water due to dissolution of anhydrite and gypsum in the circulating water.

Water type and ion ratios

A- Water type

According to groundwater samples chemical analyses, the types of water are categorized according to the prominent anions and cations into:

- Cl – Na; distinguishing 52 % of samples.
- Cl - Mg; distinguishing 24% of samples.
- Cl - Ca; distinguishing 14% of samples (Nos. 4, 15 & 18).
- SO₄ – Na; distinguishing one sample (No. 9).
- SO₄ – Mg; distinguishing one sample (No. 7).

However, the Cl – Na type is noticed in the majority of samples of groundwater, reflecting the leaching and dissolution contribution of marine deposits and high evaporation processes beside the old recharge of groundwater with a long water-rock interaction. On the other hand, the SO₄ – Na type is recorded in well No. 9 only, reflecting the intermediate stage of metasomatism of groundwater.

B- Ionic ratios

Groundwater genesis is defined through the calculation of hydrochemical parameters such as rCa/rMg, rNa/rCl, and rSO₄/rCl (meq/l) and comparing the standard values of normal sea water with these parameters (Table 2). These parameters used as a tool for detecting water contamination and water mixing from different sources. The indication of rNa/rCl ratio to sources of salinity during the flow of groundwater (Cartwright and Weaver, 2005).

i) Sodium/chloride ratio (rNa^+/rCl^-)

rNa⁺/rCl⁻ coefficient is particularly important since it is used to detect the origin of groundwater (meteoric or marine). This coefficient is less than the unity in sea water while exceeds unity in meteoric water. The rNa⁺/rCl⁻ value ranges between 0.22 and 1.91, with average is 0.78. About 48 % of the total samples have rNa⁺/rCl⁻ value more than the seawater (0.83) which indicates the continental deposition. The ratio was less than unity reflecting the leaching and dissolution processes of marine interbeds (about 76% of water samples). The samples with rNa/rCl > 1 reflect either seawater intrusion and/or Na removal through cation exchange with Ca in clay minerals.

ii) Sulfate/chloride ratio (rSO_4^{2-}/rCl^-)

Ratios of rSO₄²⁻/rCl⁻ show how an anion evolves during hydrogeochemical processes along paths of flow (Han et al., 2009). rSO₄/rCl ratio can be a good indicator to detect any excess of sulfate in groundwater associated with karst groundwater with dissolved gypsum (Liang et al., 2007) and terrestrial salts leaching or oxidation of sulfides in the aquifers. The value of rSO₄²⁻/rCl⁻ ratio ranges between 0.01 and 1.43 with a mean value of 0.42, which is more than that of sea water (0.1). It reflects the local terrestrial salts dissolution rich in sulfate. The standard values of sea water of sulfate and chloride are 2530 and 19400 mg/L, respectively.

iii) Calcium/magnesium ratio (rCa^{2+}/rMg^{2+})

rCa²⁺/rMg²⁺ ratios imply the dissolution of calcite and dolomite in the aquifer materials. Generally, values around unity and that indicate to dolomite dissolution (Mayo and Loucks, 1995). The range and mean values of this ratio are 0.31- 9.83 and 0.72, respectively. This means that, the mean value is more than sea water (0.18) and less than rain-water (7). Most of the investigated groundwater samples have rCa²⁺/rMg²⁺ less than unity (Table 2). The samples indicated that higher ratios were caused by increased gypsum or calcite dissolution.

iv) Calcium/sulfate ratio (rCa^{2+}/rSO_4^{2-})

The value of this ratio ranges between 0.05 and 29.4 with average is 6.02, which is more than the value of sea-water (0.39) and rain-water (2.63).

v) Calcium/chloride ratio (rCa^{2+}/rCl)

Water samples have values of rCa^{2+}/rCl that range between 0.03 and 0.85, with average value of 0.43 which is more than the sea-water recorded value (0.04). All groundwater samples showed that the ratio was less than one which indicates leaching of marine salt.

Table 2. Calculated ion ratios of analyzed groundwater samples in El-Qaa plain area compared to reference sea-water value.

Ion Ratios	Sea water	Groundwater Samples																				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
rNa/rCl	0.854	0.3	0.3	0.2	0.3	0.4	0.3	0.4	1.7	1.9	1.3	0.7	1	0.9	0.9	0.3	1.6	0.6	0.6	0.9	0.9	0.9
rCa/rMg	0.194	0.7	0.8	0.8	1.3	0.8	0.6	0.8	1.1	0.7	0.5	0.5	0.6	1.6	0.3	3.8	0.9	1.2	9.8	1.3	1.5	1.4
rSO ₄ /rCl	0.100	0.3	0.2	0.3	0.1	0.3	0.6	1.1	0.7	1.4	0.9	0.1	0.4	0.5	0.7	0.4	0.5	0.01	0.02	0.6	0.02	0.03

Assemblages of hypothetical salts

Considering the hypothetical salts, six main assemblages are recognized for the samples in the investigated area. About 47 % of groundwater samples are characterized by assemblage I; It is characterized by the appearance MgCl₂, MgSO₄ and CaSO₄ salts indicating the leaching effect and marine salts dissolution, terrestrial deposits and evaporites (mainly gypsiferous shale) rich in sulfate and chloride. About 24 % of groundwater samples are characterized by assemblage II, which is characterized by the presence of sulfate salts (more advanced stage that reflects the effect of leaching and dissolution of the terrestrial salts on groundwater (Table 3). Assemblage III which contain three bicarbonate salts, reflect the effect of leaching and dissolution of terrestrial salts by rain-water local infiltration during pluvial and post-pluvial processes as well as from surface water system. About 14% are characterized by assemblage IV.

The occurrence of MgCl₂ and CaCl₂ represents a marine signature. (NaCl, CaSO₄ and mixed CaNaHCO₃) are likely produced by weathering of rock salts; aquifers contain gypsum as well as return flow of irrigation.

Table 3. Assemblages of the hypothetical salts of groundwater samples.

hypothetical salts Assemblages	No.	Percent %
I: NaCl, MgCl ₂ , MgSO ₄ , CaSO ₄ and Ca (HCO ₃) ₂	10	47%
II: NaCl, Na ₂ SO ₄ , MgSO ₄ , CaSO ₄ and Ca (HCO ₃) ₂	5	24%
III: NaCl, Na ₂ SO ₄ , MgSO ₄ , Mg (HCO ₃) ₂ , Ca (HCO ₃) ₂	1	5%
IV: NaCl, MgCl ₂ , MgSO ₄ and Ca (HCO ₃) ₂	3	14%
V: NaCl, MgSO ₄ , CaSO ₄ and Ca (HCO ₃) ₂	1	5%
VI: NaCl, MgCl ₂ , MgSO ₄ , CaCl ₂ , CaSO ₄ and Ca (HCO ₃) ₂	1	5%

-Piper trilinear diagram

The types of water in the study area were identified based on their chemical composition by using the Piper trilinear diagram (Piper, 1944), which is frequently used to understand the issues concerning groundwater geochemical evolution of (Fig. 5). Different groundwater quality classes can be distinguished by their plotting in sub areas of the diamond-shaped (Fig. 5) as follows, all groundwater samples are located inside sub areas (6, 7 and 9). About 62% of samples restricted in (sub-areas 7), where the water is dominated by primary salinity character ($SO_4^{2-} + Cl$) > ($Na^+ + K^+$), and where calcium and magnesium chloride and sulfate salts present. About 33% of samples restricted inside (sub-areas 6), where hardness of non- carbonate (secondary salinity) exceed 50% and Ca-Cl type. About 5% of samples restricted in sub-area (9), wherever no one cation/anion pair more than 50% mixing process. Main water type found is Na-Cl which reflects the intermediate water phase.

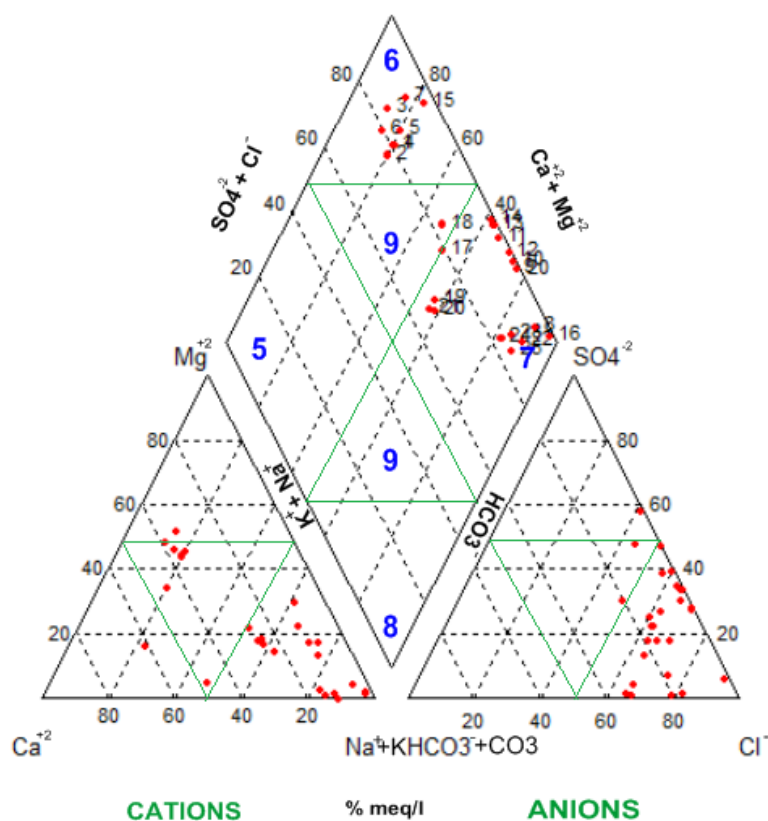


Fig. 5. Groundwater samples represented in Piper's tri-linear diagram.

Equilibrium modeling (Saturation Indices)

Different techniques have been used to represent the water saturation degree with regard to a mineral, the most useful of which is the percentage of saturation, defined as:

$$\text{Saturation percentage} = (\text{IAP}/\text{Ks}) \times 100 \text{ percent}$$

Saturation index (SI) is determined by the equation:

$$\text{SI} = \log (\text{IAP} / \text{Ks})$$

Where; IAP: is suitable product of ionic activity.

Ks: is product of mineral's solubility.

If $\text{SI} = 0$; refer to the equilibrium state between the mineral & solution.

$\text{SI} < 0$; refer to under-saturation state with respect to the minerals prevails.

$\text{SI} > 0$; refer to super-saturation conditions dominating and consequently processes of precipitation.

It is crucial to understand some carbonate (dolomite, calcite and aragonite), sulfate (anhydrite and gypsum) minerals saturation indices to identify those that might precipitate or dissolve in groundwater flow paths for determining the species distribution of equilibrium in liquid solution and important minerals state of saturation, the hydrochemical software PHREEQ-Interactive (U.S.G.S-computer program., version 3.5.0-14000) is used. The examined samples data were entered, and the saturation indices were calculated and presented in table (4). According to the obtained results, the following information is displayed:

The saturation indices reveal that all groundwater samples are under-saturated (saturation indices are negative) with reference to sulfate (anhydrite) and halides (sylvite and halite) minerals, majority of the water samples (about 84%) (have a positive value) were super-saturated with reference to aragonite, dolomite and calcite (carbonate minerals), 16% of samples are undersaturated by aragonite, calcite and gypsum (Table 4), whereas the saturation indices values are a reflection of the geochemical processes those happen during groundwater movement.

Table 4. Groundwater saturation indices.

Sample No.	Anhydrite	Aragonite	Calcite	Dolomite	Gypsum	Halite	Sylvite
1	-0.60	0.94	1.08	2.45	-0.32	-4.41	-6.00
2	-2.30	0.05	0.19	0.65	-2.04	-6.75	-7.61
3	-1.68	0.22	0.36	0.98	-1.43	-6.46	-7.39
4	-1.95	0.57	0.71	1.48	-1.69	-6.00	-7.06
5	-0.52	1.31	1.45	3.16	-0.26	-4.39	-5.86
6	-0.50	1.52	1.66	3.69	-0.25	-4.86	-6.45
7	0.06	0.84	0.98	2.23	0.28	-4.41	-5.20
8	-1.35	0.23	0.38	0.85	-1.05	-4.35	-6.03
9	-0.16	0.98	1.12	2.47	0.14	-3.44	-5.93
10	-0.18	0.75	0.90	2.23	0.11	-3.15	-5.07
11	-1.03	1.04	1.18	2.79	-0.74	-3.24	-4.69
12	-0.27	0.76	0.90	2.14	0.03	-3.04	-4.73
13	-0.02	1.20	1.35	2.62	0.28	-3.33	-4.98
14	-0.51	0.76	0.91	2.44	-0.21	-3.61	-5.67
15	-0.35	1.17	1.31	2.17	-0.04	-4.73	-5.44
16	-1.16	0.25	0.40	0.95	-0.86	-3.33	-5.03
17	-3.00	0.76	0.90	1.85	-2.69	-5.51	-6.96
18	-2.10	1.58	1.72	2.60	-1.79	-5.06	-6.30
19	-3.17	-0.09	0.05	0.11	-2.87	-6.58	-7.54
20	-3.24	0.57	0.72	1.39	-2.94	-5.91	-7.10
21	-3.27	0.19	0.33	0.64	-2.96	-6.29	-7.40

Groundwater quality evaluation

Water quality is good and clear impression of water usage of several purposes. The groundwater suitability is predicted depending on the obtained chemical analysis results. In this study, quality of groundwater is based on several factors for purposes of drinking and irrigation. Chemical analysis results are evaluated according to the WHO (2008), EHCW (1995) and Ayers & Westcot (1985) standards.

1. Drinking and domestic purposes

Uses of water for drinking and domestic purposes might be of low salinity and dissolved salts, colorless, tasteless and odorless. Quality evaluation of groundwater for purposes of drinking displayed that Na, Ca, K and TDS concentrations in most samples exceed the WHO (2008) and the EHCW (1995) limits, so those are unsuitable for uses for drinking and domestic and can cause detrimental effect on taste and human uses.

In the study area, the TDS of groundwater ranges between 363 mg/l to 24210 mg/l. According to the standards of WHO and EHCW (the recommended value is 1000 mg/l), about 29% of the samples of water fits for drinking purposes. The majority of anion concentrations exceeds the maximum permissible limits. Cl and SO₄ have found in higher concentrations than the permissible limits of domestic usage. NO₃ is important component which is controlled in the drinking water because of the negative effects on the human health. Water hardness for 33% of groundwater samples is below the maximum permissible limits for drinking water. Generally, most of water samples need treatment prior to use as drinking water.

2. Irrigation purposes

The studied wells used mainly for irrigation purpose. The quality of irrigation water is important for crop yield and maintenance of soil productivity. Two major indicators, sodium adsorption ratio (SAR) as well as salinity which were determined by water chemical variables of to assess their suitability.

The salinity hazard is a measure of the ions ability to conduct an electrical current in water. The high salinity may decrease the absorbed water quantity by the plant roots from the soil. SAR is Na ions concentration measurement in relation to the Ca and Mg ions concentrations. In case of high SAR, Na ions of water may be exchanged for Ca and Mg ions of soil, which can cause a breakdown of soil structure and reduce its permeability (U.S. Salinity Laboratory Staff, 1954).

According to the USSL classification, water salinity class of majority samples of groundwater is C4 very high salinity, except samples No. 2, 4 and 19 which belong to C2 medium salinity (TDS less than 500 mg/l - conductivity less than 500 μ S /cm) while samples No. 3, 17, 20 and 21 belong to C3 high salinity class.

2.1 Sodium adsorption ratio (SAR)

SAR is only effective assessment factor for water that used in irrigation (Ayer & Westcot, 1985), it determined by:

$$SAR = \frac{Na}{\sqrt{\frac{Mg+Ca}{2}}} \quad meq/l$$

There is a significant relation between irrigation water SAR values and the sodium amount which absorbed by the soil. Soils with high sodium concentrations have an impact on their physical condition and soil structure resulting in crusts formation, water-logging, decreased soil aeration and decreased rate of infiltration and soil permeability. On the other hand, excess sodium concentrations in soils are poisonous to crops types. SAR provides a very trustworthy evaluation of irrigation water quality in terms of sodium hazard because it is more closely related to exchangeable sodium percentages in the soil than the simpler sodium percentage (Tiwari and Manzoor, 1980).

In this research, SAR value of groundwater samples range from 0.76 mg/l (sample No. 3) to 109.60 mg/l (sample No. 16). Sodium adsorption ratio (SAR) values in table 1, about 62% of groundwater samples fall in S1 category. That refers to suitable of sample for irrigation with reference to USSL water quality assessment (Fig. 6).

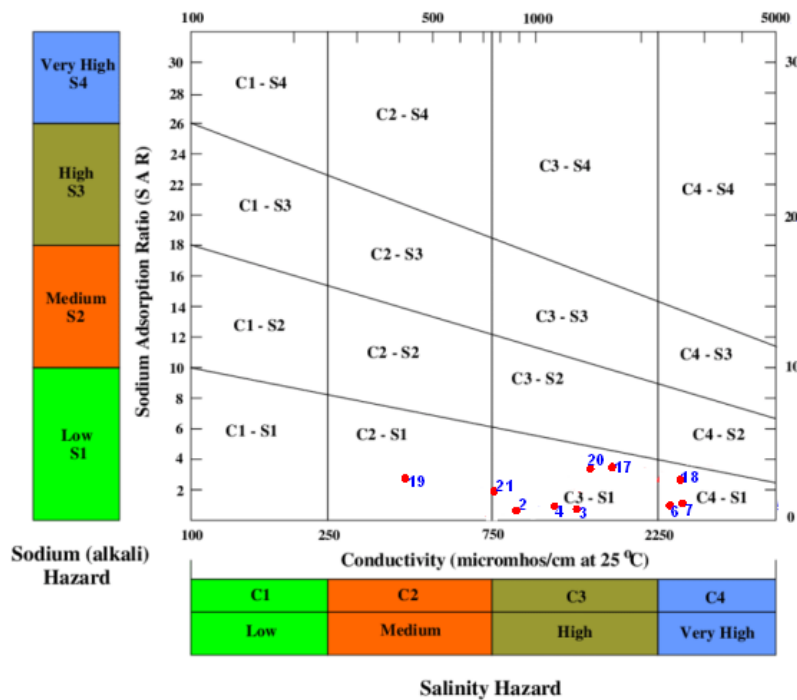


Fig. 6. United States laboratory diagram (1954) of groundwater suitability for irrigation evaluation.

According to classification of Ayers and Westcot (1985) as well as values of SAR (Table 5), most water samples are below the standards of irrigation which fall in the good and moderate class except eight groundwater samples. According to EC values, about 67% of the samples fall in the severe class. And therefore, most groundwater samples are unsuitable for irrigation purposes.

Table 5. Quality standards for irrigation purposes according to Ayers & Westcot (1985).

Potential irrigation parameters	Degree of usage restriction		
	None	Slight-to-moderate	Severe

EC ($\mu\text{S/cm}$)	700	700–3000	3000
SAR	3.0	3–9	9

2.2 According to Kelly's Ratio

Kelly's Ratio refers to the sodium to calcium and magnesium ratio. If Kelly's ratio is equal or less than to 1, that means good water quality and suitable for irrigation but if Kelly's ratio more than 1, the groundwater is unsuitable for irrigation purposes due to the excess level of sodium in the water (Kelley, 1951). Kelly's ratio (KR) can be determined by equation:

$$KR = \frac{Na^+}{Ca^{2++} Mg^{2+}} \text{ (meq/l)}$$

Based on Kelly's ratios, it's observed that all springs samples and almost of El-Qaa plain groundwater samples were more than 1 and fall within the unsafe category for irrigation purposes. According to the calculated KR values, 57% of samples are unsuitable and the rest is considered suitable as shown in figure (7) and table (6).

Table 6. Classifications of El-Qaa plain groundwater samples based on Kelly's Ratio.

Water Classes	KR	Samples	%
Suitable	<1.0	1, 2, 3, 4, 5, 6, 7, 15, 18	43
Unsuitable	>1.0	8, 9, 10, 11, 12, 13, 14, 16, 17, 19, 20, 21	57

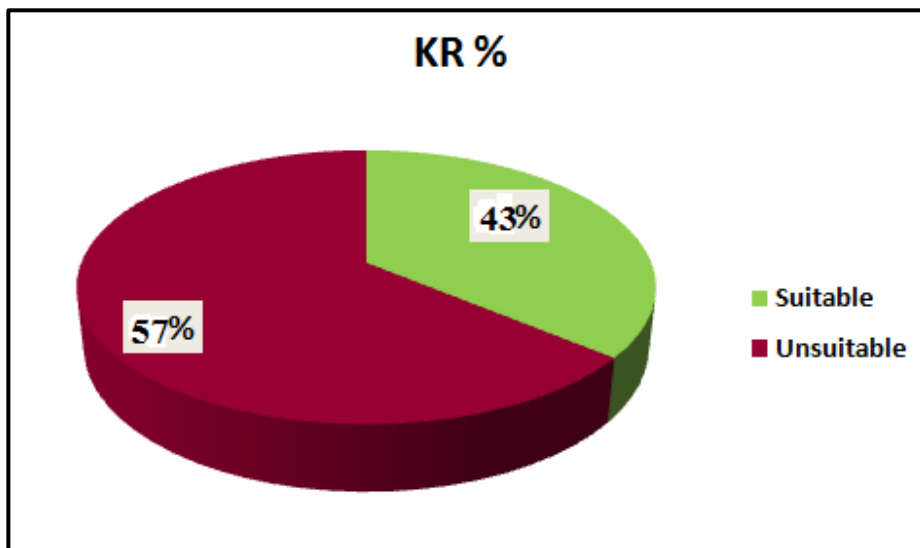


Fig. 7. Kelly's ratios percentage classification of El-Qaa plain groundwater samples.

IV –CONCLUION

The Quaternary aquifer has been found in a synclinal basin that bordered by faults in the east and west generating a graben which consider be an optimal structure for groundwater collecting and receives relatively good amounts of

precipitation. The Gulf of Suez and heavy mountain rainfall are the main sources of the Quaternary aquifer's recharging. The recharge took place essentially by surface runoffs towards the Quaternary wadis and by the fractured Pre-Cambrian basement subsurface outflow which cannot store the percolated recharge water. The groundwater flows from northeast to southwest.

Most of analyzed groundwater samples are alkaline due to presence of calcium and magnesium bicarbonate. The analysis reveals that groundwater needs some pre-consumption treatment to protect it from contamination risks. The groundwater has TDS values from 363 mg/l (fresh) to 24210 mg/l (saline). TDS gradually increase towards the west direction to the Gulf of Suez. Total hardness of the studied samples of groundwater is hard to very hard. This hardness may be caused by the dissolving of gypsum and anhydrite in the circulating water.

The abundance order of the major cation is $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$ and abundance order of anion is $\text{Cl}^- > \text{SO}_4^{2-} > \text{HCO}_3^-$. Na and Cl are predominant ions among studied cations and anions. The Piper trilinear diagram indicates that groundwater is NaCl and mixed MgCaCl type in the study area.

The concentrations of major cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and major anions (Cl^- , HCO_3^- and SO_4^{2-}) in groundwater samples increase the standard allowable limits of WHO for drinking. Bicarbonate and sulfate concentrations are higher than levels of the international health that may make the water non suitable for agricultural use. According to the United Salinity Laboratory, groundwater is considered unsuitable for irrigation which belongs to S1, of low sodium hazard category, yet it might be utilized for irrigation provided only a minor quantity of leaching takes place. The majority of groundwater samples fall into C3-S1, which has a high salinity hazard and a low sodium hazard category, this category can't use on soils with restricted drainage despite having a low risk of developing dangerous levels of exchangeable sodium.

The increases in TDS and major inorganic ion concentrations most likely due to salts dilution along the groundwater migration path from recharge zone to discharge zone in front of the Gulf of Suez, where more saline carbonate rocks can be found. The TDS increases may have been caused by the water upward leakage from the more saline underlying layers in response to the increase in pumping of groundwater also and can be used for some salt tolerance crops such as barley, olive and some vegetables.

V- Recommendations

- 1- The discharged water quantity from the Quaternary aquifer should not exceed the annual inflow rate which assumes 6.7Mm^3 .
- 2- We should manage the observed intensive withdrawal from the aquifer especially in the western part because it may reduce the groundwater storage and giving sea-water an opportunity for intrusion.
- 3- The governmental and non-governmental organizations must present new methods to improve the water quality such as the rain-water harvesting and artificial recharge.
- 4- Drilling new wells should be oriented to the carbonate zone in the eastern part where it is characterized by fresh-water.
- 5- The drilling depth should not exceed 350m below ground surface in order to avoid the effect of salt water intrusion.

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