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Deep depressions of the world between electricity hydro-power and comprehensive development based on hydrogeological investigations

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ABSTRACT

Most are postponed owing to the probability of earthquakes, deterioration of groundwater, and other environmental issues. The questions that need to answer utilizing these depressions in hydro-power electricity generation or comprehensive development and/or both. To answer the questions; geomorphology, geology, and hydrogeology aspects must be delineated to take the decision which are the main objectives of the article. Qattara Depression of Egypt which is the world's 5th deepest depression (-134 m) is selected for answering the questions. The study reveals that bringing water from the sea harms surrounding groundwater, soil, mineral resources, and environment that may be extended to highly populated Nile Delta. The applicable plan is a comprehensive development that includes agriculture, highly saline fish farms, salt extraction, industry, tourism, and urban. Electricity can generate with some limitations such as a balance between the rate of flow from the Mediterranean Sea and evaporation and prevent seepage from lake to surrounding groundwater and soil. Electricity can use for the desalination of seawater to decrease freshwater shortage and feed the proposed communities with water. Results could potentially highlight for planning the development of deep depressions and surrounding of the world with the limitation for each one.

KEYWORDS

Deep depressions |Electricity hydro-power | Hydrogeological investigations | Development

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Introduction

There are nineteen (19) depressions of the world (Table 1) and eight (8) of them are deepest than -100 m. The famous depressions are Dead Sea (-410 m), Lake Tiberias (-212 m), Assal (-174 m), Turfan (-154 m), and Qattara (-134 m). The presence of some of them near the sea encouraged their countries to plan hydro-power electricity projects using the variation of elevation. Most are postponed owing to the probability of earthquakes occurring, deterioration of surrounding groundwater quality, economic, and other environmental issues. Others are planned for agricultural and tourism projects. The questions that need to answer utilizing these depressions in hydro-power electricity generation or comprehensive development and/or both. To answer the questions; geomorphological features, geological setting, and hydrogeological conditions must be delineated to take the decision which are the main objectives of the article. Qattara Depression (QD) of Egypt which is the world's 5th deepest depression is selected for answering the questions.

The QD discovered in 1926 (Ball 1927) and surveyed in 1927 (Ball 1933). The Egyptian engineers proposed to produce electricity by bringing water from the Mediterranean Sea through a canal that stopped due to environmental, economic, and political problems. The QD is the largest and deepest one of the seven depressions in the western Egyptian desert (Qattara, Siwa, Bahariya, Fayum, Dakhla, and Kharga, Farafra) which is a part of an old system for drainage (Embabi, 2018). Also, previous geological and geophysical investigations show the existence of fluvial buried canals with southeast (SE) to the northwest (NW) runways from the plateau areas (Khan *et al*., 2014; Salem, 2013).

No.	Areas	Location	The deepest elevation (m)	No.	Areas	Location	The deepest elevation (m)
1	Dead Sea	Jordan	-401	11	Sebkha Tah	Morocco	-55
2	Lake Tiberias	Syria	-212	12	Sabkhat Ghuzayyil	Libya	-47
3	Assal	Djibouti	-174	13	Lago Enriqillo	Dominican	-46
4	Turfan	China	-154	14	Chott Melrhir	Algeria	-40
5	Qattara Depression	Egypt	-134	15	Caspian Shore	Azerbaijan / Iran / Russia	28
6	Vpadina Kaundy	Kazakhstan	-132	16	Shatt Al-Gharsah	Tunisia	17
7	Denakil	Ethiopia	-125	17	Lake Eyre	Australia	15
8	Laguna del Carbon	Argentina	-105	18	Sariqarnish Kuli	Uzbekistan	12
9	Death Valley	USA	-86	19	Laguna Salada	Mexico	10
10	Near Kulul	Eritrea	-75				

Table 1. The World's deepest depressions (after Murakami (1995).

Description of the area

The QD is and NW-SE depression, extended ~100 km with width ~190 km in 2020 and is located between 29° 05\ - 30° 35\ N and 27° 00\ - 29° 30\ E (Fig. 1). Topographically, it is surrounded by high elevated southeast and northern areas reach more than 200 m (Fig. 2). The southern part is gradually graded with gentle slope northward to less than -110 m that more extend westward to -134 m around Bir Abu Gharadig. The northern border has a steep slope. The QD is formed due to the interaction of tectonics, wind erosion, and groundwater fluctuations (Ezzat 1982). But, Albritton *et al*. (1990) mentioned that it is originated as a stream valley that was subsequently dismembered by karstic processes during the late Miocene epoch. South and eastern parts have vast areas of good soil which favorable for agricultural development.

The QD lies in arid to the semi-arid area, where the maximum temperature is 41.4 C° in August and the minimum temperature is 10.7 C° in December, the % humidity ranges from 39.5% in December to 19% in June. Wind speed reaches the maximum in September (3.7 m/Sec.) and the minimum in January and February (2.8 m/Sec.). The amount of rainfall is very little and the evaporation varied from 29.2 mm/day in May to 5.4 mm/day in December (http://globalweather.tamu.edu).

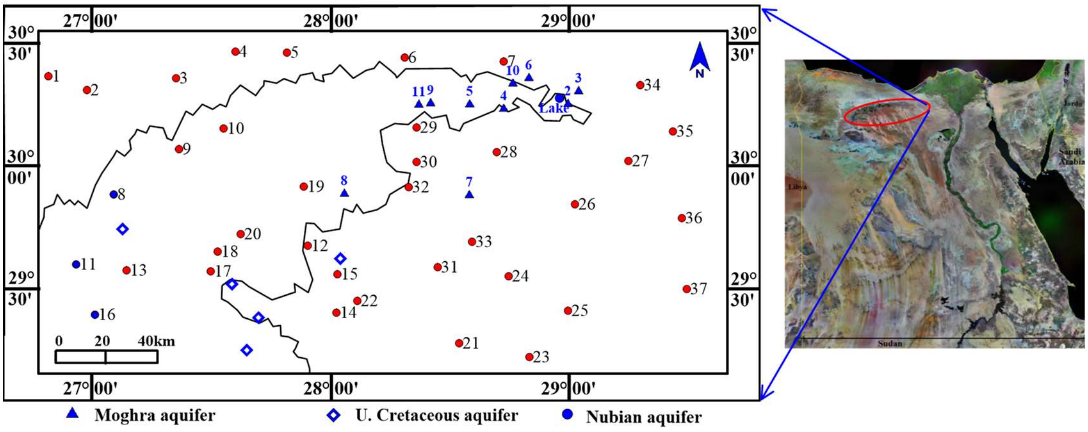

Fig. 1: Location map of the study area, and oil and water wells**.**

List of Oil Wells

1- Ghazalat N-1	2- Ras Qattara W-1	3- Zarif-1	4- Yokout-1	5- Marzouk-1
6- Qattara Rim-1	7- Sanhour-1	8- Ghazalat-1	9- Ras Qattara-1	10- Kadam-1
11- Ghorab-1	12- Site 1-1	13- Site 2-1	14- Site 6 -1	15- Site 7-1
16- Kifar-1	17- Betty-1	18- Kheit-1	19- Bed N8-1	20- Bed 8-1
21- Agnes-1	22- Bre 23-1	23- Misawag-1	24-Abu Senn n	25- SW Mubark-1
26- Rabat E-1	27- W. Halif-1	28- Sheiba-1	29- Sharib-1	30- Ghoroud
31- AG-2	32- WD 7-1	33- AG-12	34- Fayad-1	35- Tib-ix
36- Mubark-1	37- WD 57-1	• Moghra Lake		

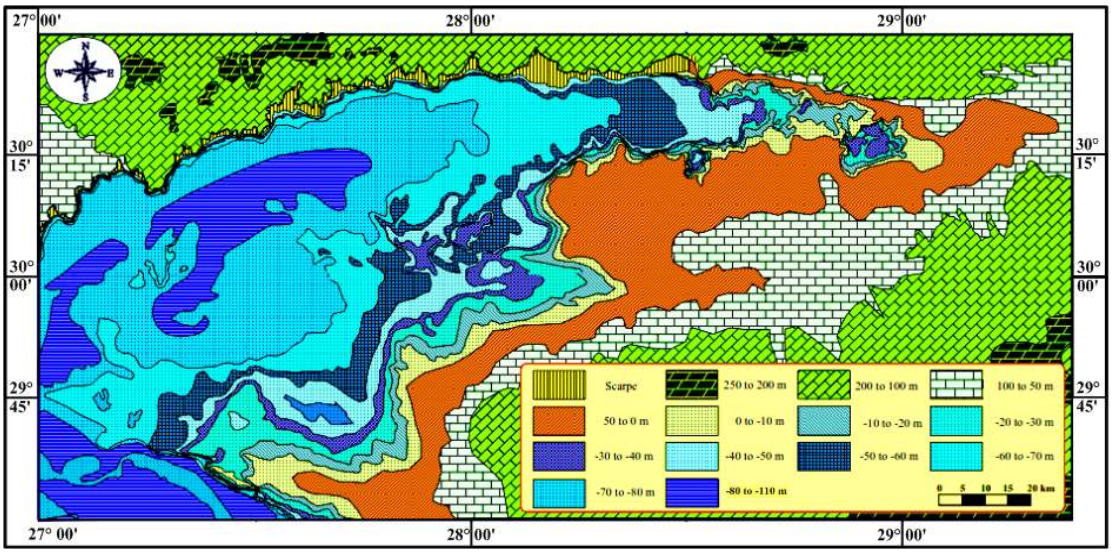

Fig. 2: Digital elevation model (DEM) of the QD.

Approach and methodology

Initially, to understand the geomorphology and surface geology of the QD (CONOCO, 1986); different information from Thematic Mapper (TM) satellite images of 1984 and 2001 years, and topographic maps were collected followed by processing, field observations, and measurements. A lot of seismic lines, well logging, and composite logs data of 37 deep drilled oil and 18 shallow groundwater wells were selected (Fig. 1) to shed light on subsurface geology and hydrogeological condition. To recognize the general variation in groundwater chemistry of the study area, 18 water samples were collected to represent Moghra (11), U. Cretaceous (5), and Nubian sandstone (2) aquifers. A Magellan global positioning system (GPS) was used to mark the location by noting down the latitude and longitude. Two samples were collected from each location of groundwater aquifers: (1) a filtered, acidified 100-mL sample for cation analyses, and (2) an unfiltered, unacidified 125-mL sample for anion and alkalinity analyses. The groundwater samples were collected after pumping for 10 min. to remove groundwater stored in the well. In-situ measurements included EC, pH, and bicarbonate which were measured using a portable field kit and titration respectively as per WHO (1996) recommendations as these parameters change with storage time. Major cations like Ca2+ and Mg2+ were analyzed by titration, while Na+ and K+ were measured on an AIMIL Flame Photometer (PE I). Chloride ion was analyzed by titration and the SO42- was measured by spectrophotometer. The chemical analysis was carried out as per the standard procedure given by ASTM (2002).

Results and discussion

***Geomorphological aspects*: Landforms**

The QD is one of the most prominent geomorphological features in the Western Desert of Egypt which has the second deepest point in Africa. Based on the geologic map, topographic maps (scale 1:100 000), SPOT and TM satellite images, field observations, and literature; a landform map of the study area was made (Fig. 3). It's divided into four units namely; structural plateaux, Qattara – Moghra depression, and sand dune belt as follows:

a. Structural Plateaux is classified into:

El Diffa plateau occupies the northern part of the study area and extends northward. It's characterized by undulating topography that declines gradually northward from about +200 m to about + 100 m above sea level, while dropping off sharply southward to -40 m below the sea level forming cliff. The plateau is composed of massive cavernous limestone that covered partially by Quaternary sand sheets. Nine isolated hills are recorded in the northwestern part of ground elevation more than +260 m. These peaks are also separated by the main NW fault system and are composed mainly of limestone that belonging to the Miocene period.

b. Qattara – Moghra depression divided into:

There are a series of sabkhas that occupy more than a quarter of the QD. They are elongated in shape and are strongly controlled by the topography of the area that varies mainly from -40m to -70m below the sea level. They are composed mainly of fine sand, silt, and clay covered by a thin salt crust. They are formed due to the upward leakage of Nubian Sandstone groundwater through faults, flowing water wells, and some natural springs. The estimated amount of groundwater flow to the depression is 3.2m3/s, while the total evaporation from the depression is 7.2m3/s (Qattara Project Authority, 1979) that allows excessive crystallization of a near-surface thick halite crust. Wetlands are recorded mostly in the western part of the largest sabkhas. They have ground elevation vary from -40 m to 0 m. They are composed mainly of fine sand and silt that allow the groundwater to upward throw their pores and become wet.

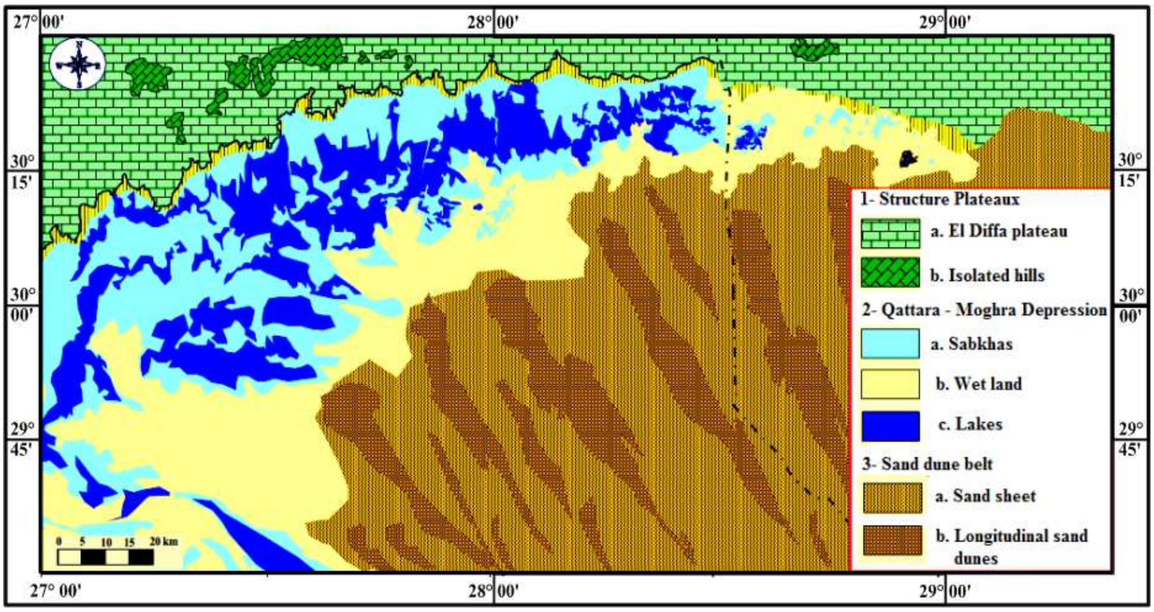

Fig. 3: Land forms of the QD area 2001

c. There are a lot of lakes in the QD, the famous of it is ML that formed owing intersection of groundwater level with surface and springs. It has shallow depths and ground elevation -36 m. The huge number of lakes in the QD originated from the springs issuing from the fissured limestone and Nubian aquifers along faults as well as seepage from Moghra aquifer. They have ground elevation vary from -35m to -97m, partially connected and slightly deep.

d. Sand dune belt occupies the southeastern part of the QD and differentiated into:

Sand sheets are composed mainly of fine to medium sand those are formed as a result of wind erosion surrounded rocks.

Longitudinal sand dunes are located to the south of forming the northern part of Gird Abu El Mahareq. The greater dunes are Badr Ed-Din, El-Faras, Abu Ghardik, Abu Senanm, and Abu Rakham. Their length varies between 6.0 and 120 km, width between 0.4 and 17.4 km, and height between 18 and 120 m (Ali 1993).

Change detection with time

Utilizing TM satellite images of 1984, 2001, 2013 and 2020; the variation of geomorphological units of Moghra Lake (ML), Abu Dewis (Heteit Lbaq) and the QD can be detected (Figs. 4 and 5). The size of the natural ML declines from 5.4, ~4.6, 4.1 to 2.7 km2 in 1984, 2001, 2013 and 2020. Abu Dewis sabkha also decreases from 37, 23.85, 14.4 to 13.3 km2 in the same periods with the disappearing of their lakes in 2013. This may due to the effect of sand dune movement, dropping of groundwater level, and active drilling in Moghra aquifer (Yousef, 2013).

The size of natural lakes in the QD dwindles to 42% from 1984 to 2001 may due to the decrease in the rate of groundwater seepage from Moghra and Nubian aquifers. But, the increase of Bir Abu Ghradiq Lake may due to the release of groundwater from the bad controlled flowing well. In contrast, sabkhas increase by 58% in the same period owing to the same reasons.

Geologic Setting

The Western Desert of Egypt is divided into two geologic provinces from south to north they are the stable and the unstable shelves (Sultan and Halim, 1988). The QD lies in the unstable province and is situated between two isolated intracratonic closed basins, Abu Gharadig in the

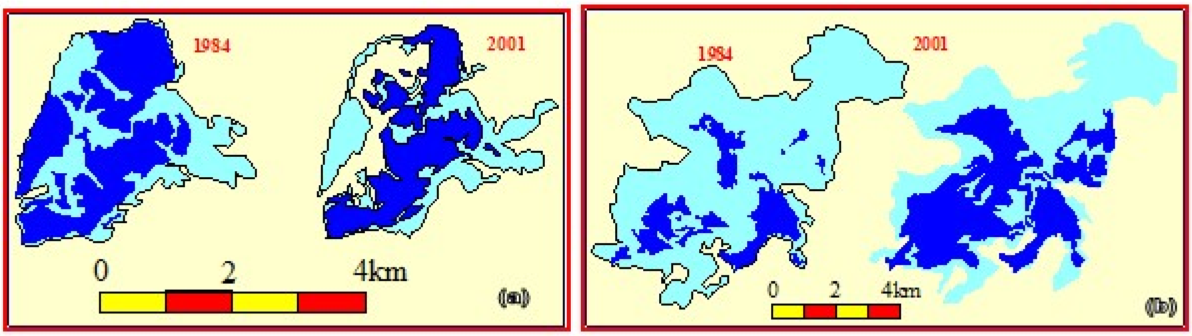

Fig. 4: Change detection of ML (a) (after Yousef, 2013) and Abu Dewis (b) from 1984 to 2001

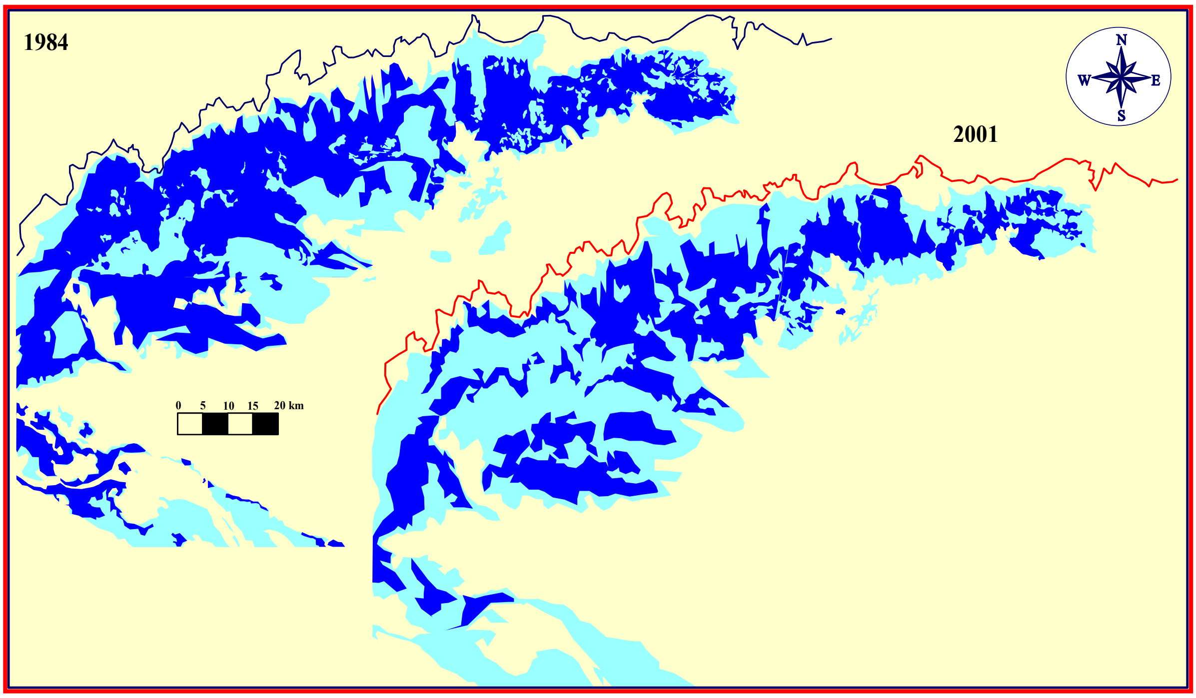

Fig. 5: Change detection of the QD from 1984 to 2001.

south and Al Alamin in the north i.e. platform trending ENE to E-W. The surface and subsurface of the QD are largely controlled by faulting with N45°W, N85°E, N45°E, N15°E and N-S trends of variable extensions and the majority of them penetrate great depths below the basement surface (Yousef and El-Hussaini, 1983). The first development of them was during the early Jurassic related to the horizontal movement of Africa relative to Eurasia which periodically influenced its sedimentary history throughout the Mesozoic and into the Tertiary (Abdel Aal and Moustafa, 1988). To the east of the QD (the area of Moghra Oasis) there is a Permo-Jurassic basin trending N-S (Abdel Aal and Moustafa, 1988), which controls the extension of the depression eastward. There are Paleozoic N-S, Cretaceous and Eocene NE-SW, and Oligocene and younger NNW-SSE folds (Said, 1962). Due to the structural setting of the QD a remarkable difference in the thickness of the sedimentary sequence in the unstable province can be observed that is characterized by deep basement rocks, a thick sedimentary column (Fig. 6), and complex structures. The subsurface stratigraphic succession of the QD and the northern Western Desert subdivided into five major regressive cycles, each terminated by a marine transgression (Said, 1962 and 1971; Sultan and Halim, 1988).

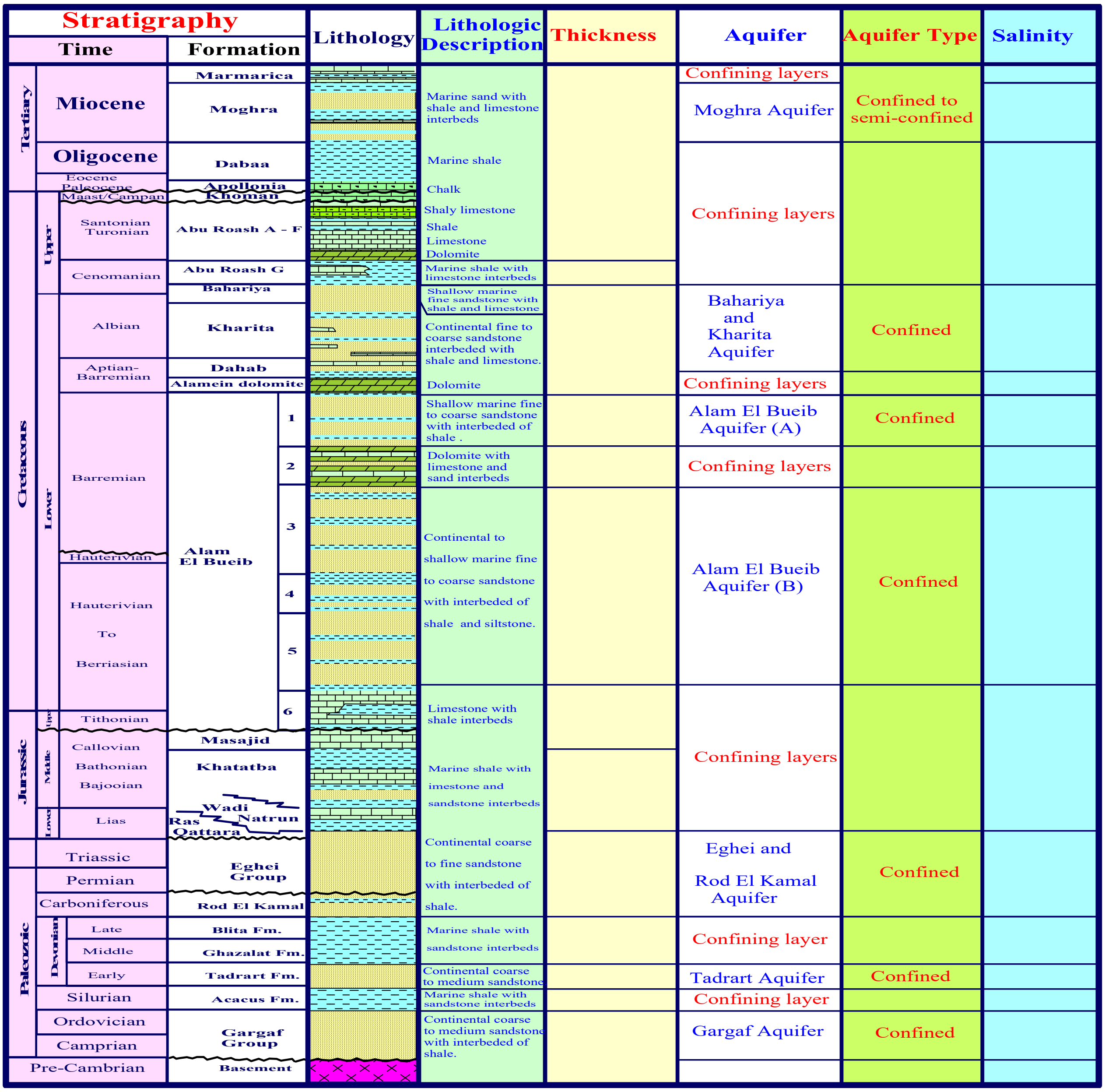

Fig. 6: Compiled geological and hydrogeological sequence of THE QD.

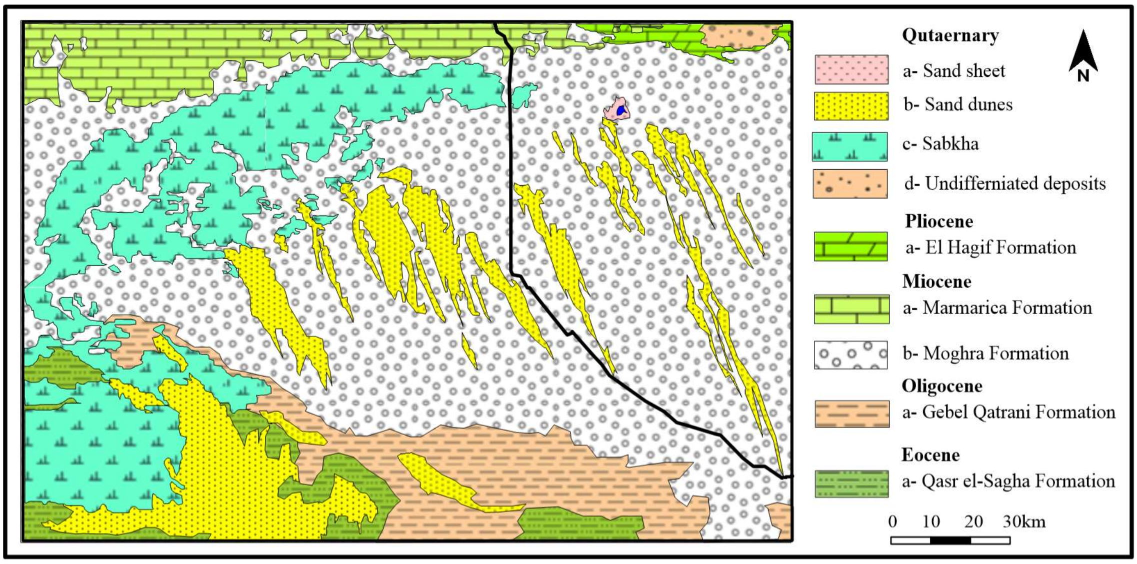

Fig. 7: Geologic map of the Qattara Depression (after CONOCO, 1986).

The exposed stratigraphic section around the QD is composed of a sedimentary sequence ranging in age from the Upper Eocene to the Quaternary (Fig. 7). Eocene and Oligocene deposits from the southern scarp of the depression and represented with Qasr el-Sagha (sandstone and claystone intercalation) Gebel Qatrani (sandstone with claystone and shale layers) Fms. Miocene sediments are represented by Moghra and Marmarica Fms. Moghra deposits form the bottom and the surroundings of the QD that are composed of sand with shale and carbonate layers. Marmarica is recorded in the northern steep escarpment and composed of fossiliferous limestone with few marly limestone intercalations. Pliocene sediments are restricted to the northeastern part and represented by El Hajif Fm that composed of limestone with interbedded marl and marly limestone. Quaternary deposits are the main rock units in the depression and represented by sabkhas (silt, clay and evaporates) cover large areas of the floor and lower slopes, NW- SE sand dunes (fine to medium sand) to the south, sand sheet (medium to fine sand) and undifferentiated deposits (duricrusts, sand, and gravel).

Groundwater Setting

The aquifer system: Based on available data sets of oil and water wells, hydrogeological cross-sections (Fig. 8), collected 20 water samples (Fig. 1) and chemical analyses (Tables 1 and 2); the main aquifers are the following:

a. Moghra aquifer

Moghra aquifer is developed above the Dabaa shale and extends east, south, and north of the QD. It is belonging to Oligocene - L. Miocene and composed mainly of sand and silt with some interbedding of clay that deposited under continental and shallow marine (Ezzat, 1982). It is covered partially by the Quaternary sediments in the QD and Marmarica shale and carbonates in the northern i.e. free to a semi-confined aquifer. The thickness map of the aquifer (Fig. 9) shows the thicker thickness restricted in and around MO with thickness from 700 to ~1500 m in oil well No. 28 (Shiaba-1), and thinning westward in QD to 70 m in oil well No. 13 (Site 2-1) owing to the impact of structural setting. Yousef (2013) divided the aquifer into three water-bearing. The top layer has low salinity owing to their recharged and connected with west Nile Delta aquifer and the connection with other layers decrease with depth and upward leakage becomes the main source of recharge. The main source of recharge in the west the QD is Nubian and Upper Cretaceous–Eocene aquifer systems (Qattara Project Authority, 1979). The average hydraulic conductivity and transmissivity of the aquifer are 24.55 m/day and 11041.45 m2/day (DRC, 2016) that reflect their high potentiality according (Gheorhge, 1979). If drill 2500 well with rate 60 m3/h from the aquifer, the drawdown 36, 39, and 46 m are after 25, 50, and 100 years (DRC, 2016).

Eleven (11) water samples have been collected from the aquifer (Table 1 and Fig. 1). The groundwater level flows from -31 m in the west of MO to the -65 m in the QD with the direction of flow. The groundwater salinity in MO changed from 2307 ppm in the east to 7435 ppm northwestward owing leaching processes and environment of deposition (Fig. 10). On the other hand the salinity in the QD has higher salinity that varies from 4496 ppm to 11121 ppm westward that leads to salt accumulations near the floor of the QD. The chemical properties of Moghra aquifer in are deep meteoric water, NaCl and Na2SO4 water type and ion dominance are Na>Ca>Mg/ Cl> HCO3>SO4 in the east MO changed into shallow marine, NaCl water type and Na>Mg>Ca/Cl>SO4>HCO3 westward. The main salts are NaCl, Ca (HCO3)2, and MgSO4 in MO changed to NaCl, MgSO4, and MgCl in the QD Owing leaching processes and nature of aquifer matrix.

b. Upper Cretaceous karst aquifer

Karst aquifer is represented by Abu Raoash that built up of limestone with shale and marl layers with thickness from 100 to 700 m that overlain and underlain by the shale layers i.e. confined to a semi-confined aquifer. The aquifer recharged mostly from the underlain Nubian aquifer system through fracture systems. Five (5) water samples are collected from the aquifer with salinity from ~28300 and 136050 ppm (Fig. 1 and Table 2). The variations of salinities are due to dense shale layers and leaching processes that affected the chemical properties. They are mostly shallow meteoric water, NaCl water type and ion dominance are Na >Mg>Ca/ Cl>SO4>HCO3. The main salts are NaCl and MgCl and CaSO4.

c. Bahariya and kharita aquifer system

The Cenomanian Bahariya aquifer is widespread in the Western Desert and the QD. It has a low thickness in the southern part and increases northward to 350 m in Sanhour-1 subsiding along NE faults and consists of sandstone with shale and limestone layers. Albian (L. Cretaceous) Kharita aquifer restricted mostly in the western part of the QD with thickness 900 m in Site-1 and decrease eastward, and built up of fine to coarse sandstone with shale and limestone layers. They are hydraulically connected through facies and structure, overlain by U. Cretaceous shale and underlain by Aptian shale i.e. confined aquifer. The isopach map of Bahariya and Kharita aquifers (Fig. 11) shows the huge thickness around Sitera (central the QD) with a maximum thickness of about 1140 m in Sit-1 well. It shows also the E-W elongate depocenter extending from Kheit-1 to Abu Sennnan-1. A sub-basin can be recognized near Ghazalat N-1 with thickness reach to 940 m. The drastic and abrupt change in thickness between wells like WD 7-1 and Ghoroud-ix, Sit 2-1, and Kifar-1 suggests activity along with an NW-SE normal fault system. The same phenomenon was recorded also between Sharib-1 and Sanhour-1, and between Yahout-1 and Zarif-1, but with lesser extent. It shows also the shallower thickness in the eastern part of the depression.

The aquifer is represented three (3) water samples in Ghazalat-1, Ghorab-1, and Mohr with groundwater salinity 1690, 6170, and 14298 ppm that reflect the impact of the environment of deposition and groundwater flow (Table 2). The variation of salinity owes the difference of shale percentage. They are deep meteoric water, NaCl and Na2SO4 water type and ion dominance are Na>Ca>Mg/ Cl>SO4>HCO3. The main salts are NaCl.

d. L. Cretaceous Alam El-Bueib aquifer

Alam El Bueib aquifer is overlain by Alamein dolomite and Dahab shale and underlain by U. Jurassic shale and limestone i.e. confined aquifer. It consists of fine to coarse sandstone with shale and siltstone layers that deposited in a deltaic environment (Abdel Aal and Moustafa, 1988). The thickness map of the aquifer (Fig. 12) reflects how strong the deposition was governed by the NW-SE and WNW-ESE folding events that are restricted the largest and deepest values in the area between Betty-1 and Ras Qattara West-1 wells west the QD, where it ranges between 930 and 1230 m. A shallow thickness of the aquifer has been identified southeast QD between Bed 8-1 and Misawag-1 wells.

The aquifer is tapped by Kifar-1 water well only with groundwater salinity 489 ppm, temperature 57°C, high pressure (5kg/cm2), and productivity 406m3/hr (Table 2). The aquifer is deep meteoric water, NaCl and Na2SO4 water type and ion dominance are Na >Ca>Mg/ Cl> HCO3>SO4. The main salts are NaCl and Ca (HCO3)2. The aquifer needs a lot of groundwater explorations owing to its low salinity and high productivity.

e. Paleozoic aquifers

There are three water bearings namely; Triassic – Carboniferous, L. Devonian, and Ordo-Cambrian that are separated by shale formations and overlain by Ras Qattara shale and i.e. confined aquifer. The aquifers built up greatly of continental coarse to medium sandstone with shale layers (Abdel Salam, 1994 and Mousa, 1986). The isopach map of Paleozoic (Fig. 13) shows the basins much controlled by NNW and E-W fault systems and restriction the main basin west the QD with thickness 1000 m in Ghazalat N-1. There is a small basin to the east with thickness 640 m in W. Halif-1 well. No water points are tapping the aquifer that needs detailed exploration owing to good potentiality.

No.	**Location**	**Ground elevation**	**Total depth (m)**	**Depth to water (m)**	**Water level (m)**	**Ec (mhos/cm)**	**Salinity ppm**	**PH**	**Cations (mg/l)**				**Anions (mg/l)**			
									K^+	Na^+	Mg^{++}	Ca^{++}	CL^-	SO_4^{--}	HCO_3^-	CO_3^-
1	Moghra Oasis	-36	-	-	-36.0	5.15	2887	7.6	17	800	60	215	1325	219	460	42
2		+17	102			4.21	2390	7.3	14	637	48	193	1031	287	328	32
3		-10		21	-31.0	4.05	2307	7.5	15	635	45	170	930	300	380	45
4		+4	120			5.20	2986	7.6	15	810	70	200	1320	400	330	12
5		+42	130	75.5	-33.5	6.30	3648	7.5	26	960	100	240	1650	530	285	0
6		+4		62.0	-58.0	7.65	4403	7.3	28	1118	170	249	2020	710	216	0
10		-18		41.0	-59	12.73	7435	7.9	60	1750	470	220	3100	1700	270	0
7	Qattara	+42	120			7.70	4496	7.6	66	1190	175	180	2000	780	210	0
9		+6		60	-54.0	11.2	6484	7.8	42	1605	360	220	2950	1210	190	0
11		-3				13.2	7723	7.9	37	1860	420	310	3320	1670	212	12
8		-26				19.3	11121	7.7	93	2850	588	355	5600	1590	90	0

Table 1. Chemical analyses of Moghra aquifer in the QD.

No.	**Location**	**Ground elevation**	**Total depth (m)**	**Depth to**	**Water level**	**Ec (mhos/**	**Salinity ppm**	**PH**	**Cations (mg/l)**				**Anions (mg/l)**			
									K^+	Na^+	K^+	Na^+	CL^-	SO_4^{--}	HCO_3^-	CO_3^-
Upper Cretaceous aquifer																
1	West the QD	-11	180	36	-47	49.0	28297	7.3	160	8090	1050	950	15400	2580	124	0.0
2		-18	220			194.5	112805	7.5	350	34200	3300	3500	62000	9910	85.4	0.0
3		+9	255	45	-36	233.4	134840	7.4	480	40200	5900	1700	71500	15000	120	0.0
4		-81	210			235.7	135075	7.5	500	37500	6100	4000	71000	16000	150	0.0
5		-75	200			235.2	136050	7.3	450	41300	3950	4300	73000	13000	100	0.0
Nubian sandstone aquifer																
7	Ghorab-1	-79	3060	-	-	105.0	6170	7.9	50	1820	140	260	2900	800	400	0.0
8	Mohr	-18	190			22.34	14298	8.1	89	4400	260	144	6600	1490	244	0.0
9	Kifar-1	-78	3000	-	-	0.85	489	7.5	11	128	10	35	180	62	125	0.0

Table 2: Chemical analysis of karst and Nubian aquifers in the QD.

Qattara Depression between electricity and comprehensive development

The QD is the world's 5th deepest depression (-134 m) and is the largest and deepest depressions of the Western Desert of Egypt. Their huge area and depth encourage Ball in 1933 to suggest a connection with the sea through an open channel and establishing a hydro-electric power station to produce electricity. Detailed feasibility studies by Institut Géographique National and Société Française Stréotopographié (1977) and Joint-Venture Qattara (1981) support this idea and salt extraction industry like the Dead Sea as well as desalination plants. The desalinating water with the groundwater can be used for the cultivation of the area around the depression (Salim and Elbeih, 2009). The Egyptian Government in the eighties of the twentieth century postponed the project owing to the probability Qattara Lake will leak into the Nile Delta fertile soils and strong earthquakes could occur that will damage highly populated Nile Delta.

Recently different authors suggested some modifications to the project to avoid a negative effect. Arnold (2016) proposed a 10,000 m³/sec flow rate from the Mediterranean Sea to make the QD a lake reservoir at -60 m that will increase energy generation at -70 m to 6800 megawatts (Adel Elsayed and Ismaeel, 2019). This requires considerations for the balance of hydraulic pressure versus the evaporation ratio as well as the expected change in the microclimatic conditions (Ibrahim, 1982 and Kelada, 2010). The QD is more stable to earthquakes than other adjacent areas in the northern parts of Egypt close to the Mediterranean Sea and the Nile River Delta (Moustafa *et al*., 2018).

4.1. Groundwater storage

To evaluate the groundwater potentialities for future sustainable development, fresh to slightly saline groundwater storage of existing aquifers must be estimated. The storage depends principally on the saturated thickness and effective porosity. The average saturated thickness of fresh, brackish, and slightly saline water in Moghra (100 m), Bahariya, and Kharita (600 m), Alam El Buieb (500 m) aquifers in the QD are ~1200 m. The groundwater storage can be calculated based on the following Darcy (1856) equation:

$$Q = \varphi eff\ D\ A$$

Q: is the stored groundwater quantity in the aquifer in m3

D: is the average saturated thickness of the aquifer in m

φeff: is the effective porosity of the concerned aquifer in decimal (0.185)

A: is the area of fresh and slightly saline in the aquifers (~10000 km2)

The stored groundwater quantity is calculated for an area of (~10000 km2) and attains ~ 2200 x109 m3. The Paleozoic aquifers (700 m) and detailed studies will increase the groundwater storage. These mean that the QD area has high to moderate groundwater potentialities for agriculture development.

4.2. Soil potentiality

Egyptian government carried out extensive national projects for the horizontal expansion of agricultural lands. The surrounding area of the QD such as MO and southeast Qattara are the new areas of agricultural expansion potential to cover the shortage of food depending on groundwater. The soil properties, suitability, and potentialities of east and south of the QD were studied by different authors such as Ismail *et al*. (2013), GARPAD (2015), El Kady and Essa (2018) and Belal *et al*. (2018) based remote sensing, soil analyses, and GIS. They are concluded that 66 to 73% are suitable and potential for agriculture purposes with no and moderate limitation to a lot of crop patterns. Bringing seawater from the Mediterranean Sea for electricity generation will affect the salinity of soil to become unsuitable to most crop pattern south and east the QD.

4.3. Mineral resources

The main mineral resources of the QD area are oil and salt rocks. A lot of oil companies discovered and product oil from relative wells, but rock salts are discovered at and near the surface of the QD floor. Rock salt cover an area of about 250 km2 of the QD with a variable thickness between ~0.5 to 2.5 m. Detail exploration may increase the area and thickness with the continuous decline of groundwater and increase of their salinity. The salts are sporadic halite and gypsum that covered by more than 120 cm thick of moist sands in the eastern part, while they are the crystallization of halite at or near the surface in the western part (Aref *et al*., 2002). The difference between them owes the variation of groundwater salinity, topography, and the rate of evaporation.

From a few years ago, rocks salts were started from the QD and Siwa Oasis to trade with good prices owing to their purity (https://emsalt.com/qatara-siwa-salt/). With the settlement of related industries, rock salts become the gold of Egypt. Filling the depression with seawater for electricity generation will destroy these economic resources.

4.4. The impact of electricity generation on groundwater aquifers

Moghra aquifer surrounded the QD from south and east, the groundwater flows from all surrounding and Nile Delta. The groundwater level varies from -31 m in the eastern part to -59 m south the QD that seeps in the depression. The proposed filling the depression by seawater to a level of -60 m will increase the salinity of the aquifer especially in MO. With the increase of filling level, the negative impact will be extended in the West Nile Delta and destroyed agriculture development.

The piezometric level of Nubian System south the QD is at least -50 m, i.e. higher than ground levels on the floor of the depression (Ezzat, 1982) and the groundwater losses in the depression varied from 1009 (Ball, 1933) to 90 m3x106/year (Ezzat, 1982). As a result of proposed filling the depression to a level of -60 m, there will be a positive effect of a 70 m head of saltwater (Ezzat, 1982). The negative impact will increase with the decline of water level and increase the salinities of surrounding oases.

Conclusion

There are nineteen (19) depressions of the world. The occurrence of some of them near the sea encouraged their countries to plan hydro-power electricity projects using the variation of elevation. Most are postponed owing to the probability of earthquakes, deterioration of groundwater, and other environmental issues. Others are planned for agricultural and tourism projects. The questions that need to answer utilizing these depressions in hydro-power electricity generation or comprehensive development and/or both. To answer the questions; geomorphology, geology, and hydrogeology aspects must be delineated to take the decision which are the main objectives of the article. The QD of Egypt which is the world's 5th deepest depression (-134 m) is selected for answering the questions.

The study based on data sets from geologic and topographic maps, satellite images, seismic lines, well logging and composite logs data of 37 deep drilled oil and 18 groundwater wells, groundwater samples and chemical analyses, cross-sections, filed observation, measurements, and software. The main conclusions are:

1. There are three landforms of the QD namely; structural plateaux, Qattara – Moghra depression, and sand dune belt. The size of natural lakes dwindles with time, but sabkhas increase to expect in MO.

2. There are five (5) groundwater aquifers namely, Miocene – Oligocene (Moghra), U. Cretaceous (karst), U. L. Cretaceous (Bahariya and Karita), L. L. Cretaceous (Alam El Beuib) and Paleozoic. Moghra is highly potential free to semi-confined aquifer with thickness from 700 to ~1500 m, water level flows -31 to -65 m, and salinities from 2307 to 11121 ppm near the QD. Karst confined to semi-confined aquifer has a thickness from 100 to 700 m and high salinity from ~28300 and 136050 ppm. Bahariya and kharita confined aquifer system is hydraulically connected through facies and structure with thickness 380 to 1400 m and salinity from 1690 to 14298 ppm owes the difference of shale percentage. Alam El Bueib confined aquifer has a thickness between 930 and 1230 m, low salinity (489 ppm), high temperature (57°C), high pressure (5kg/cm2), and productivity (406 m3/hr). There are confined three water bearings of Paleozoic separated by shale with thickness from less 100 m to 1000 m.

The proposed project for bringing Mediterranean Sea water to the QD for electricity generation plan will mostly affect surrounding groundwater, soil, mineral resources, and environment that may be extended to the West Nile Delta. The most suitable plan of the area is a comprehensive development that includes agriculture, and salt extraction, and industries. The presence of natural lakes will encourage using them for high saline fish and as pools for tourism. On the other hand, electricity generation can do with some limitations such as a balance between the rate of flow from the Mediterranean Sea and evaporation, preventing seepage to groundwater and surrounding soil. Electricity can use for the desalination of seawater to decrease freshwater shortage and feed the proposed communities with water. These methods can use in another deep depression elsewhere with limitations for each one.

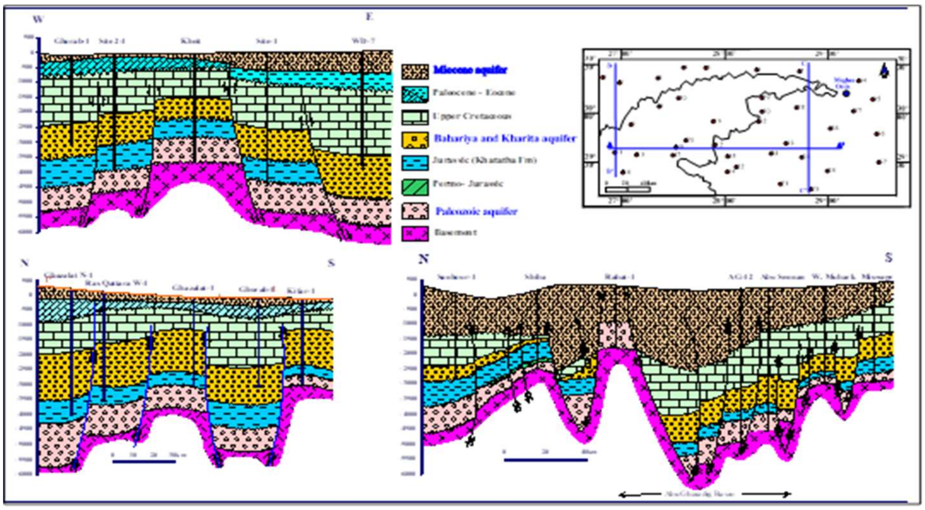

Fig. 8: Longitudinal and vertical hydrogeological cross sections the QD (based on composite logs of oil wells and seismic lines).

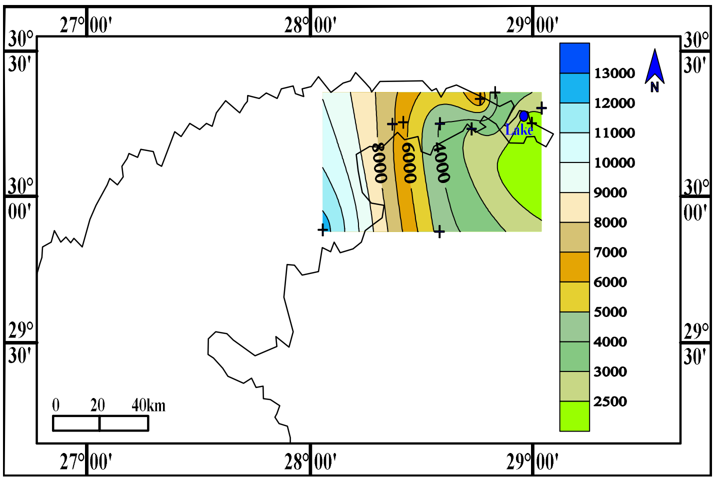

Fig. 9: Isopach map of Oligo-Miocene (Moghra) aquifer

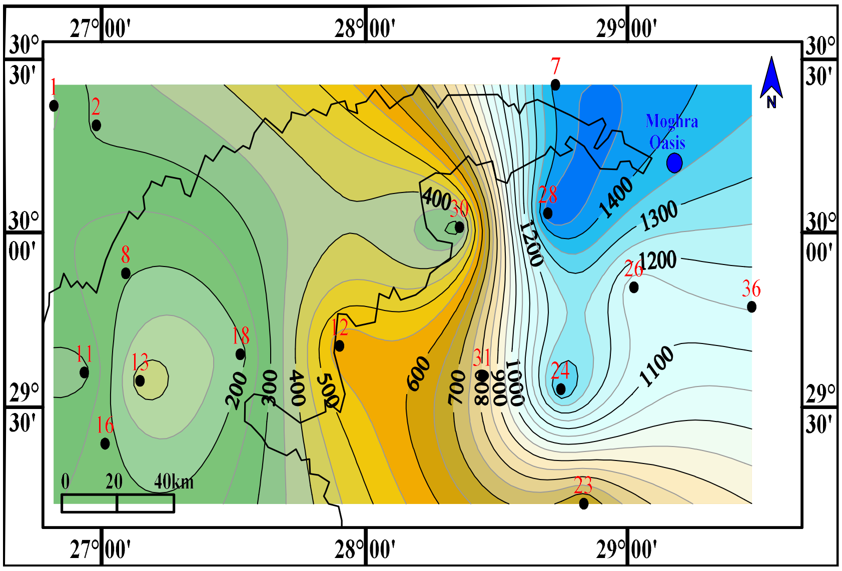

Fig. 10. Iso- Salinity of Moghra aquifer

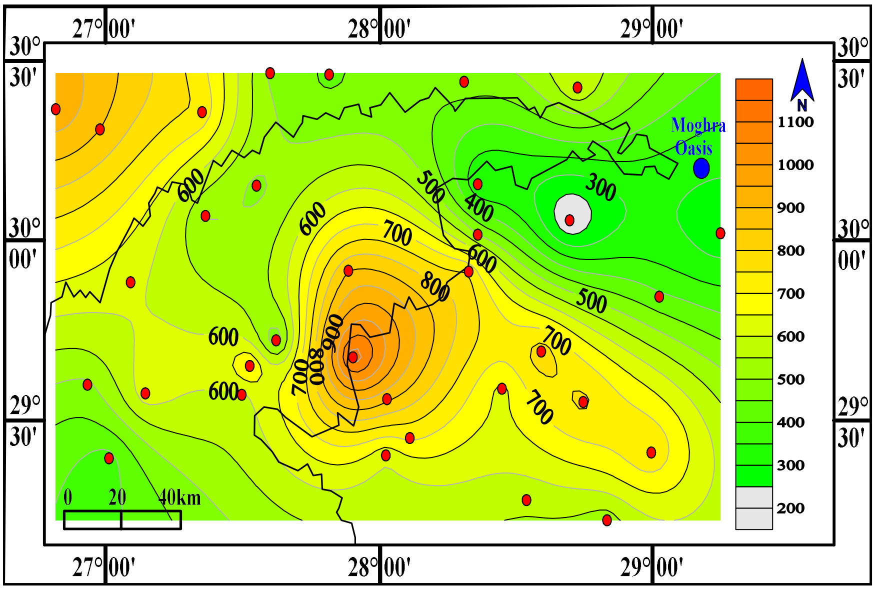

Fig. 11: Isopach map of Bahariya and Kharita Aquifer the QD.

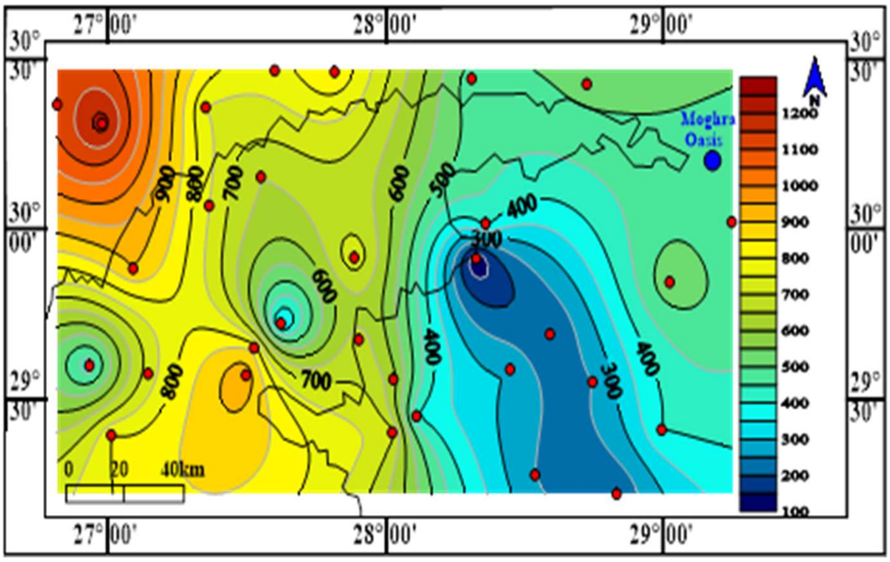

Fig. 12: Isopach map of Alam El Bueib Aquifer the QD.

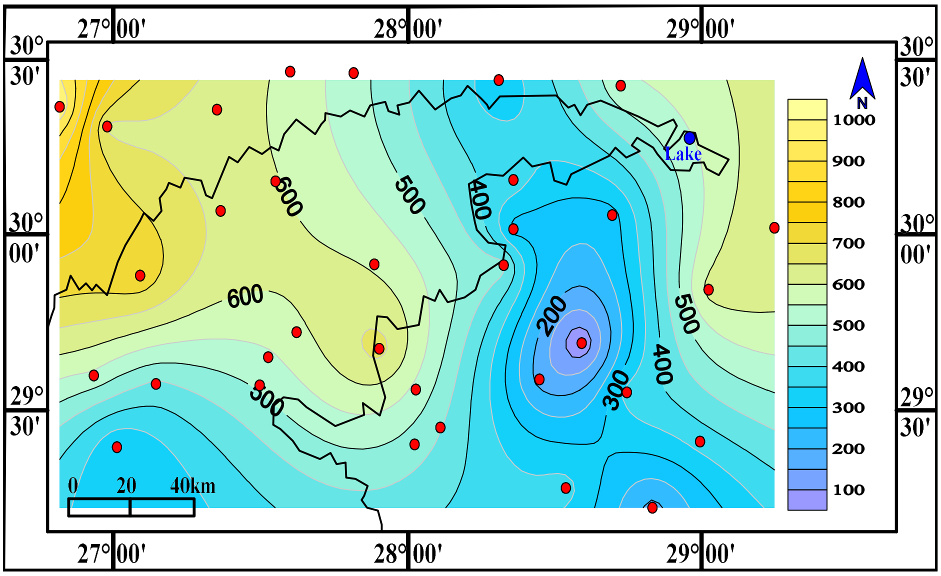

Fig. 13: Isopach map of Paleozoic Aquifer the QD.

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