

Hydrologic factors controlling groundwater salinity in northwestern coastal zone, Egypt

NAHLA A MORAD¹, M H MASOUD^{1,2,*} and S M ABDEL MOGHITH¹

¹*Hydrology Department, Desert Research Centre, Cairo, Egypt.*

²*Water Research Centre, King Abdulaziz University, Jeddah, Saudi Arabia.*

**Corresponding author. e-mail: zakimilad@hotmail.com*

The aim of this article is to assess the main factors influencing salinity of groundwater in the coastal area between El Dabaa and Sidi Barani, Egypt. The types and ages of the main aquifers in this area are the fractured limestone of Middle Miocene, the calcareous sandstone of Pliocene and the Oolitic Limestone of Pleistocene age. The aquifers in the area are recharged by seasonal rainfall of the order of 150 mm/year. The relationship of groundwater salinity against the absolute water level, the well drilling depth, and the ability of aquifer to recharge has been discussed in the present work. The ability of aquifer to locally recharge by direct rainfall is a measure of the vertical permeability due to lithological and structural factors that control groundwater salinity in the investigated aquifers. On the other hand, the fracturing system as well as the attitude of the surface water divide has a prime role in changing both the mode of occurrence and the salinity of groundwater in the area. Directly to the west of Matrouh, where the coastal plain is the narrowest, and east of Barrani, where the coastal plain is the widest, are good examples of this concept, where the water salinity attains its maximum and minimum limits respectively. Accordingly, well drilling in the Miocene aquifer, in the area between El Negila and Barrani to get groundwater of salinities less than 5000 mg/l is recommended in this area, at flow rate less than 10 m³/hr/well. In other words, one can expect that the brackish water is probably found where the surface water divide is far from the shore line, where the Wadi fill deposits dominate (Quaternary aquifer), acting as a possible water salinity by direct rainfall and runoff.

1. Introduction

During the last two decades, excessive well drilling operations tapping Middle Miocene fractured limestone have been executed searching for groundwater as a supplementary source for irrigation in summer and during drought events. From the comprehensive survey of groundwater conditions in the study area, it has been noticed that the groundwater widely ranges in salinity between 1000 and about 15000 mg/l. This great variation in salinity is mainly attributed to the dominant hydrologic

conditions controlling the groundwater occurrence and recharge.

The present work deals principally with the assessment of the relationship between groundwater salinity and the absolute water level, the drilled depth below sea level, the storm events and possibility of runoff, the attitude of water divide, and the rate of pumping causing sea water intrusion.

The area is, occasionally, subjected to heavy storms (10–20 mm/storm) causing flash floods in a number of drainage lines (over 200 Wadis) dissecting the Middle Miocene plateau in the south

Keywords. Brackish groundwater; aquifer; northwestern coast; Egypt.

and running towards the sea in the north. The study is based on the data of 150 water wells, distributed among the aquifers all over the area. Data collection started in February 2010 and continued for more than 2 years (June 2012). The area is suffering seriously from drought and water scarcity all the year round, particularly in summer months. People in this area are looking urgently for groundwater for cultivation and range vegetation, but the sources are limited and the quality is poor. The present work may help the inhabitants to find resources of less salinity and more productivity.

2. Physigraphy

The study area covers an area of about 26,000 km², extending from El Dabaa in the east to Sidi Barrani in the west (figure 1). It is bound by the Mediterranean Sea in the north and Marmarica Plateau in the south. The altitude of the study area ranges between zero level (Mediterranean Sea) and about 200 m above mean sea level (water divide). It slopes gently to the north, i.e., towards the Mediterranean Sea.

According to Zaki (2000), from the Digital Elevation Model (DEM) of the study area (figure 1), it is noticed that the distance between the shore line and the water divide varies widely from 25 km in the west of Matrouh (minimum width) to 80 km in Mersa El Asi (maximum width).

This reflects that the Wadis dissecting the plateau are represented in the area between Mersa El Asi and Sidi Barrani, where the water divide is far away from the shore line. Between Matrouh and Ras El Hekma, the water divide is very close to the shore line and Wadis are almost short and shallow.

The climate of the northwestern coastal zone is characterized by long rainless summers and short rainy winters (October to April). In general, the region is related to the Arid Mediterranean climate. The data collected from the Egyptian Meteorological Authority (EMA 1950–2000) show that the maximum temperature was recorded in August (30.4° C) while the minimum temperature was (8.2° C) in January. The average monthly evaporation per day ranges between 5.5 mm/day in January and 8.0 mm/day in April. The average annual rainfall ranges between 130 mm in El Dabaa station and 153 mm in Sidi Barrani station. The maximum rainfall in one day recorded in northwestern coastal zone was 63.8 mm (Matruh station at 13 December 1977). The number of rainy days ranges between 30 and 60 days in the area of study.

3. Groundwater occurrence and mechanism of recharge

The groundwater in the study area occurs in four rock types (aquifers) of Tertiary and Quaternary ages (figure 2). The Quaternary aquifers are dominated along the coastal plain and the dissecting

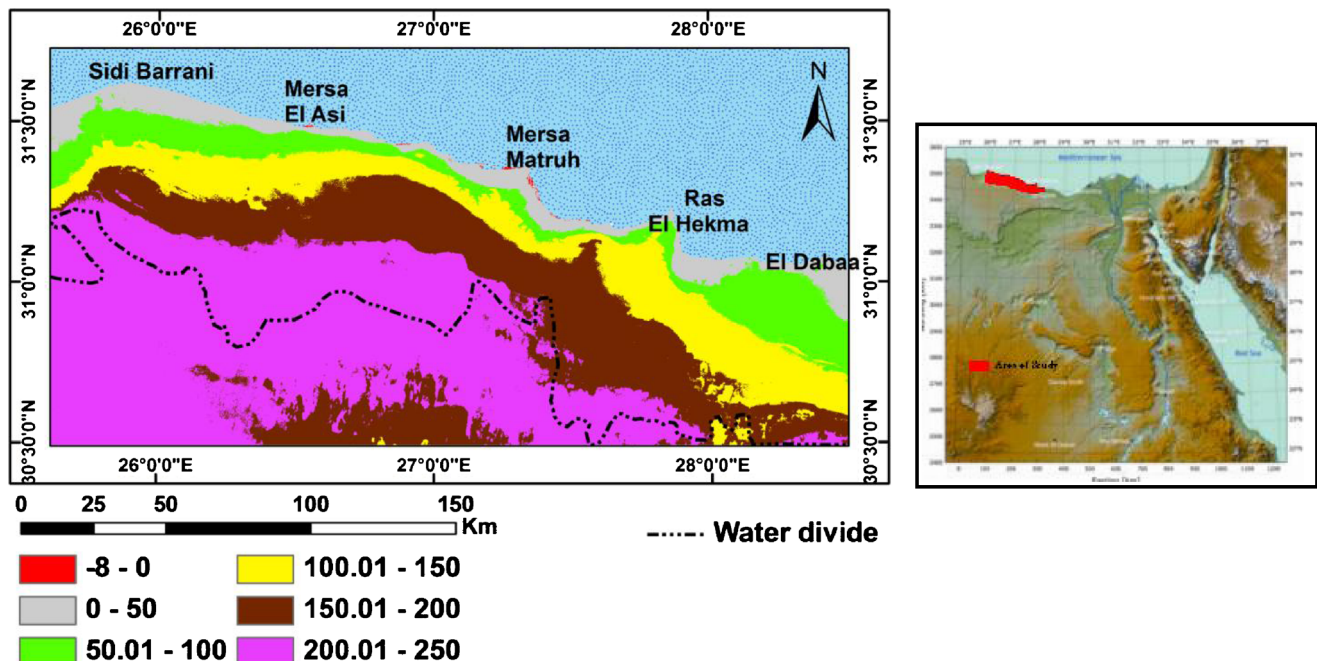


Figure 1. Location map and Digital Elevation Model (DEM) of the study area.

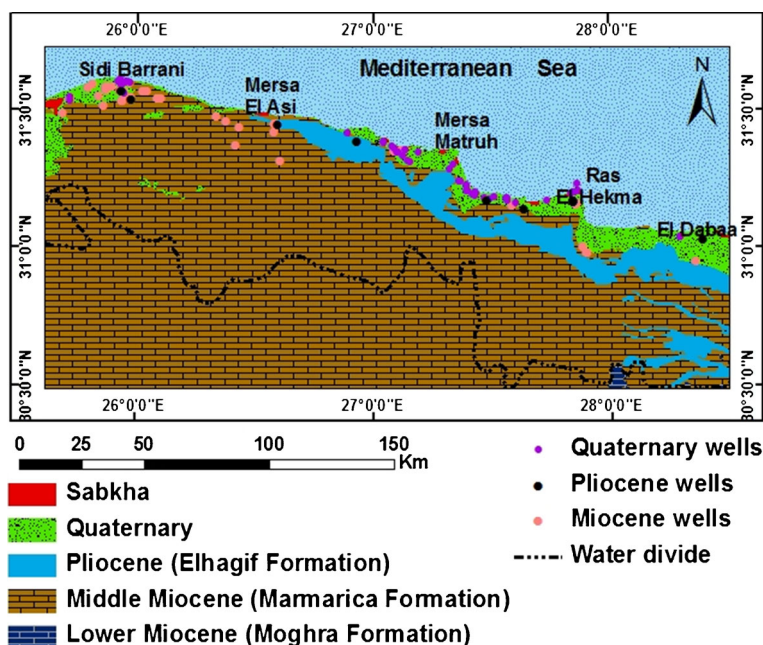


Figure 2. The main geological units of the North West Coastal Zone (CONOCO 1989), showing the edge of Miocene plateau (+200 m) and the location of wells for each aquifer.

Wadis, having an area of about 1870 km² (7% of the total area). The Pliocene rocks are either exposed on surface or underlie the Quaternary sediments, while the Miocene rocks form the surface beds of the southern plateau.

The Quaternary carbonate aquifer is directly connected to the Mediterranean Sea, which affects the groundwater salinity considerably. It is reported in the study area by two main facies; namely the Oolitic Limestone of late Pleistocene age and the Alluvium deposits of Holocene age, which are located mostly in the Wadis running perpendicular to the shore line. Due to the over-pumping from the wells tapping the Quaternary aquifer; sea water intrusion may occur causing an increased water salinity.

The Pliocene aquifer underlies the Pleistocene aquifer and overlies the Miocene aquifer. The exposed deposits cover an area of about 2300 km² (9% of the total area). The facies of the Pliocene is mainly calcareous sandstone of porous nature.

The Miocene aquifer has an area about 22,250 km² (84% of the total area), representing one of the main aquifers in the study area occupying the so called Marmarica Plateau. The groundwater of this aquifer occurs in two main forms: Perched groundwater, where the water level is above mean sea level and main water table where the water is free or in semi-confined conditions. The facies of this aquifer is fractured limestone and dolomite. Most of the rainfall on the southern plateau runs on the surface causing water runoff, while it partially recharges

the perched water table close to the ground surface.

About 130 wells were selected for the present study; these wells were drilled in three different aquifers. Tables 1, 2 and 3 show the basic data of wells, while figure 2 shows the distribution of these wells in the study area. Among the investigated aquifer, where 64 drilled wells tap the Quaternary aquifer, while 11 and 55 wells tap the Pliocene and Miocene aquifers, respectively. The percentage of wells for the three aquifer types are 50%, 8%, and 42% for the Quaternary, Pliocene and Miocene, respectively.

From the literature (Saleh 2000), the average permeability values of the investigated aquifers in the study area vary widely from one aquifer to another and from locality to locality. The permeability (K) for the alluvium (Wadi deposits) ranges between 8.2 m/day in Sidi Barrani and 25.1 m/day west of Matrouh. The Oolitic limestone (Pleistocene age) shows K values ranging from 1.2 m/day near Ras El Hekma to 22.6 m/day near Matrouh. The Middle Miocene rocks (fractured limestone) attain the lowest permeability value (0.35 m/day) among all aquifers, which is quite expected due to the fracturing nature of the building material.

The measured depth to water table from groundwater surface varies between 6 and 35 m for the Quaternary and between 30 and 90 m for the Pliocene aquifer and between 25 and 98 m for the Miocene aquifer. The depth to water table is directly proportional to the ground elevation at the measuring points.

Table 1. Basic data of the Quaternary wells.

No.	Location		Salinity (mg/l)	Drilled depth (m)	Depth to water (m)	Elevation (m) a.m.s.l.	Water table (m)
	Longitude	Latitude					
1	25.965	31.604	9837	24	16	19	3
2	25.919	31.608	7450	40	30	28	-2
3	25.913	31.608	7392	37	30	29	-1
4	25.921	31.603	1434	40	31	29	-2
5	25.921	31.603	1363	42	31	29	-2
6	25.929	31.604	4435	47	38	27	-11
7	25.931	31.603	7936	50	38	27	-11
8	25.946	31.602	7168	35	24	25	1
9	25.947	31.607	8576	46	30	22	-8
10	25.931	31.594	8256	52	34	33	-1
11	25.929	31.591	7360	49	37	39	2
12	25.937	31.561	7168	48	36	45	9
13	25.922	31.613	12032	30	22	23	1
14	25.921	31.612	6592	30	23	24	1
15	25.711	31.548	5517	47	38	42	4
16	25.711	31.536	5075	43	35	39	4
17	28.293	31.041	700	60	32	39	7
18	28.292	31.042	3328	60	30	40	10
19	28.292	31.042	1792	60	27	40	13
20	25.923	31.603	2240	40	30	29	-1
21	27.861	31.237	7040	31	25	26	1
22	27.863	31.209	11520	20	16	8	-8
23	27.847	31.207	4672	12	10	12	2
24	27.847	31.207	3200	12	10	12	2
25	27.847	31.206	8960	12	10	13	3
26	27.844	31.206	6720	12	10	12	2
27	27.842	31.206	9600	13	11	13	2
28	27.834	31.203	1306	18	16	17	1
29	27.733	31.178	3699	21	18	19	1
30	27.323	31.293	2368	30	28	31	3
31	27.339	31.309	9600	12	10	20	10
32	27.367	31.246	7552	25	16	19	3
33	27.361	31.249	5120	16	13	14	1
34	27.361	31.249	4480	21	11	22	11
35	27.392	31.233	4480	17	11	13	2
36	27.392	31.232	2048	15	11	13	2
37	27.426	31.194	15360	30	24	27	3
38	27.486	31.183	10880	32	23	23	0
39	27.469	31.186	16640	33	22	23	1
40	27.599	31.169	13440	50	28	39	11
41	27.559	31.184	8960	45	27	20	-7
42	27.564	31.187	11840	23	22	18	-4
43	27.564	31.178	12160	36	24	30	6
44	27.509	31.192	928	21	9	13	4
45	27.431	31.203	7872	18	12	12	0
46	27.428	31.204	3840	18	8	11	3
47	27.428	31.208	6016	12	6	7	1
48	27.418	31.198	3840	25	14	18	4
49	27.428	31.204	1618	17	10.4	9	-1.4
50	27.398	31.214	10560	22	14.4	17	2.6
51	27.393	31.213	16512	27	17	19	2
52	27.188	31.354	7923	10	6.94	9	2.06
53	27.043	31.389	3776	10	7	24	17
54	27.043	31.392	2560	5	4	3	-1

Table 1. (Continued.)

No.	Location		Salinity (mg/l)	Drilled depth (m)	Depth to water (m)	Elevation (m) a.m.s.l.	Water table (m)
	Longitude	Latitude					
55	27.075	31.376	2803	7	6	7	1
56	27.086	31.368	6400	20	12	18	6
57	27.101	31.354	5888	26	20	25	5
58	27.098	31.353	5184	32	23	31	8
59	26.889	31.423	1523	19	10	9	-1
60	27.133	31.362	5562	7.3	6.5	8	1.5
61	27.132	31.362	7334	8.66	7.86	9	1.14
62	27.124	31.338	3200	13	10.7	26	15.3
63	27.143	31.321	3136	10	8.4	43	34.6
64	27.156	31.318	5312	42	16.7	45	28.3

From the data of both permeability and of depth to water table from ground surface, one can conclude that the higher the permeability value and the lower the depth to water surface, the higher the potentiality or ability of aquifer recharge.

In other words, the ability of aquifer recharge by local rainfall especially for the exposed part of the rocks indicates that:

- The alluvium aquifer (Wadi deposits) has the highest ability of recharge.
- The Pleistocene Oolitic limestone has a medium ability of recharge.
- The Miocene aquifer has the lowest ability of recharge by local rainfall.

In conclusion, the groundwater in the study area occurs in four forms as follows:

- 1) Free water table in the Oolitic limestone and alluvium aquifers along the shore line, directly recharged from the seasonal rainfall.
- 2) Free water table of the Pliocene calcareous sandstone, where the rocks are exposed on the surface.
- 3) Perched water table within the Miocene rocks, which is indirectly recharged through the overlying fractured rocks.
- 4) Free to semi-confined aquifer of the Miocene fractured rocks, indirectly recharged through the natural groundwater movement from south to north.

One expects that such conditions considerably influence the groundwater salinity for each aquifer if the other hydrologic factors can be excluded.

3.1 Groundwater salinity

In general, the ground water salinity in the study area ranges between less than 1000 mg/l and about 15000 mg/l. Most of the wells (38.2%) have a salinity range from 5000 to 10000 mg/l, while 27.6%

of them have a range of 1000 to 15000 mg/l. Figure 3 shows the frequency distribution of the total salinity among the investigated aquifers. From this table the following can be noticed:

- 1) In the Quaternary aquifer, in about 46% of the total wells groundwater salinity ranges from 5000 to 10000 mg/l, while in 39% of the total wells groundwater salinity is <5000 mg/l.
- 2) In the Miocene aquifer, in more than half of the total wells (56%) groundwater salinity ranges from 5000 to 10000 mg/l, while in 45.3% of total wells, groundwater salinity is <50,000 mg/l.
- 3) All the selected wells in the Pliocene aquifer (100%) have groundwater salinity <5000 mg/l.
- 4) In general, the ground water salinity of the Pleistocene aquifer is mainly attributed to the sea water intrusion because of two reasons:
 - Overpumping of the wells tapping the Oolitic limestone aquifer.
 - The Oolitic limestone aquifer is directly connected to the sea from the lithological point of view.

The iso-salinity contour maps for both the Quaternary and Miocene aquifers (figures 4 and 5) show the following:

- In the Quaternary aquifer, the minimum salinity (1000–5000 mg/l) is located in two specific areas (between Mersa El Asi and Mersa Matrouh and East El Dabaa), while in the other two areas (between Mersa Matrouh and Sidi Barani and between Mersa Matrouh and El Dabaa), groundwater salinity ranges from 5000 to 10000 mg/l. The high groundwater salinity (>10000 mg/l) is located as a small patch between Mersa Matrouh and Ras El Hekma.
- In the Miocene aquifer, the area of low groundwater salinity (<5000 mg/l) is located in the area to the west of Mersa El Asi, between El Negila and Sidi Barrani. The maximum salinity is located in the area of El Daba (>10000 mg/l).

Table 2. Basic data of the Miocene wells.

No.	Location		Salinity (mg/l)	Drilled depth (m)	Depth to water (m)	Elevation (m) a.m.s.l.	Water table (m)
	Longitude	Latitude					
1	26.020	31.571	4781	63	48	29	-19
2	26.034	31.570	7834	38	31	31	0
3	25.972	31.550	4128	79	45	43	-2
4	26.372	31.465	4966	80	57	59	2
5	26.429	31.442	5434	98	73	67	-6
6	26.417	31.379	4435	115	95	106	11
7	26.332	31.483	5024	80	62	53	-9
8	26.096	31.546	4723	50	38	37	-1
9	26.091	31.548	4563	53	41	37	-4
10	26.094	31.546	4730	52	38	36	-2
11	26.080	31.544	4493	55	40	39	-1
12	25.933	31.538	6912	66	50	52	2
13	26.081	31.546	4595	60	40	37	-3
14	27.087	31.356	5933	40	25	29	4
15	27.086	31.361	6560	40	23	21	-2
16	27.116	31.360	8640	24	11	12	1
17	26.593	31.452	6336	90	71	75	4
18	26.580	31.424	5568	115	94	92	-2
19	25.967	31.604	10240	24	16	16	0
20	25.925	31.574	10432	55	45	47	2
21	25.925	31.573	3392	80	44	47	3
22	25.971	31.542	1574	70	41	43	2
23	25.968	31.542	1280	71	41	43	2
24	26.036	31.571	4659	38	30.65	31	0.35
25	26.021	31.571	2794	63	31	31	0
26	25.682	31.491	2688	61	30	31	1
27	26.604	31.320	5670	-	-	149	
28	26.578	31.457	5357	85	69	69	0
29	25.938	31.573	7936	55	42	40	-2
30	25.937	31.561	7808	57	48	45	-3
31	25.930	31.537	7296	61	51	49	-2
32	25.860	31.587	5069	56	44	42	-2
33	25.865	31.587	5786	60	45	42	-3
34	25.866	31.583	6784	56	44	43	-1
35	25.862	31.581	7936	67	43	44	1
36	25.807	31.594	8768	55	44	38	-6
37	25.787	31.581	6080	52	42	45	3
38	25.709	31.543	7680	54	45	44	-1
39	25.889	31.590	5754	54	47	46	-1
40	25.862	31.573	9280	50	43	45	2
41	25.833	31.554	9728	54	42	42	0
42	25.855	31.518	5267	82	68	67	-1
43	28.358	30.954	15360	80	72	68	-4
44	27.857	31.165	4480	116	98	73	-25
45	27.847	31.169	8960	114	88	84	-4
46	27.584	31.161	6624	64	55	66	11
47	27.855	31.162	4608	115	87	83	-4
48	27.901	30.985	9984	110	85	76	-9
49	27.899	30.988	12160	90	75	67	-8
50	27.882	31.008	4864	90	75	65	-10

Table 3. Basic data of the Pliocene wells.

No.	Location		Salinity (mg/l)	Drilled Depth (m)	Depth to Water (m)	Elevation (m) a.m.s.l.	Water Table (m)
	Longitude	Latitude					
1	26.931	31.392	832	120	58	95	37
2	26.592	31.451		100	90	73	-17
3	25.928	31.573	3379	62	51	43	-8
4	25.928	31.573	768	67	47	43	-4
5	25.969	31.541	1050	70	47	42	-5
6	25.930	31.573	1126	65	50	43	-7
7	27.844	31.173	3085	100	75	73	-2
8	27.843	31.173	704	100	75	74	-1
9	28.392	31.029	3053	65	42	39	-3
10	27.478	31.175	2816	51	31	40	9
11	27.636	31.145	2086	72	58	98	40

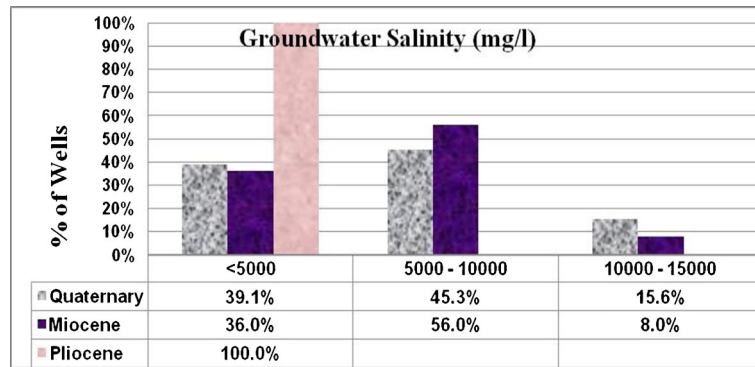


Figure 3. Frequency distribution of the groundwater salinity among the investigated aquifers.

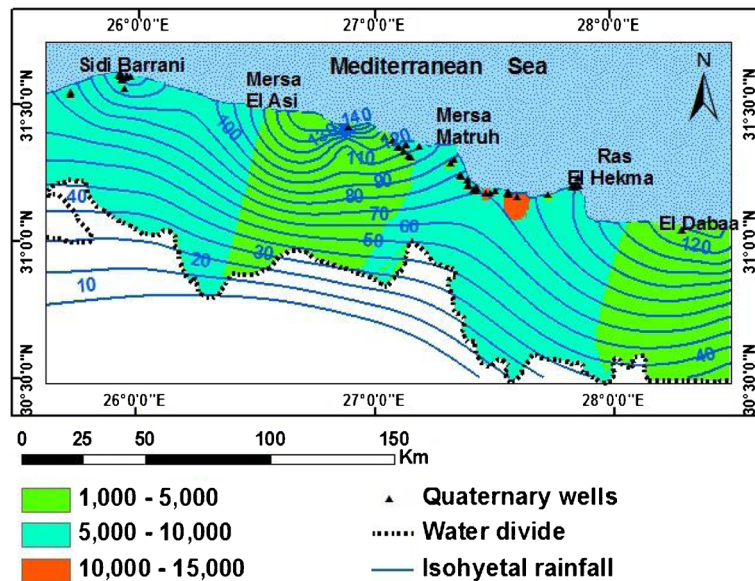


Figure 4. Iso-salinity contour map and relation between the rainfall and TDS of the Quaternary aquifer.

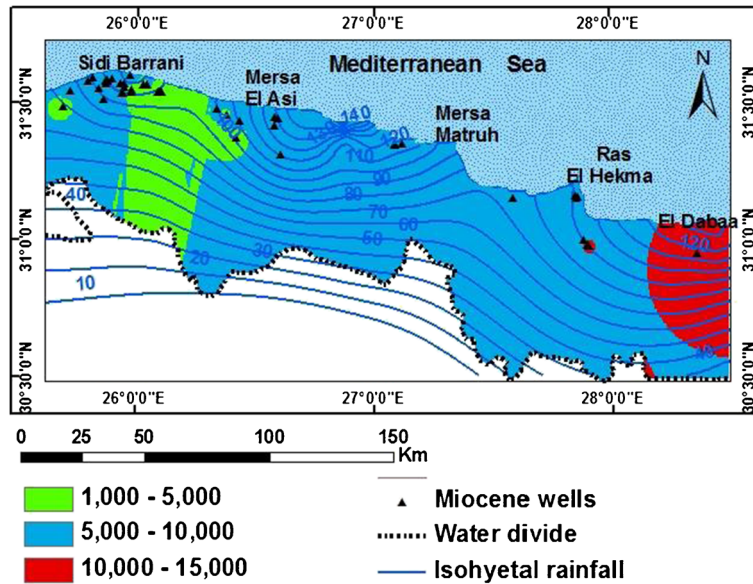


Figure 5. Iso-salinity contour map and relation between the rainfall and TDS of the Miocene aquifer.

In the present work, the main factors affecting the groundwater salinity have been assessed separately, as follows:

3.1.1 Rainfall–salinity relationship

From figures 4 and 5, the following can be concluded:

- In the Quaternary aquifer, the area having groundwater salinity <5000 mg/l is located between Mersa El Asi and Mersa Matrouh. From the Isohyetal map, this area has the maximum recorded rainfall (>120 mm/year). This indicates that the groundwater salinity and rainfall in the Quaternary aquifer are inversely proportional; i.e., the area of high rainfall rate has less groundwater salinity. This relation indicates that the Quaternary aquifer is directly recharged from the rainfall.
- In the Miocene aquifer, the area of low groundwater salinity (<5000 mg/l) is located between Sidi Barrani and west of Mersa El Asi, while the area of high rainfall is located in the center of the study area (between Mersa El Asi and Mersa Matrouh) having groundwater salinity range from 5000–10000 mg/l. This indicates that the Miocene aquifer is indirectly recharged from the local rainfall.

3.1.2 Water level–salinity relationship

From figures 6, 7 and 8, the following can be noticed:

- A majority of the wells in the study area have a water level range between -5 and $+5$.

- In the Quaternary aquifer, in the area between Sidi Barrani and West Matruh, the water level decreases in the north direction towards the sea; i.e., the movement of the groundwater is from south to north.
- In the Quaternary aquifer, a majority of the wells (75%) have a positive water level (above mean sea level). This positive aquifer emphasises the impact of direct recharge upon the exposed Quaternary deposits.
- The water level in the Miocene aquifer ranges from $+10$ to -14 m. The water level decreases in the north direction.
- In the Miocene aquifer, a majority of the wells (about 67% of the total wells) have water level below seawater level (negative), because of the lack of direct recharge either from the rainfall or from the surface runoff. In other words, there is a direct relation between the water level and the possibility of direct recharge.
- The number of wells is very few in the Pliocene aquifer (11 wells), so it cannot be studied thoroughly. The water levels in these wells vary between -17 and $+40$ m.

Although there is a proportional impact of water level upon water salinity, figures 9 and 10 show that the relationship between both variables is ill-defined in both Quaternary and Miocene aquifers. This feature may reflect that the water salinity in the area is strongly affected by other hydrological factors rather than the absolute water level.

3.1.3 Drilled depth–salinity relationship

The relationship between the groundwater salinity and the drilled depth below the sea level is

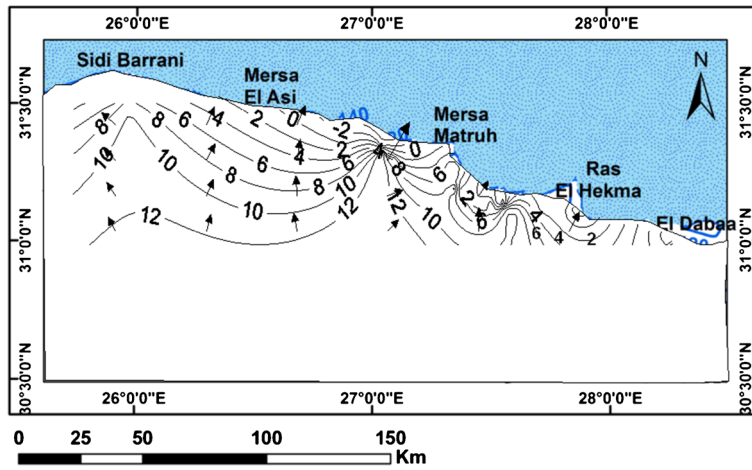


Figure 6. Water table map in the Quaternary aquifer.

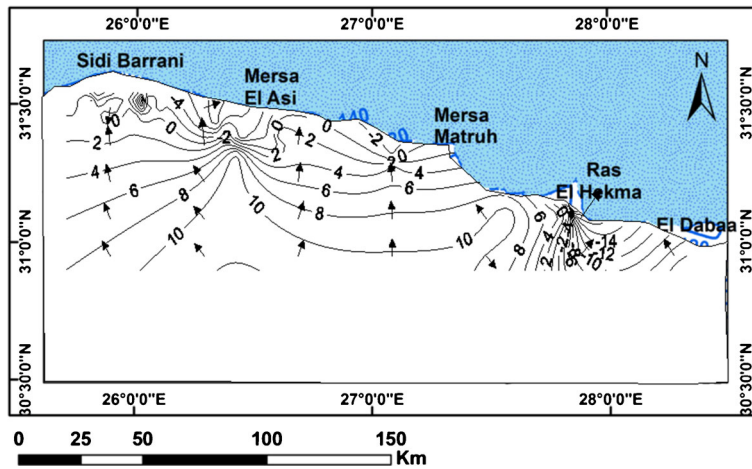


Figure 7. Water table map in the Miocene aquifer.

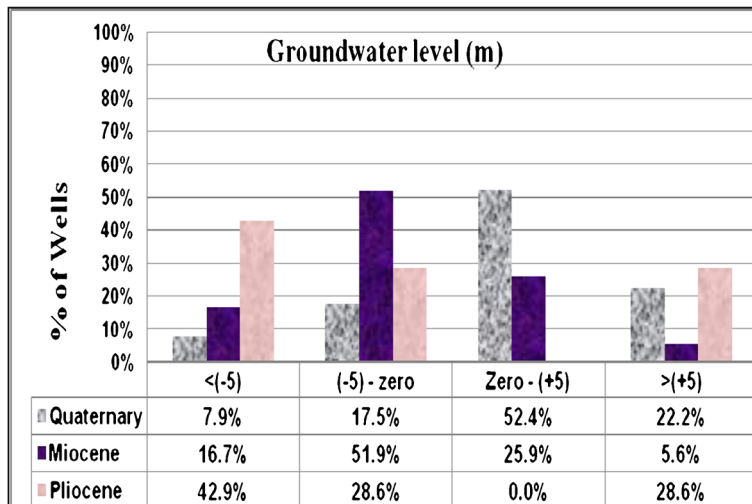


Figure 8. Relation between percentage of wells and water level.

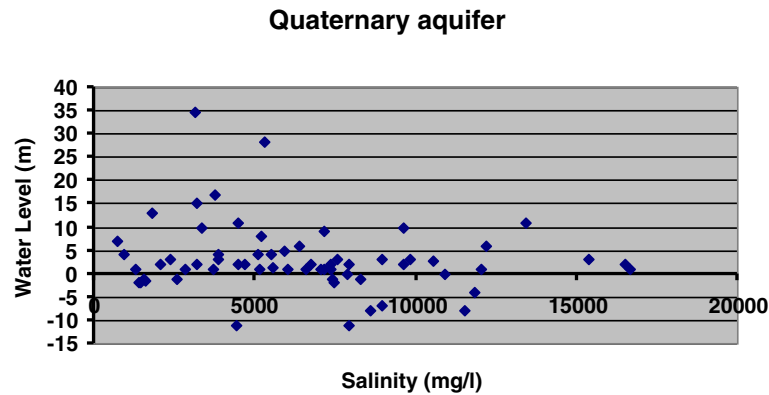


Figure 9. Relation between the water level and groundwater salinity in the Quaternary aquifer.

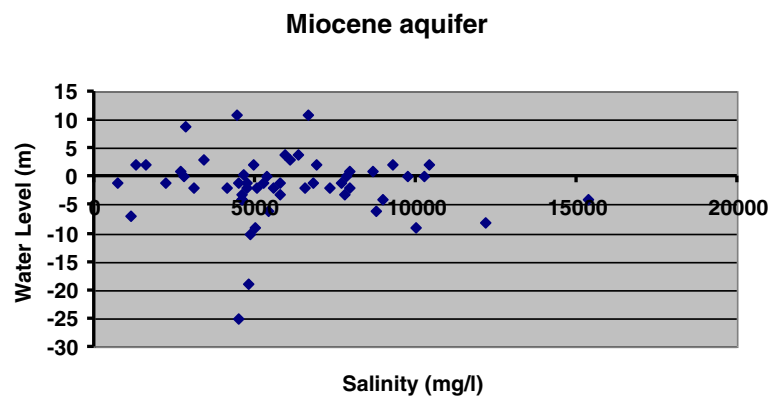


Figure 10. Relation between the water level and groundwater salinity in the Miocene aquifer.

illustrated in figures 11 and 12, where the following are noticed:

- In the Quaternary aquifer, majority of wells (62%) have salinities ranging between <5000 mg/l and >10000 mg/l regardless of the actual drilled depth below sea level ranging from zero to -10 m. About 50% of them have a salinity category between 5000 and 10000 mg. Actually, the relationship between the groundwater salinity and drilled depth below sea level is ill defined.
- In the Miocene aquifer, about 43% of the samples are within the range of 1000–5000 mg/l regardless of the actual drilled depth, which ranges between -30 and -10 m below sea level. This also is another indication that there is no trend governing the relationship between drilled depth and groundwater salinity.

3.2 Estimated optimum yield of brackish groundwater

To estimate the maximum discharge, which can be taken from the aquifer, for brackish water (<5000 mg/l), we assume that the safe distance between wells to avoid well interference (cone of

depression) is 500 m, i.e., 9 wells/km². Such an assumption is based on the following equation to calculate the transmissivity (T) (Brown *et al.* 1972)

$$T = \frac{Q}{2\pi S_w} \ln \left(\frac{re}{rw} \right)$$

where Q is the well discharge (m³/day), S_w is the drawdown in a pumped well (m), rw is the radius of well (m) and re is the radius of influence (m).

The aquifer test data in the study area indicate that the transmissivity (T) ranges between 25 and 40 m²/day for the fractured Miocene and from 120 to 180 m²/day for Oolitic limestone. However, for conditions commonly encountered in unconfined aquifers, radius of influence (re) is generally about 300 m (Hamill and Bell 1986). The average well discharge was measured in the field as 10 m³/hr for the Quaternary aquifer (porous media) and 5 m³/hr for the Middle Miocene (fractured media). The maximum discharge from aquifers for brackish groundwater, according to the iso-salinity maps (figures 4 and 5) was estimated as follows:

- The maximum discharge which can be taken from the Quaternary aquifer, for salinity 1000–5000 mg/l is 425,000 m³/day (52,200 m³/day

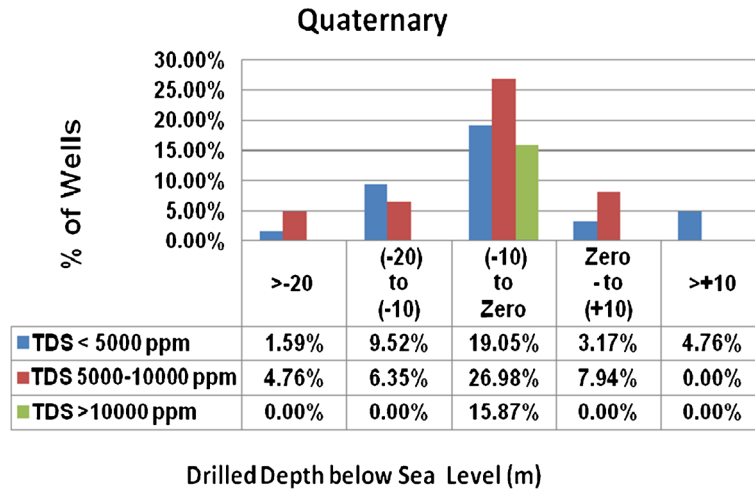


Figure 11. Percentage of wells and corresponding drilled depth below sea level for different salinity in the Quaternary aquifer.

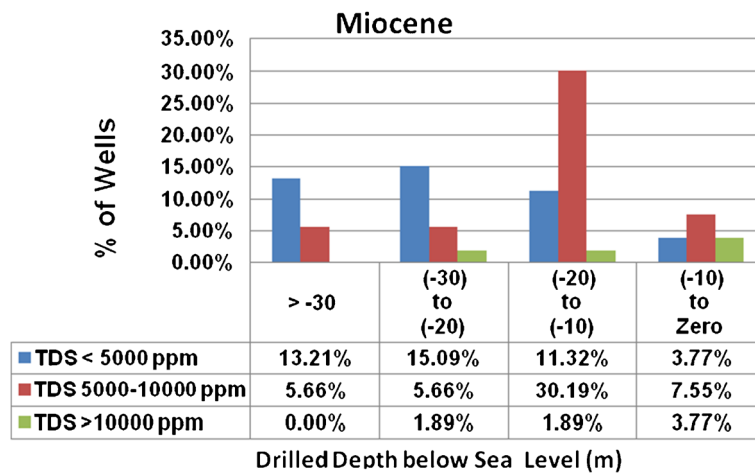


Figure 12. Percentage of wells and corresponding drilled depth below sea level for different salinity in the Miocene aquifer.

in Sidi Barani area and 372,600 m³/day in Matrouh–El Dabaa area).

- In the Miocene aquifer, the maximum discharge for salinity 1000–5000 mg/l is 135,000 m³/day (in the area of Sidi Barani).
- Groundwater having more than 5000 mg/l should be excluded as a supplement source for irrigation, since it actually harms the soil, especially the fragile soil dominating the Middle Miocene Plateau.

4. Conclusion

In the study area, the absolute groundwater level is slightly positive (above the mean sea level) for the Quaternary and Pliocene aquifers, while it is negative, i.e., below sea level, for the Middle Miocene aquifer. This may indicate that both aquifers in the area are probably hydraulically connected, or

that each of them has its own factors influencing the contained groundwater salinity.

The area embraced between Mersa Matrouh and Mersa El Asi in the west is structurally affected by the high land, bounding it from east and west, namely Ras Alam El Roum and Abu Laho causing the surface water divide in this specific area to be shifted northward. This leads to a reduction of the width of the coastal plain in this particular area (25 km) and consequently to a high degree of flood hazard in the existing Wadis, e.g., Wadis El Garawla, El Ramla, Umm Ashtan and Madwar.

The Pleistocene Oolitic limestone aquifer in this particular area attains the highest category of groundwater salinity (5000–10000 mg/l), while to both west and east directions of this area, the groundwater salinity gets lower and lower.

In general, the Oolitic limestone aquifer in the whole study area has the highest ability to directly recharge from the local rainfall, due to the high permeability of its building material. Unfortunately,

this aquifer is directly affected by sea water intrusion due to the direct connection between such deposits and the Mediterranean Sea. These conditions affect the groundwater salinity seriously in this particular aquifer.

The Middle Miocene aquifer (fractured limestone) shows a different manner, where in the area lying directly to the east of Sidi Barrani exhibits the lowest category of groundwater salinity (1000–5000 mg/l) among the whole investigated area, bearing in mind that the coastal plain in this area (80 km width) is the widest among the whole study area. Naturally, the ability to directly recharge of the Middle Miocene aquifer by local rainfall is expected to be much less than that of the Quaternary aquifer, unless a favourable geologic structure may help in this process. However, the area to the east of Sidi Barrani is highly dissected by long, deep and wide Wadis (e.g., Wasi Mahgin, El Sanab, El Tawila and El Shebity).

Worth mentioning, the relationship between the groundwater salinity and the absolute water level with respect to the mean sea level was found ill-defined in the present work. The same conclusion is also applied for the well drilling depth below sea level, in both aquifers, where no considerable changes in water salinity due to those variables were seen.

In conclusion, the groundwater salinity in the study area is highly influenced by different factors, among them the most effective are the geologic

structure, ability to recharge by direct rainfall and runoff, and by sea water intrusion especially if the aquifer strata are directly connected with the sea water.

In order to get brackish water with salinities <5000 mg/l, one can recommend that the promising area for well drilling in the Miocene aquifer is the area that lies in the west of Mersa El Asi (between El Negila and Sidi Barani), while for the Quaternary aquifer two subareas are recommended for well drilling namely between Mersa El Asi and Mersa Matrouh and East El Dabaa.

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