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THE IMPACT OF HYDRULIC ENGINEERING CONSTRUCTION ON THE GROUNDWATER SITUATION IN EL HAMMAM AREA, EGYPT (CASE STUDY)

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The newly introduced hydraulic engineering constructions for carrying excess of water from the western Nile Delta to the Mediterranean Coast of Egypt during the end of 20th century changed the hydrogeologic setting. This is obvious within the El Hammam area where the following phenomena have been arised:

1- The occurrence of new Holocene, Pleistocene alluvial and Miocene Aquifers.
2- The increase of the water level of the oolitic limestone aquifer more than 15 m since 1975 and about 3.0 m since 1986.
3- The change of the hydraulic regime and the appearance of new water ponds.
4- The decrease of groundwater salinities in the oolitic limestone aquifer from 18,000 ppm in 1975 to 2890 ppm in 2006 due to the continuous recharge from the new irrigation canals.

This situation can be replicated in other parts in the country, and the planner must take into consideration the possible effect of any surface water construction upon groundwater occurrence. The new groundwater resources can be used in the future for reclamation of other areas as a supplementary source of irrigation after hydrologic evaluation.

Keywords: Engineering, construction, groundwater, El Hammam, Mediterranean Coast, Egypt.

At the beginning of the seventies, the Egyptian Government excavated El Nahda Canal south of the Mediterranean Sea (Fig. 1) in an area that has ground elevations varying from +14 to +16 m, to receive the surplus drainage water from West Nile Delta. The excess water is used to irrigate the suitable areas north of Burg El Arab and El Hammam with ground elevations less than +14m. The impact of this canal on the hydrogeologic conditions in El Hammam and Burg El Arab was studied by Hilmy *et al.* (1978) and Guindy (1989) based on a few water wells.

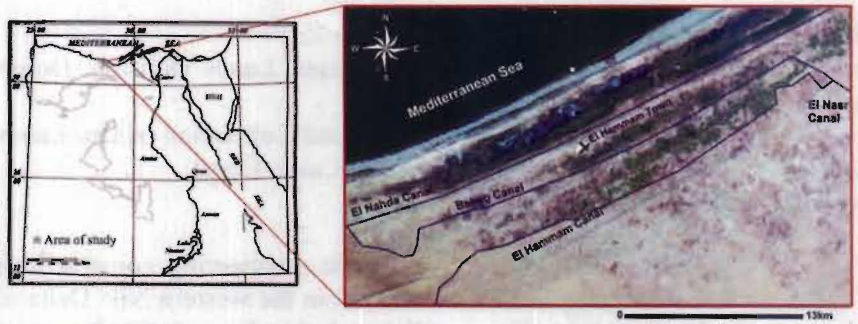

Fig. (1). Location map of El Hammam area and the main irrigation canals.

At the start of the eighties, with the increase of the agricultural drainage water in west Nile Delta, the Egyptian government excavated El Nasr Canal with a ground elevation more than +60 m (Fig. 1) to mix the surplus drainage water with the irrigation water to irrigate the new reclaimed areas of ground elevation less than +20 m along the Baheg Canal (about +30 to about +20 m). With the increase of water in the El Nasr Canal, the a new canal called El Hammam canal with ground elevations ranging from about +60 m to about +40 m has been excavated for the irrigation of the suitable lands with ground elevation less than +40 m.

Due to the variation of the geologic structural setting along the Mediterranean coast, which is characterized by a sequence of synclines and anticlines from east to west that were initiated since the Pre-Cambrian and rejuvenated throughout the geological history of the area (Meshrif, 1990), there is a variation of the groundwater occurrence between the synclinal and anticlinal areas. However, the synclinal areas are highly deformed by many fault systems, water levels are higher, ponds and wells are abundant and water quality is relatively good.

To demonstrate the impacts of the hydraulic engineering projects on the groundwater system, El Hammam area that lies in the syncline, has been selected. It is located to the west of Alexandria and runs parallel to the coast for about 25 km with a width of about 12 km. It is bounded by longitude 29° 17' 00" to 29° 30' 00" and latitude 30° 53' to 30° 47' (Fig. 1). It is crossed by several paved roads, such as the Alexandria – Matruh and the El Hammam-Burg El Arab Roads. It is dissected also by irrigation and drainage systems. Topographically, the surface undulating which the elevation is ranging from more than 70 m in the southern part to less than 0 m in the northern part with an alternating series of calcareous ridges and depressions that have variable elevation. From the climatic point of view, it is located within the arid belt of Egypt, where the rainfall reaches 140 mm/year and the maximum temperature is 35 °C.

With the initiation of the new engineering construction (surface water canals), the hydrologic regime of the study area has changed and caused the rise of groundwater level and the occurrence of water ponds in low areas. They support the Egyptian government's efforts to ensure the sustainability of the reclamation projects using groundwater as supplementary irrigation during the shortage of surface water. New wells that were drilled for cultivation in the new reclaimed area revealed much new subsurface geological and hydrogeologic informations. In addition, recent satellite images were used to support the researcher in explaining the impact of the hydraulic constructions on the groundwater occurrence, distribution and their relations. Furthermore, changes in groundwater aquifers with time from 1975 to 2006 were interpreted.

RESULTS AND DISCUSSION

1- Geomorphologic Aspects

Based on the satellite image, geologic map, topographic maps and field observations, a geomorphologic map was constructed. It is divided into four main geomorphologic units: namely, the table land, footslope and coastal plain (Fig. 2). They are discussed as follows from south to north:

The table land is termed Maryut Table Land. It is located in the southern part of the study area and extends southward to merge gradually with the El Diffa Plateau. It is characterized by undulating topography that rises gradually southward to about +100 m above sea level. It is dissected by some wadis and their tributaries that debouch their water in the coastal plain and Mallahet Maryut. Table land is composed mainly of massive cavernous limestone rocks that belonging to the Milazzian to the Sicilian (Middle Miocene) (Philip, 1955). It is covered partially by sand sheets belonging to the Quaternary Period. Kashm El Esh Ridge is present in the northern part, while Alam Shaltut-Alam El Afrag Ridge has been eroded.

The footslope is located to the north of the table land, and is characterized by ground elevations ranging from over +40 m in the southern part to +28 m to the north with relatively low gradient. The width varies from about 200 m to about 900 m. It is composed mainly of pink limestone belonging of Middle Miocene age that is covered partially by coarse sand and gravel belonging to the Quaternary Period. It is partially cultivated with irrigation from surface and groundwater.

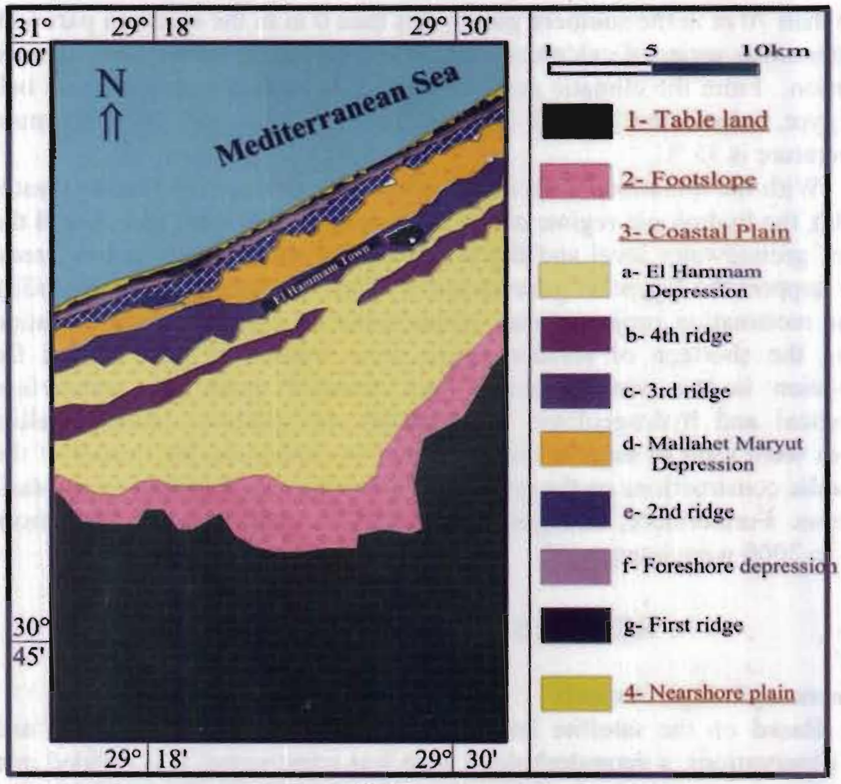

Fig. (2). Geomorphic units in El Hammam area.

The coastal plain occupies most of the study area and is characterized by an alternating series of calcareous ridges and depressions (Fig. 3) that are partially cultivated. They are as follows from south to north:

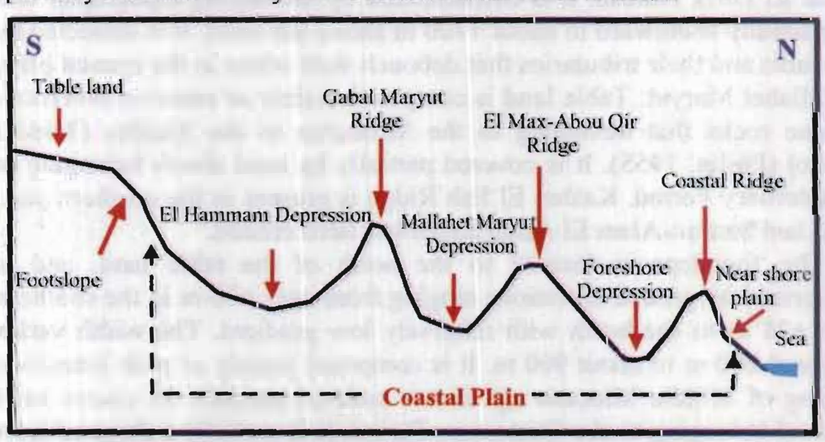

Fig. (3). Sketch Cross section in El Hammam area.

i- El Hammam Depression occupies the southern part of the coastal plain and extends from the piedmont plain to Gabal Maryut Ridge (3rd ridge). It is characterized by relatively low land in the center and it increases in elevation to the north and south. It is characterized also by the presence of scattered, disconnected ridges. It is dissected by some wadis that debouch their water from the table land to Mallahet Maryut. It is covered by calcareous sediments with variable thickness that reaches over 10 m.

ii- Gabal Maryut Ridge (3rd ridge) is located north of the El Hammam Depression with ground elevation ranging from about +36 m to about +20 m and width varying from about 400 m to over 1000 m. It is dissected by some wadis that debouch their water into Mallahet Maryut in the northern part. It is composed mainly of relatively hard oolitic calcareous limestone rocks that are used for tourism constructions. El Hammam Town was built mainly on this ridge.

iii- Mallahet Maryut Depression is recorded between the Gabal Maryut and El Max-Abu Sir ridges. It is characterized by ground elevation ranging from +7 m in the western part to about +1 m in the eastern part. It has a width reaching about 2000 m. It is partially covered by water due to the seepage from the groundwater. It is composed mainly of calcareous sediments with evaporites. It is partially cultivated in the western part.

iv- El Max-Abu Sir Ridge (2nd ridge) is located north Mallahet Maryut Depression. It has a ground elevation between +12 m and +26 m and a width ranging from 200 to 800 m. The ridge is composed mainly of semi-consolidated oolitic calcareous limestone.

v- Foreshore depression is located between El Max-Abu Sir and the coastal ridges. It is a narrow depression and has width between 100 m and few hundred meters. It is characterized by ground elevation ranging from about +5 m in the western part to about +1 m in the eastern part. It is composed mainly of calcareous sand with evaporites.

vi- Coastal Ridges (1st ridge) is the northernmost ridge and lies parallel to the shoreline. It has a ground elevation ranging from +10 to +16 m with fewer than ten meters in width. It is composed mainly of relatively low consolidated carbonate sand. Large parts of the tourism villages were built on this ridge.

vii-Near shore plain is located parallel to the shoreline of the Mediterranean Sea. It is narrow with a width varying from a few meters to a few hundred meters. It has ground elevations ranging from + 4 m to about +0.5 m. It is composed mainly of carbonate sand with shells and shell fragments.

2- Geologic Characteristics

Based on the satellite image, field observations and measurements, as well as literature (Said, 1962 and 1990; Abdallah, 1966; Attia, 1975 and Korany, 1975 as well as Shata, 1978); the surface geology of the study area is represented by Miocene and Quaternary deposits (Fig. 4). The Miocene Rocks are located in the southern part and are represented by the Marmarica Formation belonging to Middle Miocene. It is composed mainly of reddish to grayish, hard cavernous sandy limestone with shale beds. The Quaternary deposits occupy most of the northern part and are represented by Pleistocene (oolitic calcareous ridges) and Holocene sediments (alluvial, sabkha and beach). The detrital oolitic limestone sediments that belong to the Pleistocene are exposed as ridges. They are built mainly of whitish layers of oosparite with detrital texture that developed along successive paleo-shore lines of the Mediterranean Sea (Hilmy *et al.*, 1978). On the other hand, the Holocene alluvial sediments are deposited mainly in El Ḥammam Depression and composed mainly of calcareous coarse sand in the southern part changing northward to become mainly fine sand and silt. They are overlain by an evaporite series of alternating gypsum and clays, from which gypsum is quarried at both the El Gharbaniat and El Hammam localities. The sabkha deposits are recorded between the Pleistocene northern ridges and are composed mainly of evaporties (gypsum with halite). The beach deposits are located parallel to the present shoreline and are built mainly of calcareous white loose medium sands with shells.

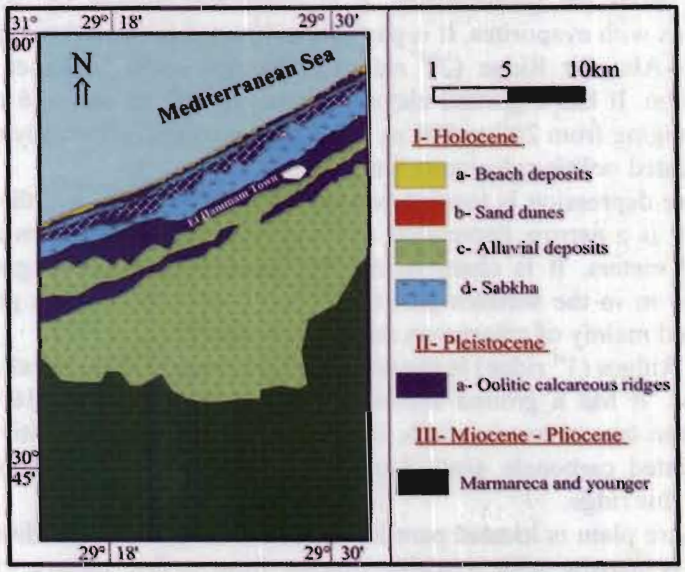

Fig. (4). Geological map of the study area (modified after Said, 1962 and 1990; Abdallah, 1966; Attia, 1975 and Korany, 1975 as well as Shata, 1978).

3- Water Resources Aspects

The hydrological factors which affect the hydrologic regime of the area are manifested by:

i- The new introduced system of surface water originates as a result of the newly excavated irrigation canals (Baheg and El Hammam) in the southern part of the area and the presence of ponds in the northern part of the investigated area, along with of the previously excavated El Nahada Canal. The areas to the north of these canals are mostly low with general slope to the north. The groundwater regime in this portion of the area has been generally modified since the excavation of Baheg and El Nahada Canals, with an increasing effect after the excavation of El Hammam Canal.

ii- The occurrence of artificial activities that include the irrigation and drainage systems of the cultivated area, the waste water of El Hammam town and pumping of the groundwater for supplementary irrigation.

iii- The proper connection between Pleistocene oolitic limestone and Holocene aquifers are affected by the systems of irrigation and drainage.

a- Surface water

The study area is dissected by four main canals (Fig. 5) with different ground elevations (Table 1): namely El Nasr, El Hammam, Baheg and El Nahda. El Nasr Canal fresh water (mixed water from the drainage water of the cultivated lands in the western Nile Delta and fresh irrigation water) is the main source of the Baheg and El Hammam canals. The surface water flows mainly by gravity from the relatively high to the relatively low lands. The ground elevation of each canal differs from others in order to irrigate cultivated lands of different elevations. The salinity of these canals increase northward from about 470 ppm to about 540 ppm (Table 1), except El Nahda Canal that reaches 1970 ppm because the canal partially acts as a groundwater drain and the effects of the surrounding sabkha.

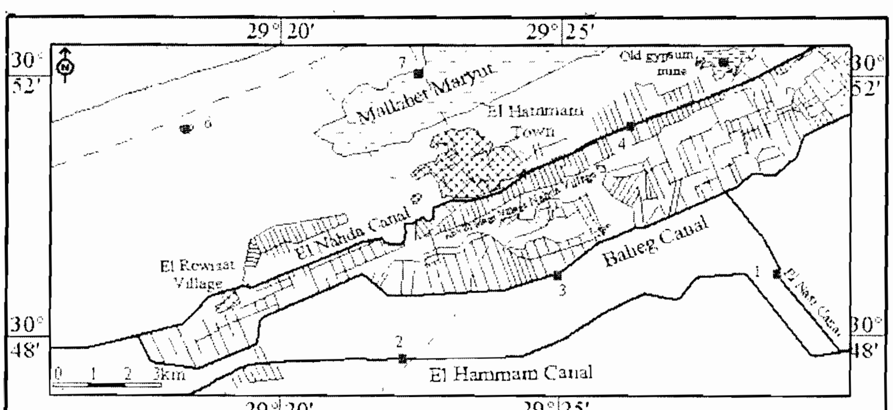

Fig. (5). Location map of the irrigation and drainage systems as well as the selected location for surface water sampling.

Table (1). Chemical analyses of surface water in El Hammam area.

No.	Location	Ground elevation above sea level (m)		EC (mmohs/cm)	TDS (ppm)	PH	K^+ (ppm)	Na^+ (ppm)	Mg^{++} (ppm)	Ca^{++} (ppm)	Cl (ppm)	$SO_4^=$ (ppm)	HCO_3 (ppm)
		From	To										
1	El Nasr Canal	63.0	28.0	0.73	467	8.30	12.0	85	9	50	110	40	195
2	El Hammam Canal	57.0	42.0	0.81	522	8.80	13. 0	100	13	45	135	50	190
3	Baheg Canal	28 0	19.0	0.87	557	8.64	7.4	125	16	35	160	55	175
4	El Nahda Canal	15.0	14.0	3 07	1965	8.92	19.5	480	58	76	700	270	250
5	Gypsum pond	10 0	9.0	6.88	4403	6.92	32. 0	1090	135	165	1850	400	410
6	Nawar pond	0 5	0.0	74 2	47488	8.30	400. 0	11000	2400	1000	18400	10000	450
7	Mallahet Maryut	2.0	1.0	135.16	86500	8.20	157 0	26500	1900	710	36500	15000	305

b- Groundwater Aquifers

Based on the lithological description of the continuous cores from 5 drilled wells, the available composite logs of the drilled wells (Fig. 6), hydrogeologic cross section (Fig. 7), chemical analyses of the collected water points (Table 2), field observations and measurements, and literature, the hydrogeological setting of El Hammam area can be differentiated into Holocene, Pleistocene and Miocene Aquifers. They are discussed as follows:

i- The Holocene Aquifer

The Holocene Aquifer occurs mostly in the low lying depressions between the oolitic limestone ridges and is tapped by more than 100 hand dug wells. It is underlain directly by calcareous sandy and clayey sediments of variable thickness ranging from 1.0 m to about 8.0 m and overlain lagoonal deposits (series of banded gypsum with clay layers) and dry creamy massive limestone, i.e. unconfined aquifer. It is composed mainly of calcareous medium to coarse sand.

Fifteen water wells have been selected to represent the aquifer (Fig. 6 and Table 2). The depth to water ranges mainly from 0.6 m to about 7.0 m from the ground surface. The absolute water level varied between +12.0 and –2.4 m with the hydraulic gradient northward. The groundwater salinity ranges from about 800 ppm near El Hammam Canal to about 6110 ppm near the Mediterranean Sea. It is recharged by several types of hydraulic aspects such as El Hammam, Baheg and El Nahda Canals, beside the systems of irrigation and drainage as well as the local seasonal rainfall.

ii- Pleistocene Aquifers

The Pleistocene aquifers can be classified into two water bearing units according to the types of aquifer sediments; namely oolitic limestone and alluvial. They are as follows:

1- The water bearing oolitic limestone aquifer

It constitutes the main productive aquifer in the study area, where it is tapped by more than 80 water wells. It is overlain partially by calcareous sandy and clayey sediments of variable thickness and underlain by dry creamy massive limestone, i.e. the unconfined aquifer. It is composed mostly of friable to relatively hard oolitic limestone and was deposited under littoral-continental conditions with porosity reaching 41% by volume and coefficient of permeability as high as to 411 g/d ft^2 (Hilmy *et al.*, 1978).

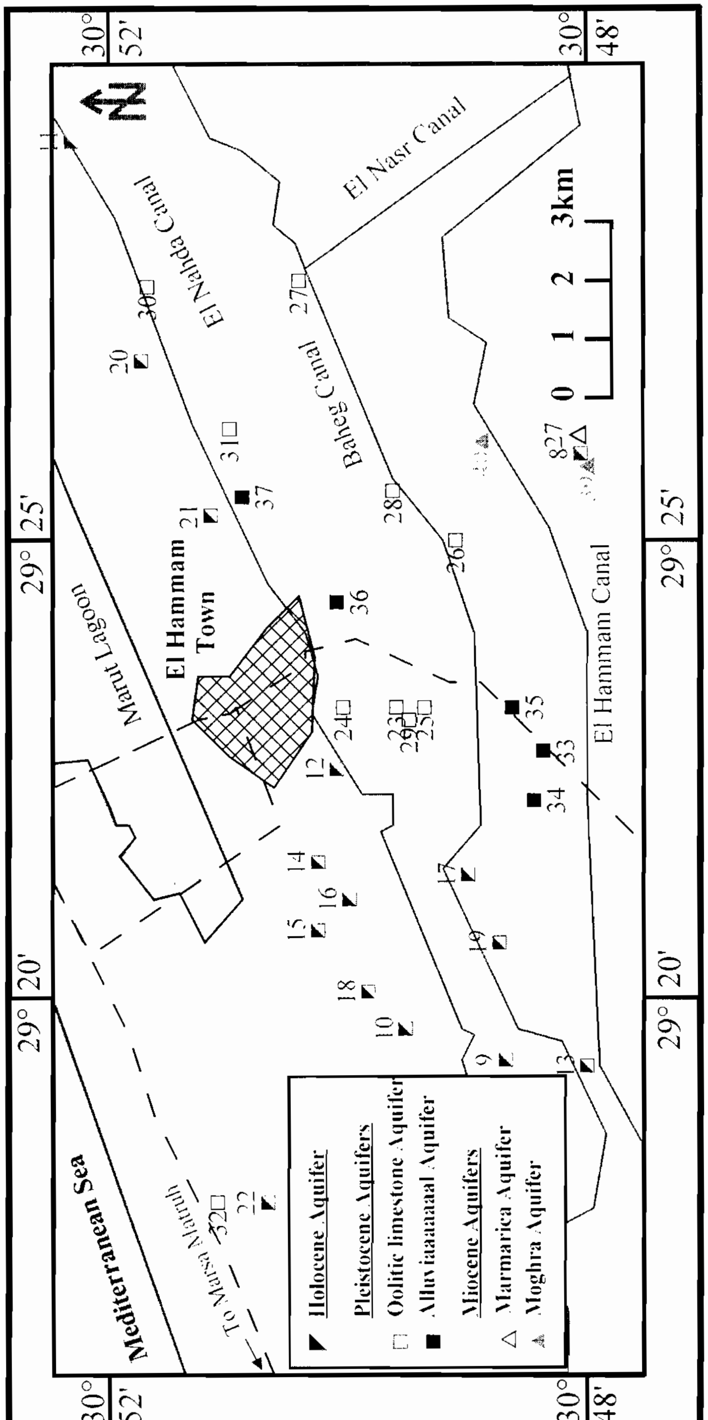

Fig. (6). Location map of selected groundwater points.

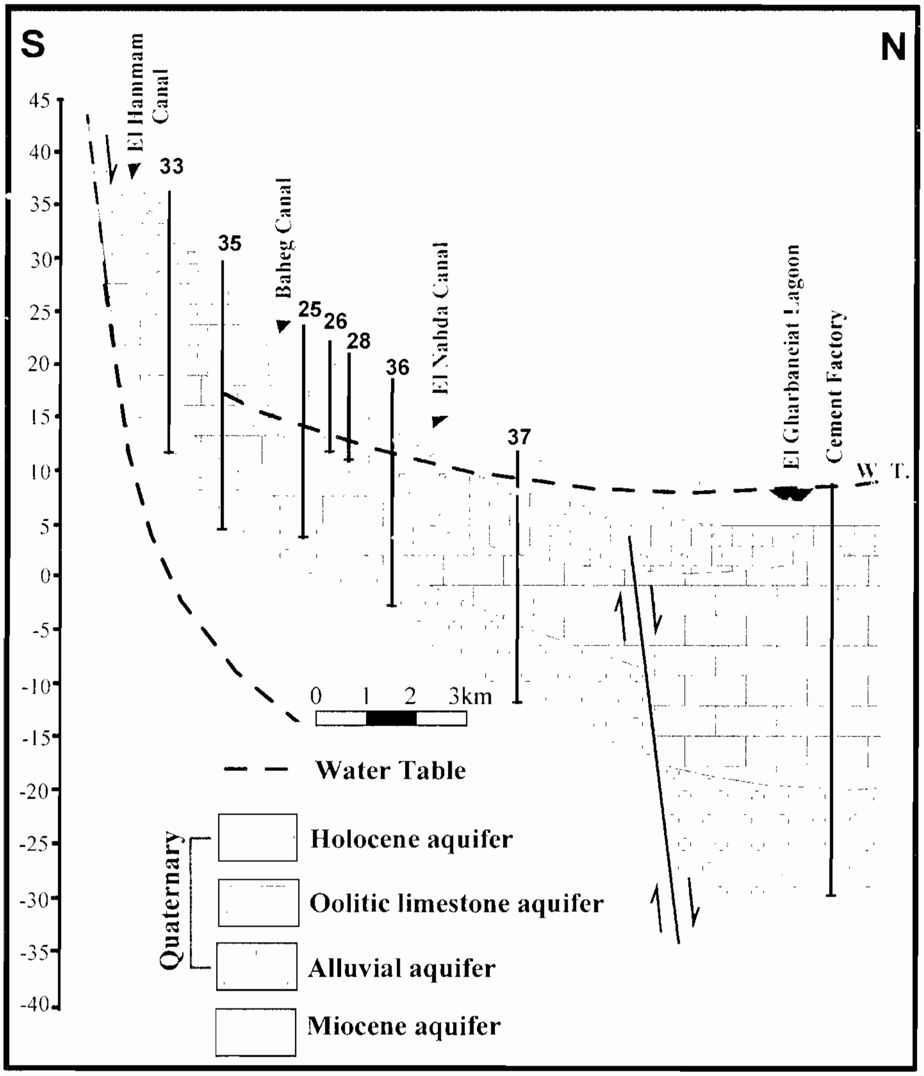

Fig. (7). Hydrogeological cross section of the study area.

Ten water points have been selected to represent this aquifer (Fig. 8 and Table 2). The depth to water varies generally between 3.0 m and about 9.6 m from the ground surface. The absolute water level ranges mostly from +17.2 to 9.0 m. The groundwater salinities increase from 687 ppm south of Gabal Maryut Ridge due to the effect of Baheg Canal to 1811 ppm close to El Nahda Canal and even higher northward to 5094 ppm in El Max-Abu Qir Ridge in the vicinity of the Mediterranean Sea owing to the effect of leaching processes. It is recharged by several hydraulic sources such as the Baheg and El Nahda Canals, in addition to irrigation and drainage systems and the local seasonal rainfall.

Table (2). Chemical analyses of the groundwater aquifer system in El Hammam area.

No	Aquifer system		Well Name	Elevation	Total Depth (m)	Depth to water (m)	Water level (m)	EC	TDS (ppm)	pH	K^+ ppm	Na^+ ppm	Mg^{++} ppm	Ca^{++} ppm	CL^- ppm	$SO_4^=$ ppm	HCO_3^- ppm
8	Quaternary	Holocene	Sanousy –3	64	20.0	13.00	48.00	1.25	800	8.55	15.0	165	10	75	330	50	100
9	Quaternary	Holocene	Shaaban	22	16.0	11.30	11.00	2.37	1517	8.38	24.0	210	16	240	350	570	49
13	Quaternary	Holocene	Ramadan	19	25.0	10.30	7.70	9.31	5958	8.11	2600.0	900	45	2600	2600	900	45
10	Quaternary	Holocene	Khaled Kahka	15	16.0	4.20	10.80	2.37	1517	8.42	20.0	270	90	75	610	245	65
11	Quaternary	Holocene	Kholef	27	27.0	17.00	9.00	1.94	1242	8.45	18.0	210	60	100	532	150	65
12	Quaternary	Holocene	Naga Tarban	12	8.0	3.50	8.50	9.55	6112	8.12	2740 00	800	70	2740	2740	800	70
14	Quaternary	Holocene	Shabab	11	14.0	3.50	7.50	14.60	9344	7.95	92.00	1850	450	500	4000	1400	70
15	Quaternary	Holocene	Rashad Fouad	16	12.0	0.60	10.00	6.95	4448	7.86	33.10	900	190	270	1900	450	349
16	Quaternary	Holocene	Abdel Haleem	16	14.0	4.00	12.00	2.83	1811	7.78	26.00	215	110	190	443	600	70
17	Quaternary	Holocene	Ashraf El Safy	12	9.0	6 00	6.00	2.70	1728	7.76	31.00	200	110	150	355	660	60
18	Quaternary	Holocene	Ahmed Mousa	17	14.0	7.00	10.00	2.53	1619	7.75	24.00	290	80	100	532	400	65
19	Quaternary	Holocene	Said Amar	10	6.0	0.80	9.20	8.57	5485	7.24	42.90	1220	155	360	2450	550	262
20	Quaternary	Holocene	Mokhemer	12	2.2	1.60	10.40	5.51	3526	7.15	30.80	800	148	140	1320	600	300
21	Quaternary	Holocene	University	13	5.5	3.75	9.25	5.42	3469	7.34	17.90	900	100	120	1400	420	310
22	Quaternary	Holocene	Amer Gad Allah	4	9.0	6.50	-2.40	9.19	5882	7.40	43.00	1450	222	180	2500	950	65
23	Quaternary	Pleistocene	Malek Ebeid-1	24	24.0	9.55	11.50	2.48	1587	8.65	18.00	299	63	107	590	125	285
24	Quaternary	Pleistocene	Gomma	12	6.5	3.00	9.00	2.83	1811	8.64	16.40	180	100	220	500	400	262
25	Quaternary	Pleistocene	Hag Fathallah	24	17.0	11.00	13.00	2.18	1395	8.69	16.00	250	51	100	450	98	349
26	Quaternary	Pleistocene	Abdel Atty	27	10.6	9.36	17.60	1.10	704	8.99	7.80	150	12	60	150	67	305
27	Quaternary	Pleistocene	Abdel Raoef	26	11.8	8.80	17.20	1.84	1178	8.90	8.19	270	24	60	280	100	420
28	Quaternary	Pleistocene	Khames	24	10.4	8.96	15.00	173 00	687	8.70	11.00	80	60	37	150	60	300
29	Quaternary	Pleistocene	Malek Ebeid-2	22	12.7	8.95	13.00	2.20	1408	8.72	14.80	250	54	95	460	105	310
30	Quaternary	Pleistocene	Eng. Kadry	14	14.0	3.70	10.30	2.74	1754	8.55	21.00	380	74	70	600	150	350
31	Quaternary	Pleistocene	Seleem Fady	15	6.3	4.30	10.70	2.68	1715	8.75	14.80	300	96	100	560	180	400
32	Quaternary	Pleistocene	Awad Alam	12	26.0	20.60	-8.60	7.96	5094	8.38	48.40	1200	180	200	2250	500	262
33	Quaternary	Pleistocene	El Weshy	37	26.0	24.50	11.70	3.18	2035	7.58	26.90	445	60	130	700	250	349
34	Quaternary	Pleistocene	Sand dune	39	29.2	27.20	11.80	3.38	2163	7.52	30.00	465	51	160	750	300	350
35	Quaternary	Pleistocene	Goma Kobeily	28	24.0	18.50	9.50	3.78	2419	7.55	38.00	560	70	125	840	350	380
36	Quaternary	Pleistocene	Mahmoud	19	21.0	10.50	8.50	5.14	3290	8.01	23.00	770	100	160	1200	494	370
37	Quaternary	Pleistocene	Ali (Nahda)	12	24.0	5.40	6.60	5.18	3315	7.23	20.00	802	113	140	1260	450	400
38	Miocene		Sanousy -1	64	45.0	39.60	24.40	8.86	5670	7.78	15.00	85	20	60	215	80	50
39	Miocene		Sanousy -2	64	70.0	45.50	18.50	15.50	9914	8.04	60.00	2500	330	300	4700	900	70
40	Miocene		Gamal Mostafa	47	70.0	29.50	17.50	48.40	30976	7.95	220.00	7300	1240	1000	16000	1000	75

Ec= Electric conductivity   TDS= Total dissolved salt K^+= Potassium
Na^+= Sodium Ca^+= Calcium Cl^- = Chloride
SO_4^{--} = Sulphate HCO_3^- = Bicarbonate

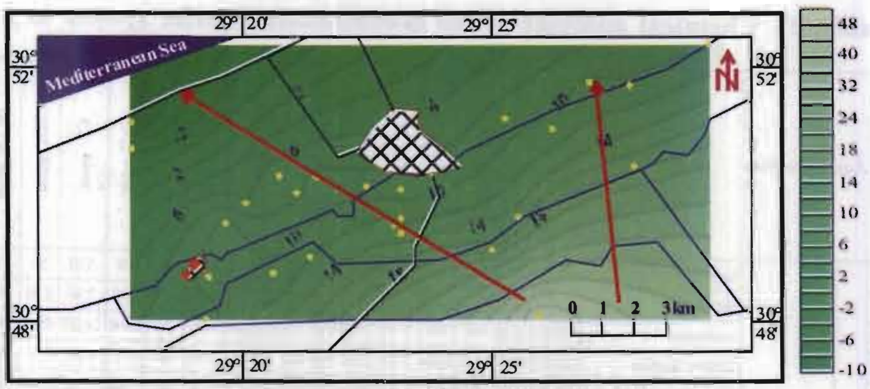

Fig. (8). The water level map of the Quaternary aquifer system.

The oolitic limestone and Holocene aquifers are hydraulically connected with each other through faults and pores. Whereas the variation of the depth to water is related to the effect of topography, the variation of groundwater salinity is a result of the variation of the type of aquifer sediments. These interpretations were used to draw the water table and salinity maps of the aquifers. The water level map (Fig. 8) shows the groundwater flow from +48.0 m in the southern part to –8.6 m in the northern part with the hydraulic gradient toward the Mediterranean Sea. Locally, flow directly toward Mallahet Maryut has been detected. The main sources of recharge besides the leaching process of the aquifers sediment greatly affects the salinity, which increases from 800 ppm close to El Hammam Canal in the southern part of the area to about 6110 ppm in the northern part (Fig. 9).

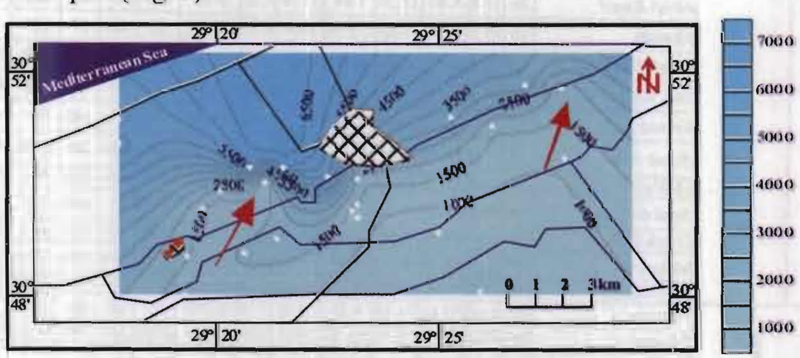

Fig. (9). Iso-salinity map of the Quaternary aquifer system.

2- The Alluvial Aquifer

The Alluvial Aquifer is represented and tapped by 5 water wells in the area between El Hammam and El Nahda Canal (Fig. 6 and Table 2). It directly underlies the dry creamy massive limestone and overlies creamy marly limestone, and is therefore confined aquifer. It is composed mainly of white, coarse to medium sand with some clay lenses. It was deposited under continental to fluvio-marine condition (Hilmy *et al.*, 1978). It is hydraulically separated from the other aquifers. It may equivalent to the Hosh Eisa (Nubariya Formation) aquifer in Abu Mina Basin east the area of study, which has a transmissivity range from about 474 to about 504 m^2/day (DRI, 1966).

The depth to water ranges from 5.4 to 27.22 m from the ground surface. The absolute water level varies between +11.8 m and +6.6 m with a hydraulic gradient northward. It is recharged mainly from the southern Miocene aquifers in addition to the effects of the El Hammam Canal. The groundwater salinities increase from 2035 ppm in the southern part close to El Hammam Canal to 3315 ppm in the northern part due to the effect of leaching processes.

iii- Miocene Aquifers

The Miocene aquifers can be differentiated according to the type of aquifer sediments into the Marmarica and Moghra. They are discussed as follows:

1. Marmarica Aquifer (M. Miocene)

It is present in the southern part of the area and is tapped by only one water well near El Hammam Canal of 45 m total depth (Fig. 6 and Table 2). It is composed mainly of cavernous sandy limestone with clay interbeds. It is deposited under marine (mainly neritic) to fluvio-marine conditions (Hilmy *et al.*, 1978). The depth to water is 39.6 m from the ground surface, while the absolute water level +21.4 m. It is recharged mainly from the seasonal rainfall on the table land. The groundwater salinity reaches 5670 ppm due to the effects of leaching processes.

2. Moghra Aquifer (L. Miocene)

It is present only in the southern part of the area around El Hammam Canal and tapped by two wells (Fig. 6 and Table 2). It is underlain the by Middle Miocene shale and overlain by the Lower Miocene shale, and therefore is a confined aquifer. It is composed mainly of pebbly to medium sandstone with shale interbeds. It was deposited under marine to fluvio-marine conditions (Hilmy et al., 1978). The depth to water varies between 29.5 m and 45.5 m from the ground surface and the absolute water level ranges from +15.5 m to +14.5 m with hydraulic gradient northward toward the Mediterranean Sea. It is recharged mainly from seasonal rainfall on the table land and the El Hammam Canal through a fault system. The groundwater salinity ranges from 9641 ppm near El Hammam Canal to 30976 ppm northward owing to the marine and fluvio-marine origin of this unit.

4- Hydrogeochemical Characteristics

The chemical analyses of the collected water samples (Table 2) and the hypothetical salt percentages in the study area (Tables 3 and 4) reflect the type of aquifer sediments and the source of recharge, which control the geochemical properties of water. The major characteristics are summarized as follows:

Table (3). The hypothetical salt percentages of the examined surface water samples in El Hammam area.

Sample	Location	KCL	NaCl	$MgCL_2$	$CaCL_2$	Na_2SO_4	$MgSO_4$	$CaSO_4$	$NaHCO_3$	$Mg(HCO_3)_2$	$Ca(HCO_3)_2$
1	El Nasr Canal	4.25	39.22	0.00	0.00	11.69	0.00	0.00	0.11	10.22	34.51
2	El Hammam Canal	4.17	43.61	0.00	0.00	10.73	2.35	0.00	0.00	11.01	28.12
3	Baheg Canal	2.19	50.70	0.00	0.00	11.83	1.61	0.00	0.00	13.53	20.14
4	El Nahda Canal	1.67	65.30	0.00	0.00	4.40	14.70	0.00	0.00	1.23	12.69
5	Gypsum pond	1.21	70.14	5.77	0.00	0.00	10.66	1.68	0.00	0.00	9.95
6	Nawar pond	1.39	64.99	4.23	0.00	0.00	22.59	5.79	0.00	0.00	1.01
7	Mallahet Maryut	0.30	76.11	0.00	0.00	9.37	11.59	2.26	0.00	0.00	0.37

a- Surface water

i. The pH ranges mostly from 6.92 to 8.92.

ii. The TDS of the irrigation canals water ranges from 467 to 557 ppm (fresh,) except that of Nahda Canal reaches 1965 ppm (brackish water) because it acts as a drain in places and the effect of surrounding sabkhas. On the other hand, the Gypsum and Nawar water ponds which act as drains, have TDS of 4403 ppm (brackish water) and of 47488 ppm (saline water) respectively, while the TDS of Mallahet Maryut (the main discharge area) is 86500 ppm (saline water) due to the effects of evaporation and leaching processes.

iii. The dominant ion sequences of the irrigation water are $Na^{+} > Ca^{++} > Mg^{++}$ – $Cl^{-} > HCO3^{-} > SO4^{--}$, while the dominant sequences of the Gypsum and Nawar water ponds and Mallahet Maryut are $Na^{+} > Mg^{++} > Ca^{++}$ – $Cl^{-} > SO4^{--} > HCO3^{-}$ due to the effect of evaporation.

iv. The hypothetical salt dominance of the irrigation canals water are mainly NaCl, $Ca(HCO_3)_2$, $Mg(HCO_3)_2$ and Na_2SO_4, while the main salts of the drains (water ponds and Mallahet Maryut) are NaCl and Mg SO_4 due to the effect of evaporation and leaching processes.

b- Groundwater

1. Holocene Aquifer

i. The pH varies mainly from 7.34 to 8.55 due to the variation of aquifer sediments.

ii. The TDS of the Holocene Aquifer in El Hammam Depression is around 1500 ppm (brackish water) in the southern part owing to the effect of the seepage from the irrigation canals and increases northward to around 5000 ppm (brackish water) due to the effect of leaching processes. On the other hand, the TDS of the aquifer in the Mallahet Maryut Depression is around 3200 ppm in the southern part, changing northward to become around 6000 ppm (brackish water) related to the effect of leaching processes.

iii. The dominant ionic sequence of El Hammam Depression changes generally from $Na^{+}>Ca^{++}>Mg^{++}$ – $Cl^{-}> SO4^{--}> HCO3^{-}$ in the southern part to $Na^{+}>Mg^{++}> Ca^{++}$ – $Cl^{-}> SO4^{--}> HCO3^{-}$ in the northern part. On the other hand, the sequence of ions in Mallahet Maryut Depression is mainly $Na^{+}>Mg^{++}>Ca^{++}$ – $Cl^{-}> SO4^{--}> HCO3^{-}$ due to the effects of leaching processes.

iv. The hypothetical salt percentages of El Hammam Depression change mostly from NaCl, $MgCl_2$ and $CaSO_4$ in the southern part to NaCl, $MgSO_4$ and $CaSO_4$ in the northern limb. On the other hand, the main salt combinations of Mallahet Maryut Depression are NaCl and $MgSO_4$ owing to leaching processes and the evaporites.

Table (4).The hypothetical salt percentages of the examined groundwater samples in El Hammam area.

Sample	Aquifer system		KCL	NaCl	$MgCL_2$	$CaCL_2$	Na_2SO_4	$MgSO_4$	$CaSO_4$	$NaHCO_3$	$Mg(HCO_3)_2$	$Ca(HCO_3)_2$
8	Quaternary	Holocene	3.17	59.14	6.78	8.53	0.00	0.00	8.70	0.00	0.00	13.69
9			2.67	39.59	1.49	0.00	0.00	4.22	48.47	0.00	0.00	3.56
10			2.21	45.97	24.84	4.17	0.00	0.00	17.08	0.00	0.00	5.09
11			1.23	56.62	20.15	0.00	0.00	2.46	11.20	0.00	0.00	8.34
12			1.30	62.48	15.02	2.62	0.00	0.00	13.52	0.00	0.00	5.06
13			2.36	46.76	25.27	3.75	0.00	0.00	16.30	0.00	0.00	5.56
14			1.21	56.65	23.38	0.00	0.00	1.68	15.87	0.00	0.00	1.21
15			1.22	56.71	21.02	0.00	0.00	3.80	16.41	0.00	0.00	0.80
16			1.63	55.55	21.62	0.00	0.00	3.94	16.46	0.00	0.00	0.80
17			2.33	32.73	12.70	0.00	4.08	18.97	28.87	0.00	0.00	4.39
18			3.05	33.40	3.98	0.00	0.00	30.76	24.83	0.00	0.00	3.98
19			2.48	50.84	8.14	0.00	0.00	18.39	15.79	0.00	0.00	4.37
20			1.44	63.54	3.12	0.00	0.00	19.11	3.78	0.00	0.00	9.01
21			0.85	72.72	0.47	0.00	0.00	14.82	1.61	0.00	0.00	9.54
22			1.21	68.97	6.97	0.00	0.00	13.00	8.68	0.00	0.00	1.17
23		Pleistocene	1.92	54.18	13.44	0.00	0.00	8.15	2.75	0.00	1.06	19.55
24			1.53	28.49	22.72	0.00	0.00	7.22	23.98	0.00	0.00	16.06
25			2	53.09	6.93	0.00	0.00	9.99	0.00	0.00	3.57	24.42
26			1.87	37.59	0.00	0.00	13.07	0.00	0.00	10.24	9.22	28.01
27			1.24	45.55	0.00	0.00	12.36	0.00	0.00	11.46	11.66	17.73
28			2.84	32.93	4.88	0.00	0.00	12.03	0.00	0.00	29.80	17.51
29			1.86	53.18	9.02	0.00	0.00	10.81	0.00	0.00	1.89	23.24
30			2.02	62.01	0.33	0.00	0.00	11.90	0.00	0.00	10.61	13.14
31			1.44	49.56	9.48	0.00	0.00	14.38	0.00	0.00	6.14	19.00
32			1.59	66.70	12.74	0.00	0.00	6.18	7.13	0.00	0.00	5.48
33			2.19	61.48	0.67	0.00	0.00	15.01	1.99	0.00	0.00	18.67
34			2.32	60.93	0.55	0.00	0.00	12.09	6.78	0.00	0.00	17.33
35			2.61	61.03	0.00	0.00	0.00	15.41	0.00	0.00	0.00	16.74
36			1.17	66.04	2.27	0.00	0.00	16.35	3.58	0.00	0.00	12.06
37			0.99	67.48	0.55	0.00	0.00	17.44	0.79	0.00	0.00	12.75
38		Miocene	4.41	42.36	18.85	0.00	0.00	0.00	19.51	0.00	0.00	9.60
39			1.01	71.34	14.59	0.00	0.00	3.22	9.09	0.00	0.00	0.75
40			1.19	66.82	21.47	5.86	0.00	0.00	4.41	0.00	0.00	0.26

2. Pleistocene Aquifer:

a- Ooltic Limestone

i- The pH ranges mostly from 8.38 and 8.99.

iii- The TDS of the Gabal Maryut Ridge changes mainly from less than 1000 ppm (fresh water) in the southern limb to about 4760 ppm (brackish water) in El Max- Abu Qir Ridge due to the effect of leaching processes.

iv- The dominant sequence in the vicinity of the Gabal Maryut Ridge changes mainly from $Na^{+}>Ca^{++}> Mg^{++}$ – $Cl^{-}>HCO_3^{-}>SO_4^{--}$ in the southern limb to $Na^{+}>Mg^{++}> Ca^{++}$ – $Cl^{-}>HCO_3^{-}>SO_4^{--}$ in the northern limb. On the other hand, the sequence of El Max- Abu Qir Ridge is $Na^{+}>Mg^{++}> Ca^{++}$ – $Cl^{-}> SO_4^{--}> HCO_3^{-}$ due to the effect of leaching processes.

v- The hypothetical salt percentages of the Gabal Maryut Ridge changed mostly from NaCl and $Ca(HCO_3)_2$ in the southern limb to NaCl, $Ca(HCO_3)_2$ and Mg SO_4 in the northern limb. On the other hand, The main salt combinations of El Max- Abu Qir Ridge are NaCl and $MgCl_2$.

b-Alluvial Aquifer

i- The pH ranges mostly from 7.23 to 8.01.

1. The TDS of the water samples ranges from 2035 ppm to 3315 ppm (brackish water).
2. The dominant ionic sequence of the alluvial samples changes from $Na^{+}> Ca^{++}>Mg^{++}$– $Cl^{-}> SO_4^{--}> HCO_3^{-}$ in the southern part to $Na^{+}> Mg^{++}>Ca^{++}$ $Cl^{-}> SO_4^{--}> HCO_3^{-}$ in the northern part.
3. The hypothetical salt percentages are NaCl, $Ca(HCO_3)_2$ and $MgSO_4$, respectively due to the effect of their fluvio-marine origin.

3. Miocene Aquifer:

i- The pH ranges mostly from 7.78 – 8.04.

ii- The TDS of the Marmarica Aquifer water is 5670 ppm (brackish water), while the TDS of Moghra Aquifer ranges from 9914 ppm (Brackish water) to 30976 ppm (saline water).

iii- The sequence of ions in the Marmarica water samples is $Na^{+}> Ca^{++}> Mg^{++}$- $Cl^{-}> SO_4^{--}> HCO_3^{-}$, while in Moghra Aquifer are $Na^{+}> Mg^{++}> Ca^{++}$– $Cl^{-}> SO_4^{--}> HCO_3^{-}$. The main salt combinations in Marmarica Aquifer are NaCl and $CaSO_4$, while in Moghra Aquifer one are NaCl and $MgCl_2$ due to the variation of aquifer sediments.

When the above mentioned hydrogeological and chemical analyses are plotted on the diagram of Piper (1944) and the diagram of Sulin's (1948) (Fig. 10), most of the groundwater samples of the different aquifers are attributed to infiltration (meteoric type). However, the chemical composition of the aquifers reflects the influence of the aquifer sediments.

5- Changes of the Groundwater Situation with Time

The above mentioned studies can be used to assess the groundwater changes caused by hydraulic engineering construction over time from 1975 (Hilmy et al., 1978), and from 1986 (Guindy, 1989) with the study in 2006 (Table 5). The main hydrogeological and chemical quality changes can be summarized in the following:

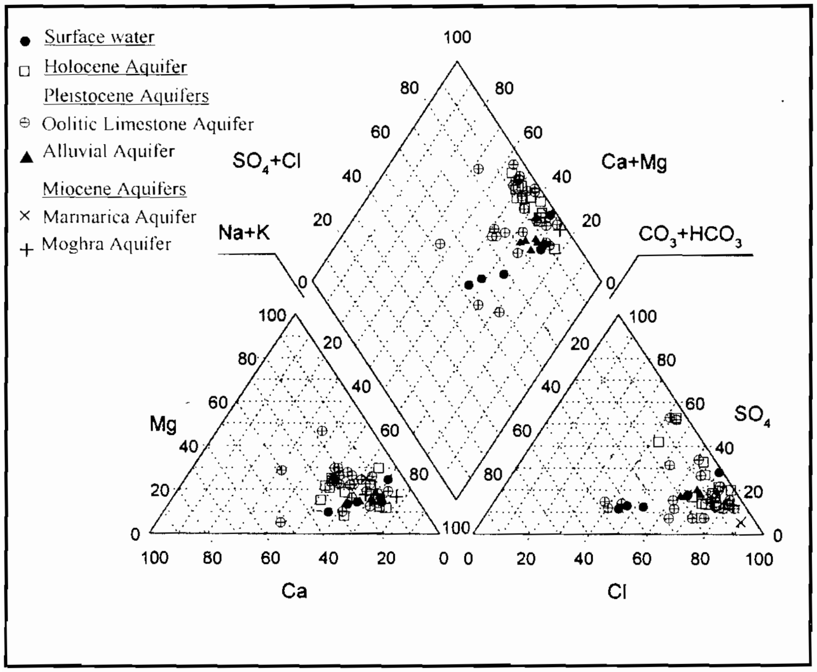

Fig. (10). Genetic classification of water points in El Hammam area.

Table (5). Changes in the chemical quality of groundwater aquifer system between 1975 and 2006.

Aquifer system		In 1975 (Hilmy et al., 1978)	In 1986 (Guindy, 1989)	In 2006 (author)
Holocene	No. of wells	Not recorded	Not recorded	More than 100
	Pizometric head			+48 0 m to −2.4 m
	Salinity (ppm)			about 1240 - about 6110
	Dominant salts			NaCl, $CaSO_4$ and $MgSO_4$
Pleistocene	No. of wells	5	16	More than 80
	Pizometric head	+2 to −2.5 m	+15.0 m to less than 0 m	+17.6 m to −8.6 m
	Salinity (ppm)	6266 – 102272	1425 – 13922	about 690 - about 5090
	Dominant salts	$MgCl_2$, NaCl and $MgCl_2$	NaCl, $MgCl_2$, Mg SO_4 and $Ca(HCO_3)_2$	NaCl, $Ca(HCO_3)_2$ and Mg SO_4
	No. of wells	Not recorded	Not recorded	5
	Pizometric head			+11.8 m to +6.6 m
	Salinity (ppm)			2035 - 3315
	Dominant salts			NaCl, $Ca(HCO_3)_2$ and $MgSO_4$
Miocene	No. of wells	Not recorded	Not recorded	1
	Pizometric head			+24.4
	Salinity (ppm)			5670
	Dominant salts			NaCl and $CaSO_4$
	No. of wells	Not recorded	Not recorded	2
	Pizometric head			+15.5 m to +14.5 m
	Salinity (ppm)			9641 - 30976
	Dominant salts			NaCl and $MgCl_2$

a. The presence of new hydraulic projects, represented mainly by the El Hammam and Baheg Canals, as well as the systems of the irrigation and drainage changed the hydraulic regime and the main sources of groundwater recharge to become mainly from the irrigation canals.
b. The occurrence of new groundwater aquifers in the area with the exception of the Pleistocene oolitic limestone aquifer, which was present before the new projects.
c. The increase in groundwater level over 15 m higher than in 1975 and about 3.0 m higher than in 1986. This rise was accompanied by the presence of new ponds, filling of the gypsum quarries with water, and by water logging in the northern cultivated lands. The increase in drilling of water wells (more than 180) to irrigate the newly reclaimed area or as a supplementary irrigation to decrease the effect of rising water table.
d. On the other hand, the decreasing of the groundwater salinities of the oolitic limestone aquifer from 6266-102272 ppm in 1975 to 690-5090 ppm in 2006, and the changes of the main salts from $MgCl_2$, NaCl and $MgCl_2$ in 1975 to NaCl, Ca(HCO3)2 and MgSO4 are due to the effect of continuous fresh water recharge from the newly constructed canals.

On the other hand, the lessening of the groundwater salinities of the oolitic limestone aquifer from 6266-102272 ppm in 1975 to 690-5090 ppm in 2006, and the changes of the main salts from $MgCl_2$, NaCl and $MgCl_2$ in 1975 to NaCl, Ca(HCO3)2 and MgSO4 are due to the effect of continuous fresh water recharge from the newly constructed canals.

CONCLUSION

With the end of 20^{th} century, the Egyptian Government excavated El Nahda, Baheg and El Hammam to receive surplus drainage water from West Nile Delta to irrigate the new reclaimed areas south of the Mediterranean Sea. The ground elevation of each canal differs from others to irrigate the cultivated lands of different elevations by gravity. The aim of this article is to delineate the hydrogeologic situation based on the new drilling and to assess the impacts of the hydraulic engineering structures on groundwater conditions in the El Hammam area.

Based on the lithological description of continuous cores from 5 drilled wells, the available composite logs of the drilled wells, hydrogeologic cross section, chemical analyses of the selected water points, field observations and measurements as well as literatures, the hydrogeological setting of the study area is discussed as differentiated into aquifers i.e. Holocene, Pleistocene and Miocene aquifers.

The Holocene Aquifer is recorded mostly in the low lying depressions between the oolitic limestone ridges. It is unconfined aquifer, composed mainly of calcareous coarse and medium sand with a variable thickness ranging from 1.0 m to about 8.0 m. The Pleistocene Aquifers are classified into the oolitic limestone and the alluvial aquifers according to the type of aquifer sediments. The oolitic limestone aquifer constitutes the main productive aquifer in the study area. It is an unconfined aquifer.

The oolitic limestone and Holocene aquifers are hydraulically connected with each other through faults and pores. The groundwater flows from +48.0 m in the southern part to –8.6 m in the northern part with the hydraulic gradient toward the Mediterranean Sea. Locally, a flow directly toward Mallahet Maryut has been detected. The salinity increases from 800 ppm close to El Hammam Canal in the southern part to about 6110 ppm in the northern part.

The Alluvial Aquifer is recorded between El Hammam and El Nahda Canal. It is overlain directly by dry creamy massive limestone and underlain by creamy marly limestone, and therefore it is a confined aquifer. It is composed mainly of white coarse to medium sand with some clay lenses. It is hydraulically separated from the other aquifers. The potentiometric surface varies between +11.8 and +6.6 m with the hydraulic gradient northward. The groundwater salinities increase from 2035 ppm in the southern part close to El Hammam Canal to 3315 ppm in the northern part due to the effect of leaching processes.

The Miocene aquifers are recorded in the southern part and divided into Marmarica (M. Miocene) and Moghra (L. Miocene) Aquifers. The potentiometric surface of the Marmarica Aquifer is +21.4 m with groundwater salinity reaching 5670 ppm. The Moghra Aquifer (L. Miocene) is confined aquifer and the potentiometric surface ranges from +15.5 to +14.5 m with a hydraulic gradient northward toward the Mediterranean Sea. The groundwater salinity ranges from 9641 ppm near El Hammam Canal to 30976 ppm northward owing to their marine and fluvio-marine nature .

To demonstrate the impacts of the hydraulic engineering constructions on groundwater situation in the El Hammam area, the hydrogeological and chemical quality changes from 1975 and 1989 until the present (2006) are compared. They showed the following:

a. The occurrence of the Holocene, Pleistocene alluvial, Marmarica and Moghra Aquifers, which were not present earlier.
b. The increase of the water level of the oolitic limestone aquifer over 15 m higher than in 1975 and about 3.0 m higher than in 1986.
c. The changes of the hydraulic regime and the appearance of new ponds.
d. The decrease of groundwater salinities of the oolitic limestone aquifer from 18000 ppm in 1975 to 2890 ppm in 2006 due to the continuous recharge from the newly constructed irrigation canals.

This situation can be replicated in other parts in the country and planners must take into consideration the side effects of the proposed engineering hydraulic structures. The newly created groundwater aquifers can be used in the future as a source of water for reclamation of other areas or as a supplementary irrigation after considering the following criterias:

a. Calculation of the quantities of surface water in the main irrigation canals (El Nasr, El Hammam, Baheg and El Nahda) to the west of Nile Delta.
b. Calculation of the surface water seepage from the rainfall, the main irrigation canals, the irrigation and drainage systems to the groundwater aquifers.
c. Calculation of the groundwater storage of every aquifer.
d. Determination of the quantity of groundwater discharge by pumping from different aquifer.
e. Calculation of the groundwater discharge to the Mediterranean Sea, Mallahet Maryut and the water ponds.
f. Determination of the available quantity of groundwater for abstraction to irrigate the proposed reclaimed area.

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أثر المنشات الهندسية المائية على أوضاع المياه الجوفية في منطقة الحمام، مصر (دراسة حالة)

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المنشات الهندسية المائية المستحدثة في نهاية القرن العشرين لنقل المياه الزائدة من غرب الدلتا إلى الساحل الشمالي الغربي في مصر غيرت الأوضاع الهيدروجيولوجية له. هذا الأثر اتضح بشكل كبير في منطقة الحمام نظرا لظروفها التركيبية ممثلا في الظواهر الآتية:

١- تواجد خزانات جوفية جديدة هي خزان الهالوسين، خزان الرواسب الفيضية البليستوسينى، وخزانات الميوسين.
٢- ازدياد منسوب المياه الجوفية بما يزيد عن ١٥ متر مقارنة بعام ١٩٧٥ و ٣ متر مقارنة بعام ١٩٨٦.
٣- تغير في النظام الهيدروليكي للمنطقة وتكون برك مياه حديثة.
٤- انخفاض في ملوحة مياه خزان الحجر الجير البطروخى من ١٨٠٠٠ جزء في المليون عام ١٩٧٥ إلى ٢٨٩٠ جزء في المليون عام ٢٠٠٦ نتيجة التغذية المستمرة من مياه الترع الجديدة.

هذه الظروف يمكن تكرار تواجدها في العديد من مناطق العالم، لذا يجب على المخطط أن يأخذ في اعتباره الآثار الجانبية للمنشات الهندسية المائية المقترحة. كذلك من الممكن استخدام مياه الخزانات الجوفية الجديدة في المستقبل كمصدر مائي لاستصلاح أراضى أخرى أو كرى تكميلي بعد تقييم الأوضاع الهيدرولوجية في هذه المناطق.