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Assessment of Surface Water -Groundwater Relationship in the Area Between Borg El Arab and West El Hammam, North West Coastal Zone, Egypt

تقييم العلاقة بين المياه السطحية و المياه الجوفية فى المنطقة بين برج العرب و غرب الحمام–الساحل الشمالى الغربي مصر

Nahla A. Morad and Abdel Latif R.M.

KEYWORDS:
El Hammam Canal, groundwater, Northwest coast, Egypt, water logging and water seepage

***الملخص العربي*:- يتناول هذا البحث العلاقة بين المياه السطحية و المياه الجوفية فى المنطقة بين برج العرب و غرب الحمام – الساحل الشمالى الغربى – مصر و قد خلصت الدراسة إلى ان الخزان الجوفى الرئيسى فى المنطقة هو خزان البليو بليوسين (الرالات) و المصدر الرئيسى للتغذية لهذا الخزان هو التسرب من ترعة الحمام و ترعة بهيج و الفائض من مياه الرى و تقدر كمية التغذية السنوية للخزان الجوفى بحوالى ١١,٧٠٥ x 106 م٣ /سنة و قد أدى تراكم هذه الكمية طوال الثلاثين عاما الماضية إلى أرتفاع منسوب الماء الجوفى بواقع نصف متر فى السنة مما تسبب فى حدوث غدق مائى فى بعض المناطق .**

***Abstract*— The study area, between Borg El Arab and El Hammam, is recently subjected to intensive land reclamation projects aiming to cultivate about 57000 feddans. It is supplied by two main sources of irrigation, i.e. the surface water as a main source (Bahig canal and El Hammam canal), and the groundwater from more than 600 shallow wells tapping the Ralat aquifer (calcareous sandstone) of Plio-Pleistocene age as a supplement source.**

During the last three decades (1985 – 2014), conjunctive use of surface water together with groundwater has resulted in serious hydrologic problems e.g. water losses, canal seepage and water logging, where the depth to water level has risen up from about 20 m (1985) to less than 5.0 m (2014). Meanwhile, the groundwater salinity decreased during this period from more than 5000 ppm to less than 2000 ppm, indicating a dilution effect by seeped water.

The water seepage from the dissecting canals is estimated in the present work by 65.18 x 106 m3/year replenishing the groundwater system in the down gradient areas. Might as well, the irrigation return flow through permeable soil in the study area is estimated by 4.125 x 106 m3/year due to the applied flood irrigation technique. In other words, 95% of the total groundwater replenishment is from the canal seepage, while only 5% from direct percolation.

The investigation of wells tapping the Ralat aquifer in the study area has indicated that water levels are ranging from 21.0 m to 1.0 m above mean sea level. More than 57.6 x 106 m3/year (average 84% of the natural groundwater discharge) are pumping from such wells to get water of about 2000 ppm salinity, indicating a significant hydraulic connection between the surface water canals and the underlying aquifer. The calculated water balance of the Ralat aquifer has resulted in an amount of annual surplus water of the order of 11.705 x 106 m3/year as groundwater storage.

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I. INTRODUCTION

THE present work was carried out in the frame of a research program titled "Study of the main constraints of the agriculture development in the area along El Hammam canal and its extension" Funded by the Desert Research Center from 2011 to 2015. The authors carried out all the field, lab. and office works in this research including: data wells collection from 2011 to 2014, infiltration tests, pumping tests and Piezometers drilling (*Internal Report, 2015 in Arabic*).

The study area (250 km2) is extended from east Borg El Arab town to west El Rowissat town and from Mallahet Maryut in the north to El Hammam canal (Abu Mina basin) at south (fig.1). Mallahat Maryut at north (Coastal plain) acts as a great discharge area, while El Hammam canal at south (Deltaic plain) acts as a main source of irrigation in the area.

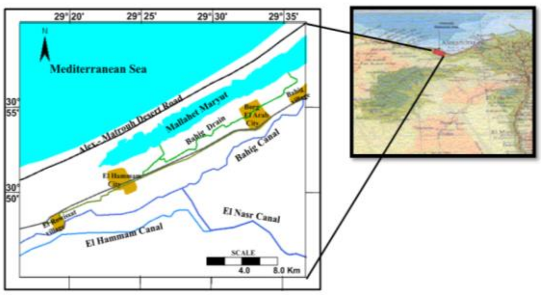


Fig. (1) Location Map of the study area

The study area suffers from many hydrologic problems due to the excessive use of both surface water and groundwater for irrigation. The well spacing (less than 100 m) and the pumping rate and duration from each well is continued (average 700 m3/day/well), have resulted in surplus water in the reclaimed area exceeding the drainage capacity of Bahig drain. The mismanagement of water resources in the area is well represented by water shortage in Bahig canal (the irrigation rotation is only five days every (45 days) and the illegal withdrawal of El Hammam canal water, where hundreds of pumps are installed along the canal, which affects greatly the water distribution and hence the crop requirements of water.

The general objective of this study is to evaluate such hydrologic problems and to assess the relationship between the surface water and groundwater to assist for resources management plans. A detailed hydrologic survey of drilled wells (40 wells) as well as the irrigation and drainage canals was done for the basic data collection and assessment. The water quality of the different water bodies was also determined.

The possible importance of winter precipitation as well as the irrigation return flow, with respect to infiltration and groundwater recharge has been verified in the present work by considering the results of seven infiltration tests distributed in the coastal and piedmont plain. The results show that soil permeability ranges between 2.2 m/day (moderately rapid) in the coastal plain at north and 5.4 m/day (rapid) in the deltaic plain at south. The transmissivity of the aquifer has been calculated from a selected number of pumping and recovery tests carried out in the study area. The results indicate that the aquifer attains relatively high values of transmissivity ranging between 1107 m2/day and 2048 m2/day i.e. high potential aquifer. Seven piezometers were constructed in the study area having 30 – 50 m depth, in order to assess the hydraulic gradient between El Hammam canal at south and Bahig drain at north (4.5 km distance), where the gradient is of the order of 2.5 m/km.

Climatologically, the study area is characterized by long rainless summer and short rainy winter (140 mm/year). The relative humidity ranges from 60% to 70% while the evaporation value ranging between 2.7 mm/day and 5.9 mm/day. The maximum temperature (30.6 ºC) is recorded in (August), while the minimum (8.4 °C) is recorded in January. Surface wind velocity varies from (5.3 to 11.9 km/h). The lowest and highest wind velocities are recorded in October and March, respectively (*Sayed, 2013*).

II. PHYSIOGRAPHIC AND GEOLOGY

Based on the Geological Map of Egypt (Alexandria Map) (CONCO,1987) the surface deposits in the study area belong essentially to the Tertiary Quaternary age. On regional scale, the main physiographic units in the study area are from north to south as follows (fig. 2):-

A. The Coastal Plain

This plain comprises three elongated calcareous ridges and two depressions in between, running parallel to the shoreline and extends for more than 9.0 km from the Mediterranean shoreline to the south. The study area partially occupies the southern boundary of the coastal plain at north and the piedmont plain at south, and extends partially to the Deltaic plain (Abu Mina basin).

B The Piedmont Plain

This plain occupies the area between the coastal plain at north and the Maryut tableland at south through Abu Mina basin. Bahig canal (30 km) is dissecting the northern portion of this plain from east to west. Between Bahig and El Hammam canals, the Piedmont plain is covered with calcareous soil accumulation overlying an evaporite series of alternating thin gypsum and clays.

C. The Deltaic Plain (Abu Mina Basin)

This basin covers an area of about 500 km2; it traverses the Maryut tableland to the northeast. The surface of Abu Mina basin is partially dissected by El Hammam and El Nasr canals. The ground elevation of this basin ranges between +100 m and +20 m (above mean sea level). The sequence of deposits from surface downwards is as follows:

- 0 -5 m loamy deposits (soil cover)
- 5-15 m lagoonal deposits consisting of sand and sandy clay rich in salts
- 15-40 m deltaic deposits consisting of gravelly sand (water bearing)
- 40- 300 m clay

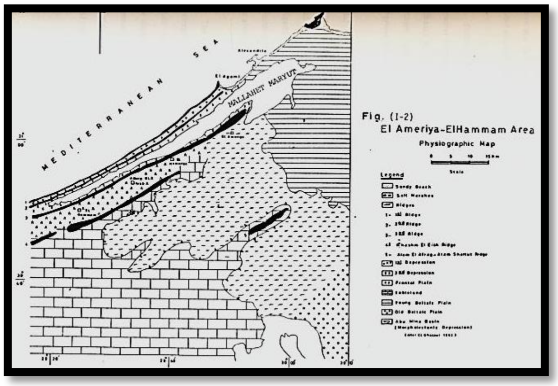


Fig. (2) Physiographic Map of the study area (Guindy, 1989)

From the Digital Elevation Model (DEM) of the study area (fig. 3), the study area has a gentle slope (0.15 m/km), where the altitude of the study area ranges between Zero (Mallahet Maryut) at north to about 100 m above mean sea level at south (Tableland).

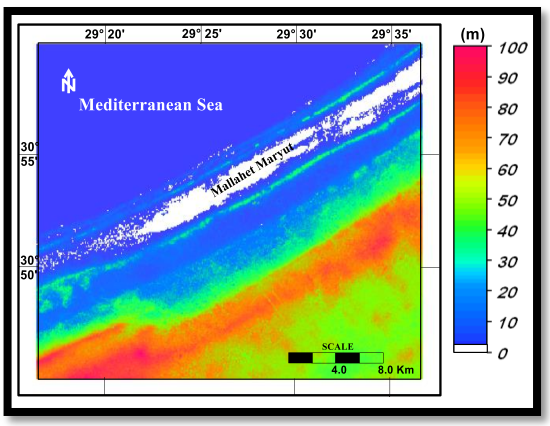


Fig. (3) Digital Elevation Model (DEM) of the study area

III. SURFACE WATER HYDROLOGY

A. Irrigation and Drainage Systems

The main irrigation canals in this area are El Hammam canal (constructed at 1995) and Bahig canal (constructed at 1979) and the main drain is Bahig drain (fig. 4). All the data concerning the irrigation canals and drains were collected during the field trips (2011 – 2014) from the local authorities of the Ministry of Irrigation and Water Resources in El Hammam and Alexandria cities.

1) El Hammam Canal

El Hammam canal is located in Abu Mina Basin at south of the area of study and is branched from El Nasr canal. It has a length of 50 km (first stage). The area served by this canal is 45000 Feddans, with a discharge of 28.75 m3/sec at the intake of the canal. The bed width ranges between 7.50 m to 6.50 m. The water level in El Hammam canal ranges from +50.44 m to +27.20 m. The ground elevation in the south is of the order of 70 m, while in the north it does not exceed 50 m above mean sea level. The salinity of water in this canal is about 700 ppm.

2) Bahig Canal

Bahig canal (30 km length) is branched from Maryut canal, at the northern boundary of the piedmont plain, to irrigate about 12000 feddans in the study area. The bed width of this canal is about 5.00 m. The salinity of water in the canal is about 600 ppm. The rotation of irrigation water in this canal is only 5 days every 45 days, indicating a serious water shortage in the canal most of the days. Due to the shortage of irrigation water at the end of Bahig canal, another intake was recently constructed from El Hammam canal to face such shortage at the sector west of El Rowissat town. This intake leads to a change in the direction of water flow in Bahig canal in this particular sector; i.e. from west to east instead of the designed water direction from east to west.

3) Bahig Drain

The main drain in the study area is Bahig drain, extending in an east-west direction (28 km length), to collect the drained water from the irrigated land to be drained in Mallaht Maryut at north. The salinity of the drained water ranges between 2500 ppm and 4000 ppm. From the investigation of Bahig drain along its trajectory from El Rowissat in the west to Borg El Arab in the east, the following can be noticed:-

a) In the sector between El Rowissat and El Hamman (10 km length), the floor depth of the drain (4.0 m from the ground surface) is lower than that of the groundwater level in this area (average 3.0 m from the ground surface). This can explain why the drain in this sector is full of water all the time.

b) The sector between El Hammam and Borg El Arab (18 km length), the bottom of the drain is actually higher than the depth to ground water (5.0 m - 7.0 m). This explains why the drain is almost dry in this particular section all the time.

▪ From the above, one can conclude that Bahig drain acts as a collector for the groundwater (Base flow) west of El Hammam town, rather than an agriculture drain. This concept is emphasized by the similarity of the groundwater salinity (average 3000 ppm) and that of the drain water salinity in this sector (3500 ppm). In other words, Bahig drain in its old design, is actually doesn't act as an agriculture drain. A new drain (2005) has been constructed east of El Hammam town between El Hammam and Mallahet Maryut, i.e. perpendicular to the topographic contour lines, in order to overcome the drainage problems in the irrigated lands. Such new construction acts as a good agricultural water collector having salinity of 3500 ppm, where it is used successfully by the farmers to irrigate the surrounding new agriculture lands.

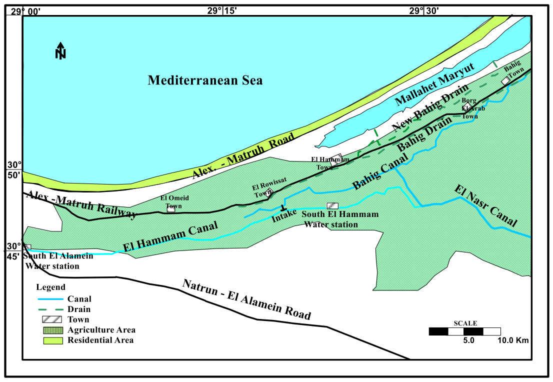


Fig.(4) Irrigation and Drainage systems in the study area

- Noteworthy, there is a waste of groundwater through Bahig drain due to the intersection of the drain floor with the groundwater table in some parts of this area, particularly between El Rowissat and El Hammam towns. In fact, the amount of wastewater should be actually added to the groundwater discharge from the Ralat aquifer. Worth mentioning, the added surface water to Bahig canal from El Rowisat intake has probably lead to serious water logging phenomenon in this area.

B Soil Permeability

Seven infiltration tests were conducted in the study area by the authors during field trips within the research program, four tests in the piedmont plain and three tests in the coastal plain (Fig.5). The data of infiltration tests are processed based on Philip formula (1957):-

$$i = 0.5St - 0.5 + A \quad (1)$$

Where: -

I is the infiltration rate (m/day)

S is the sorpitivity (Rate of penetration of the wetting front)

t is time after start of infiltration;

A is a steady state infiltration rate

The results (table 1) indicate that the soil permeability in the Coastal Plain (average 2.5 m/day) is much lower than that of the Piedmont Plain (average 5.0 m/day). This may refer to the dominance of clay loam and gravelly silt soil types respectively ((Johnson, 1963). The depth to water varies from 3.0 m to 5.5 m in the coastal plain (loam soil) and from 12.0 to 14.0 m in the piedmont plain (gravelly silt), which indicates that the depth to water is strongly related to the soil type.

According to Kohnke classification (Khonke, 1980), the investigated soils vary from rapid (3.0 -6.0 m/day) in the area between El Hammam canal and Bahig canal (in the piedmont plain) to moderately rapid soil (1.5 – 3.0 m/day) in the Coastal plain. This may indicate that the irrigation return flow between Bahig and El Hammam canals is considered high, while to the north it is limited. In other words, the soil permeability increases southwards, where illegal irrigation practices by farmers take place using El Hammam canal water.

TABLE

(1) RESULTS OF INFILTRATION TESTS IN THE STUDY AREA

Test No.	Location	Long.	Lat.	Soil infiltration Rate (m/day)	(Kohnke classification)	Soil Type	Depth to water (m)
1	piedmont Plain	29.35	30.81	4.795	Rapid	Gravelly Silt	14.00
2		29.06	30.75	3.659	Rapid	Gravelly	-
3		29.34	30.81	4.079	Rapid	Gravelly	12.00
4		29.48	30.85	5.418	Rapid	Gravelly	12.00
5	Coastal Plain	29.29	30.79	2.235	Moderately rapid	Clay	-
6		29.44	30.85	2.442	Moderately rapid	Clay Loam	5.5
7		29.41	30.84	2.961	Moderately rapid	Clay Loam	3.0

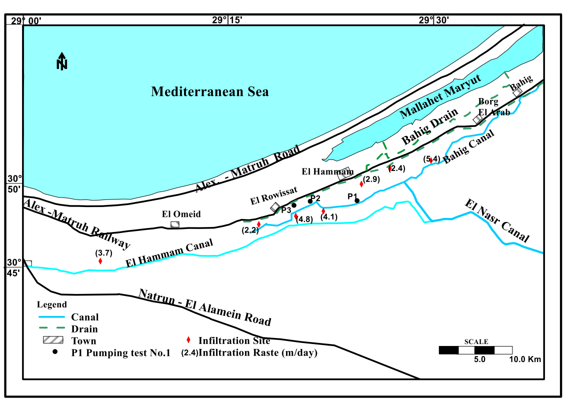


Fig (5) Location Map of Infiltration & Pumping Tests (present work)

IV. GROUNDWATER HYDROLOGY

A Aquifer System

Three aquifers are recognized in the area of study as follows, from south to north:-

- The Deltaic aquifer (Pleistocene):-

This aquifer covers the southern region of the study area. It is widely extended occupying an area of about 500 km2. It is represented in both Abu Mina basin and the Modern Deltaic Plain. It belongs to the Pleistocene age. In the Piedmont Plain, this unit is occasionally overlain by the Oolitic limestone unit (Guindy, 1989).

- The Ralat aquifer (Plio–Pleistocene):-

This aquifer covers the majority of the study area. It represents the main aquifer in the study area. It belongs to the Plio-Pleistocene age. This aquifer is a multi-layered aquifer consisting of an alternation of consolidated calcareous sand and clay. The source of groundwater in this aquifer is mainly from the seepage of irrigation canals and return flow from surface irrigation. The groundwater in this aquifer is under piezometric head (confined aquifer). The main characteristics of this aquifer are studied in details from the pumping tests, well logs and drilled piezometers carried out in the study area during the present work.

- The Oolitic limestone aquifer (Pleistocene):-

In the coastal plain, the Oolitic limestone is extended widely covering a wide area. It is tapped by hundreds of hand- dug wells, with drilled depths up to 30 m. It is of limited potentials. The saturated thickness of the aquifer ranges between 19 m and 30 m. The Oolitic limestone aquifer is directly recharged from rainfall. Groundwater within this aquifer exists under free conditions, and the general gradient is towards Mallahat Maryut and the Mediterranean Sea. Groundwater salinity varies from 1500 ppm to 3000 ppm. The total groundwater extraction reaches about 1.5x106 m3/year (CEDARE, 2009).

B Aquifer Test Analysis

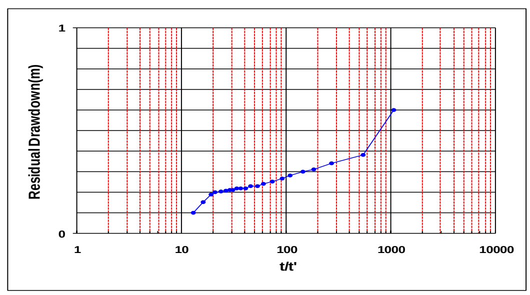
Three drilled wells tapping the Ralat aquifer were selected (Fig.5), to calculate the transmissivity of the aquifer, which is defined as the ability of the aquifer to transmit water, by applying Jacob method (Jacob, 1947). The following are noticed from the pumping tests data:-

- All the tests were done where Bahig canal is dry since the irrigation rotation in this canal is every 45 days.
- The discharge of the wells ranges between 40 – 70 m3/hr (average 55 m3/hr).
- The pumping from the well was carried out for about three hours at a constant rate.
- The drawdown of water level ranges between 0.5 m and 1.5 m.
- The recovery of water was only in five minutes after stop pumping.
- No change in quality of water was noticed during the pumping test.

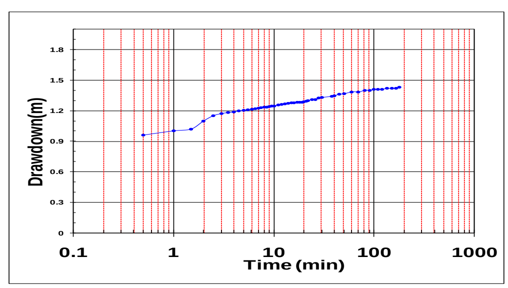
The analyses of these tests are shown in Fig. (6). The calculated transmissivity values (Table 2) show that the aquifer attains high values of transmissivity ranging between 1107 m2/day and 2048 m2/day. According to Krasny classification (Krasny, 1993), the groundwater supply potential is classified as "Withdrawal of great regional potential" and the aquifer is designated as very high potential where the transmissivity value is more than 1000 m2/day on average. However, the plotted curve of both pumping and recovery tests indicate that a source of recharge (recharge boundary) is lying very close to the well field, where an equilibrium state due to pumping has been reached after only 30 minutes from starting point and five minutes after stop pumping (recovery).

TABLE (2)
RESULTS OF PUMPING TESTS

Test No.	Long.	Lat.	Transmissivity (m^2/day)		
			Pumping	Recovery	Mean value
1	29.41	30.82	1636	2461	2048.5
2	29.35	30.81	1830	1160	1495
3	29.33	30.80	1515	700	1107.5
Average			1660	1440	1550



Q = 70 m3/hr - Δs = 0.19 m -T = 1636 m2/day
(Pumping Test)



Q = 70 m3/hr - Δs' = 0.125 m - T = 2641 m2/day
(Recovery Test)
Fig. (6): Analysis of pumping and recovery of test No.1

C Groundwater Flow and Fluctuation

In order to assess the hydraulic gradient as well as the groundwater flow in this area, seven piezometers were constructed, by the authors during the field trips within the research program, from El Hammam canal at south through Bahig canal to Bahig drain at north (Fig.7). The basic hydrological data for these piezometers are shown in table (3).

TABLE (3)
BASIC DATA OF THE DRILLED PIEZOMETERS (PRESENT WORK)

Piezometer No.	Location		Total Depth (m)	Elevation	1st Reading (5/2014)				2nd Reading (9/2014)				3rd Reading (3/2015)			
	Lat.	Long.			Depth to water (m)	Water Level	TDS (ppm)	pH	Depth to water (m)	Water Level	TDS (ppm)	pH	Depth to water (m)	Water Level	TDS (ppm)	pH
P1	30° 49' 17"	29° 22' 12"	30	7	1.90	5.10	719	7.3	1.60	5.40	3110	7.6	1.94	5.06	3610	7.3
P2	30° 49' 07"	29° 22' 16"	30	18	6.50	11.50	804	7.2	6.25	11.75	-		6.50	11.50	3610	7.2
P3	30° 49' 10"	29° 23' 03"	30	18	7.00	11.00	1280	7.2	7.40	10.60	1920	7.64	7.00	11.00	3968	7.2
P4	30° 48' 06"	29° 23' 07"	30	29	9.00	20.00	1256	7.1	9.00	20.00	5050	7.84	9.00	20.00	4928	7.1
P5	30° 49' 10"	29° 21' 13"	30	7	2.20	4.80	1410	7.3	2.84	4.16	2790	7.6	2.20	4.80	2790	7.3
P6	30° 47' 46"	29° 22' 25"	50	42									26.00	16.00	2560	8.6
P7	30° 48' 18"	29° 22' 57"	50	31									19.00	12.00	2662	8.6

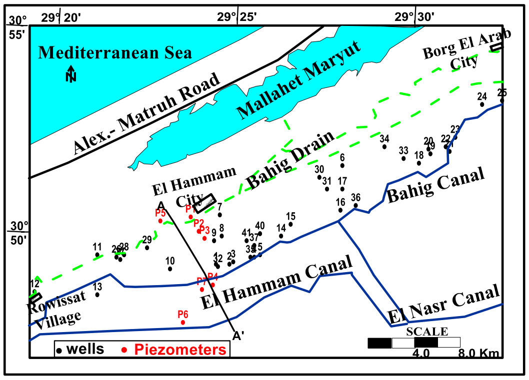


Fig. (7) Location of wells and drilled piezometers in the area of study

A cross section (A – A') was plotted, along the flow direction (SW- NE direction), from El Hammam canal to Bahig drain, to show the successive layers in the study area (Fig. 8).

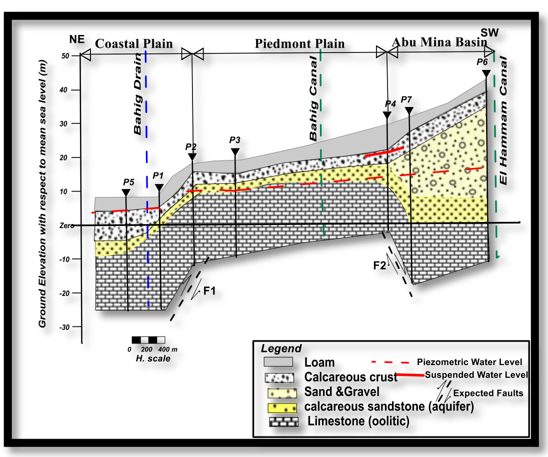


Fig. (8) Hydrogeological Section (A- A') (present work)

From this cross section, some important features can be concluded as follows :-

1) Three different hydrologic conditions indicating different hydrologic environments are distinguish in this area:-

- The coastal plain (shallow marine environment) in the area between P5 and P2 (around Bahig Drain), where the main aquifer is the Oolitic limestone and the main source of recharge is the direct rainfall.
- The piedmont plain (Transitional environment) between P2 and P4 (around Bahig canal), where the main aquifer is the Ralat calcareous sandstone. The source of recharge is from the canals seepage and irrigation return flow and the recharge by direct rainfall is quite limited.
- Abu Mina Basin (Deltaic environment) to the south of P4 (from P4 to P6) (around El Hammam canal), where El Hammam canal is the main source of recharge.

2) The thickness of the Ralat aquifer varies from south (P6), where its thickness is 13.0 m to north (P5) with thickness 5.0 m, where it decreases gradually from P4 and northward. This aquifer is considered a confined aquifer, where it is overlain by a hard calcareous crust, with different thicknesses.

3) Two expected normal faults (F1 & F2), are separating the Piedmont Plain from Abu Mina Basin at south and the coastal plain at north influencing the water flow from south to north.

4) The groundwater salinity of the drilled piezometers differs from south to north according to the hydrologic environment. In Abu Mina Basin (Delatic environment), the ground water salinity is about 2600 ppm, while it increases in P4 (at the northern boundary of Abu Mina Basin) to 4900 ppm. In the north, the groundwater salinity ranges from 2790 ppm to 3960 ppm.

The data collected during the field trips (2011 – 2014), by the authors during the field trips within the research program, from the production drilled wells (40 wells) are shown in table (4) and figure (7). These data include the well basic data, the hydraulic measurements and the water quality properties. In the study area, the Plio-Pleistocene aquifer made of calcareous sandstone (El Ralat aquifer) is considered the main aquifer. The drilled wells are concentrated in the area between Bahig canal and Bahig drain. The total cultivated area is 12000 Feddans. Each well irrigates about 20.0 Feddans, which means that the number of wells is about 600 wells. These wells are working for about 8 hours /day, with discharge varies from 40.0 to 70.0 m3/hr. These wells are classified according to its location (table 4) (14 wells are drilled in the Coastal plain and 25 wells in the piedmont plain). From this table, the following can be noticed: -

1) The drilled depth ranges between 10 m to 22 m in the coastal plain and from 12 m to 45 m in the piedmont plain. In general, the wells in the coastal plain are shallower than that of the piedmont plain.
2) The depth to water varies from 3.0 m to 9.0 m in the coastal plain, while it reaches 25 m in the piedmont plain. The depth to water contour map (fig. 9) shows that the depth to water, in general, increases in the south direction towards Bahig drain.
3) Three water logged areas are noticed in the area of study, each have area of about 1.0 km2. The first one is located close to Bahig canal, and it is due to the inefficient drainage systems in this area, where the drainage water is accumulated over the impervious layer (calcareous crust). Another water logged area is located around Bahig drain, and it is due to the razing of land in this area and consequently lowering the ground elevation. The third one is located at El Rowissat village, where the depth to water is less than 1.0 m.

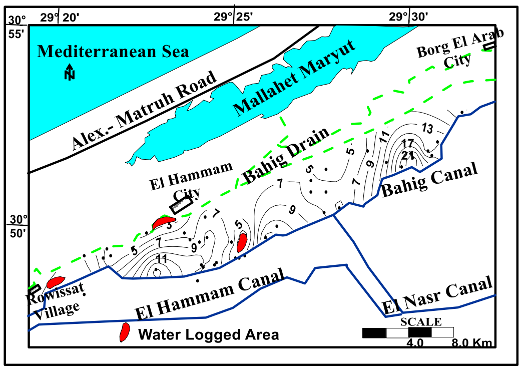


Fig.(9) Depth to water contour map (2014) (Present work)

4) In order to get the change in depth to water during the last 30 years, a depth to water map is plotted for the year 1985 (Guindy, 1989) (fig.10). The resultant map (fig. 11), which is the difference in depth to water between 1985 and 2014, shows that the depth to water in general decrease from 5 m to 15 m in average during this period. This is due to the canal water seepage and irrigation return flow in these new reclaimed lands.

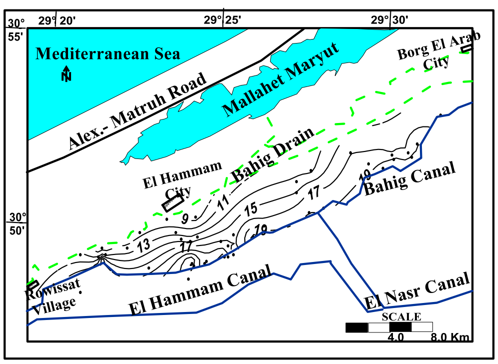


Fig. (10) Depth to water contour map in 1985 (Guindy,1989)

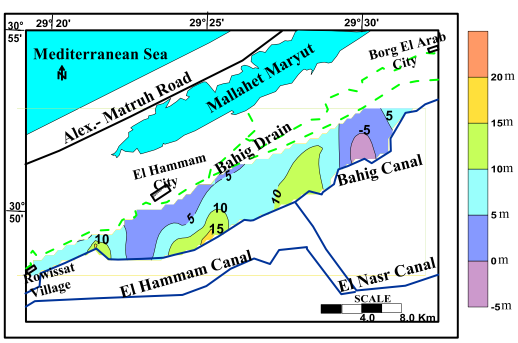


Fig. (11) Resultant Map showing the difference in Depth to water between 1985 and 2014

5) The water level ranges from +1.0 m to +21.0 m above mean sea level. The groundwater flows from south to north, i.e. from Bahig canal to Bahig drain and then to Mallahat Maryut (fig. 12).

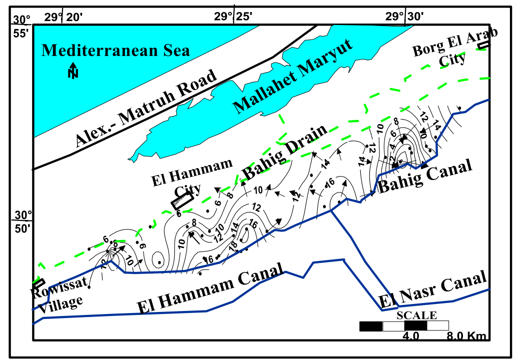


Fig. (12) Water Level Map in the area of study (Present work)

6) In the east of the study area, around Bahig canal, a mound (closed contour) is noticed in the water level map; i.e. the groundwater level decreases in the south direction toward Bahig canal from +14 m to +1m above mean below sea level. This is due to the over pumping in this area. It is also noticed that this area have high salinity (up to 5000 ppm).

TABLE (4) BASIC DATA OF THE INVESTIGATED WELLS TAPPING EL RALAT AQUIFER IN THE STUDY AREA

Well No.	Environment	Total Depth (m)	Depth to water (m)	EC (µmhos)	TDS (ppm)	pH	Ground Elevation (m)	Water Level (a.m.s.l.)*
1	Piedmont Plain	25	14	2880	1840	7.4	29	15
2		25	8	2500	1600		24	16
3		25	7.8	2550	1630	7.5	24	16.2
4		25	6	3000	1920		24	18
5		25	6	3500	2240		21	15
8		18	10	2750	1760	7.4	18	8
9		14	7	4120	2637	7.22	18	11
10		30	18	1320	845	8.96	20	2
13		30	12	3000	1920		22	10
14		19	14	2870	1837	8.02	28	14
15		15	12	2900	1856	8	22	10
16		13	7	1180	800	8	24	17
17		13	7	2000	1280		23	16
18		45	22	6000	3500		25	3
19		30	25	7370	4720		26	1
20		30	22	7400	4736	7.65	23	1
21		25	17	5500	3520	8	26	9
22		22	13	6200	3968	7.45	24	11
23		25	15	6500	4160		27	12
31		15	5.5	2550	1200		20	14.5
32		15	7	2700	1750		23	16
33		20	14	5500	3520		22	8
37		21	1.5	4070	2600	7.45	22	20.5
40		21	1.5	3700	2368	7.78	22	20.5
41		12	7	2100	1344	7.9	21	14
6	Coastal Plain	22	3	3000	1920	7.6	17	14
7		12	8	4000	2560	8.3	12	4
11		15	9	5400	3520	7.6	15	6
12		15	7	2200	1408	7.88	14	7
24		11	7	7000	4480		25	18
25		20	7	7000	4480		24	17
26		12	6	2570	1645	7.53	14	8
27		12	3	2180	1395		22	19
28		10	4	1350	864	7.9	14	10
29		10	4	1500	960		13	7
30		15	7	2700	1728	7.8	18	11
34		20	7	4900	3136	7.9	21	14
35		11	3	1300	832	8.17	24	21
36		10	4.24	1200	768	8.48	24	19.76

7) The Iso salinity map (fig. 13) shows that the salinity of groundwater varies from 800 ppm (wells no. 10 &16) to 5000 ppm (wells no. 24 &25) (from fresh to brackish water). The low salinity is noticed along Bahig canal and

increase towards the drain. This means that Bahig canal plays an important role in the salinity dilution of the groundwater, i.e. the recharge of the groundwater is affected directly by the seepage from the surface water system, where the salinity of surface water ranges between 600 and 700 ppm.

8) The frequency distribution of the salinity (fig. 14) shows that 44% of the samples lie in the category between 1000 – 2000 ppm. According to (Guindy, 1989), the salinity of the groundwater was more than 5000 ppm in 1985 for all wells in this area. This means that the salinity decreased from 5000 ppm to less than 2000 ppm from 1985 to 2014. Moreover, the average salinity of the groundwater in this particular area was about 10000 ppm in 1975 (DRC, internal report, 1975).

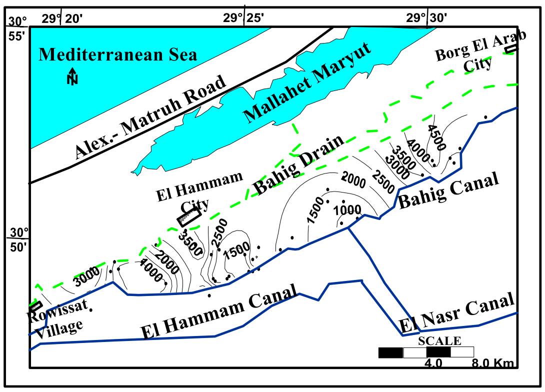


Fig.(13) Iso- Salinity map in the area of study (Present work)

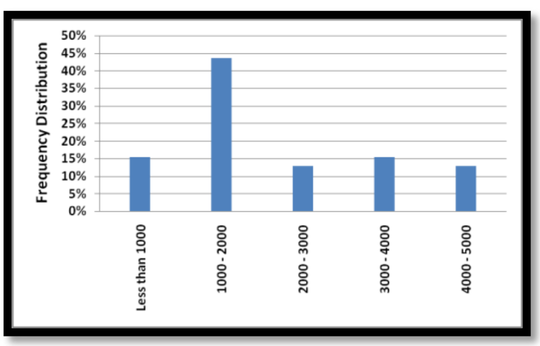


Fig. (14) Frequency Distribution of salinity (ppm) in the study area

D Surface Water - Groundwater Relationship

In order to get the relation between the surface water and the groundwater in the study area, a graph is plotted for the water level of surface and groundwater (Fig 15). From this figure, the following can be concluded :-

- The direct connection between the surface water and groundwater is quite obvious at two points of intersection: at a distance equal 1.0 km north of Bahig canal and at Bahig drain. However, both water bodies (surface and groundwater) are merged together at Mallahat Maryut, which acts as a major discharge area.
- The calculation of the gradient of groundwater from P6 at the extreme south and P5 at the extreme north of this section is 2.5 m/km for a distance of 4.5 km.
- The groundwater level is passing below Bahig canal, while it is crossing Bahig drain. In other words, this means that Bahig canal doesn't receive groundwater seepage from El Hammam canal, while Bahig drain is directly connected with groundwater.
- P4 location represents a suspended water level, probably recharged from direct rainfall, where it lies at the margin between the Deltaic aquifer at south and El Ralat aquifers at north.
- The salinity of groundwater changes from 2560 ppm at P6 to 3610 ppm at P5. In Abu Mina Basin, the average salinity is about 2500 ppm, indicating that the seepage from El Hammam canal (700 ppm) is influencing the groundwater body causing a serious dilution of the water salinity.
- Down gradient from P7 (excpet P4), the groundwater salinity is about 3500 ppm in average, which means that dissolution takes place through the flow path from south to north (4.5 km distance). The salinity at P4 shows different behavior, where it reaches 5000 ppm, indicating that there is no significant recharge from El Hammam canal at this location where the expected fault F2 exists.
- The salinity of ground water at P1 (3610 ppm) is almost similar to that of the Bahig drain (3500 ppm), which indicates obviously that Bahig drain intersects the groundwater flow line. This may explain that Bahig drain is filled of water all the time in its part between El Hammam and El Rowissat towns, while, it is almost dry to the east. A new drainage system was constructed, running perpendicular to the old drains towards Mallahet Maryut as a main discharge area at north.

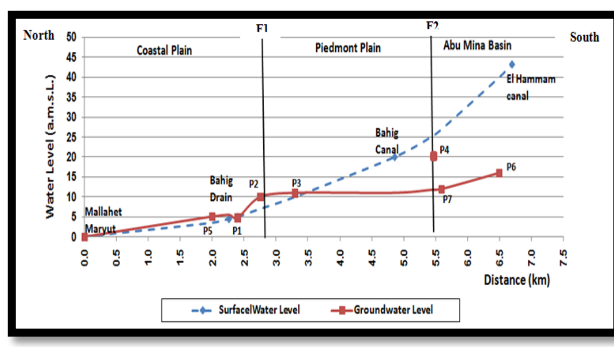


Fig. (15) Water Levels for both surface and groundwater crossing the area from south to north

V. THE RALAT AQUIFER RECHARGE - DISCHARGE RELATIONSHIP

As mentioned before, the main aquifer in the study area is the Ralat aquifer, where hundreds of wells are drilled. So, one of the main important targets in this study is to calculate the recharge-discharge relationship of this particular aquifer, keeping in mind that the main source of recharge is coming from the southern surface water system and the Deltaic aquifer in Abu Mina basin through the canal seepage and irrigation return flow. The possibility of recharge through direct rainfall is quite insignificant since the aquifer is confined where it is capped with hard crust.

A. Canal Seepage

Losses from canals are defined, even when the canal is lined. Providing perfect lining can prevent seepage loss from canals but cracks in lining develop due to several reasons and performance of canal lining deteriorates with time. The seepage rate is a function of not only the lining material, but also the permeability of the native soils. The seepage loss from canals is governed by hydraulic conductivity of the subsoil, canal geometry, and potential difference between the canal and the aquifer underneath. A well-maintained canal with 99% perfect lining reduces seepage of about only 30-40% (Wachyan et.al., 1987). One of the common empirical formula used is Mortiz formula quoted by U.S. Bureau of Reclamation (USBR, 1967). This formula is :-

$$S = 0.2C\sqrt{\frac{Q}{V}} \quad (2)$$

Where: -

S = Seepage loss in ft3/sec/ mile length of canal
Q = Discharge of canal (ft3/sec)
V = Mean velocity of the flow (ft/sec)
C = constant. Its value is 0.33 in case of concrete lining.

Table (5) shows the calculated seepage from El Hammam and Bahig canals, according to the field measurements, using Mortiz formula. The seepage from El Hammam canal along its path is equal to 1.861 m3/sec, which means 58.68 x 106 m3/year. For Bahig canal, as mentioned before, the rotation of irrigation water in this canal is 5 days every 45 days, so it is estimated that the irrigation water in Bahig canal is available for only 8 days every 45 days (3 days more until the canal is empty) i.e. 73 days in the year. The seepage from Bahig canal is equal to 6.50 x 106 m3/year. The total seepage from both canals is equal to 65.18 x 106 m3/year.

B. Irrigation Return Flow

Irrigation return flow is defined as the part of irrigated water that is neither consumed by the crops nor evaporated and then drains to the water table. The estimation of the return flow after irrigation essentially depends on the percentage of the irrigation efficiency in the cropped areas. The irrigation efficiency is about 50% for crops irrigated using surface irrigation method (FAO, 1980).

According to the field investigation, the area between El Hammam canal and Bahig canal is irrigated using more than 50 pumps along the path of the canal (50 km). The discharge of every pump is about 50 m3/hr and works for about 10 hours/day. The total discharge from the canal every day is estimated by 25000 m3/day, i.e. 7.5 x 106 m3/year. The irrigation efficiency is about 50% for crops irrigated using surface irrigation method, keeping in mind that the area between El Hammam and Bahig canals is characterized by rapid infiltration rate (average 4.5 m/day)

The return flow from irrigation =
7.5 x 106 x 50% = 4125000 m3/year
= 4.125 x 106 m3/year
The estimated annual recharge to El Ralat aquifer is :-
65.18 x 106 +4.125 x 106 =
69.305 x 106 m3/year

This means that the Ralat aquifer receives about 69.305 x 106 m3/year from both the canal seepage and the irrigation return flow. These are the main sources of recharge for this aquifer. As mentioned before, the direct rainfall can't represent one of the significant sources of recharge, since the aquifer is confined aquifer.

TABLE (5) CANAL SEEPAGE CALCULATED DATA

Canal	Segment Interval (From km to km)	Segment Length (Km)	Canal Discharge m^3/sec	Water Velocity m/sec	Seepage m^3/ sec / km	Seepage for total Segment Length (m^3/sec)
El Hammam canal	0.0 – 20.0	20	14.16	0.72	0.0438	0.87
	20.0 – 30.5	10.5	9.18	0.72	0.0351	0.369
	30.5 – 49.5	19	7.90	0.72	0.0327	0.622
Bahig canal	0.0 – 30.0	30	7.25	0.6	0.0344	1.031

C. Artificial Discharge from the Ralat Aquifer:-

The discharge from El Ralat aquifer is calculated according to the number of wells drilled in the area of study, where the total cultivated area is equal to 12000 feddans. In general, the wells in this area have a discharge ranging from 40 to 70 m3/hr (average 55 m3/hr) to irrigate about 20 feddans per well. This means that the total discharge extracted from the groundwater in El Ralat aquifer in the area between Bahig canal and Bahig drain is equal to 57.6 x 106 m3/year.

However, (CEDARE, 2009) estimated the extraction rate from El Ralat aquifer in this area as 26.80 x 106 m3/year in 2009. This means that the extraction rate from the Ralat aquifer during the period 2009 to 2014 is almost doubled. This is due to the excessive well drill in this area to face the serious water shortage in Bahig canal and the increasing need for new land reclamation expansion.

The difference between the recharge and the artificial discharge represents the storage groundwater in the aquifer :-
Groundwater Storage = Recharge – Discharge
Storage in El Ralat aquifer =
69.305 x 106 - 57.6 x 106
= 11.705 x 106 m3/year

However, the accumulated storage of groundwater may cause the rise in water level during the past 30 years for about 0.5 m/year.

VI CONCLUSION & RECOMMENDATIONS

The study area is distinguished into three morphologic units of different hydrologic conditions. The northern coastal plain dominated by the shallow marine Oolitic limestone aquifer of Pleistocene age mainly recharged by the direct winter rainfall, having limited potentials and poor water quality. The piedmont plain dominated by the Ralat calcareous sandstone confined aquifer of high potentials and brackish water quality, and is mainly recharged through seepage from the irrigation canals in the area (Bahig and El Hammam canal). The southern Deltaic plain, where the Pleistocene aquifer is dominant having high potentials and better water quality, replenished directly from seepage of El Hammam irrigation canal as well as from the irrigation return flow.

In the present work, the hydraulic characteristics of the surface water canals including the depth, width, levels, discharge and flow velocity have been investigated and assessed for the calculation of the rate of canal seepage, resulting in a total amount of 65.18 x 106 m3/year directly replenishing the Ralat aquifer down gradient. On the other hand, the close investigation of the Ralat aquifer hydraulics through 40 production wells has resulted in high values of transmissivity (average 1550 m2/day), continuous rising up of water level (average 0.5 m/year) and slightly brackish water quality (average 2000 ppm). The calculated water balance of the Ralat aquifer has resulted in an amount of annual surplus water of the order of 11.705 x 106 m3/year as groundwater storage. For instance, the accumulated groundwater storage, which could cause an appreciable rise in water table, may discharge or spill into the nearby drainage network (Bahig drain) instead, so that the subsequent rise in water table becomes smaller in some parts of the network, which is the case to the west of El hammam town. Meanwhile, the rising-up of the water level in Mallahet Maryut, as a main drainage area, from zero level in 1968 (Abdel Moghith, 1968) to +4.0 m at present i.e. 1.0 m every 10 years is another example of the excessive water applied for flood irrigation in this area, as well as of the surplus aquifer storage over the years together with the inefficiency of the on-farm drainage network.

In the present work, seven infiltration tests were conducted and seven piezometers were drilled from 30 m to 50 m depth, to assess the influencing conditions of aquifer recharge, water table gradient and fluctuation and water salinity variations. Two water tables are encountered in the study area:

i) The suspended water table underneath the soil layer at the piedmont plain indicating that infiltration capacity decreases with depth and some of the percolating water may become interflow and move laterally above the main water table.

ii) The main water table moving freely from south to north towards the groundwater system at a gradient of 2.5 m/km.

Additionally, the monitoring of water level fluctuation in the production wells and the drilled piezometers shows an irregular manner from locality to another indicating, probably, seasonal rise and fall in level as a usual response of the applied water, i.e. attaining maximum elevation in winter and minimum in summer. However, continuous rise of water level in El Ralat aquifer at different rates is quite noticed, which means more rapid lateral water movement from south to north rather than vertical movement of direct percolated water.

To avoid the above hydrologic problems in the area of study, the following is recommended:-

1. Strictly controlling the irrational use of El Hammam canal water and illegal behavior of some investors along the canal path.

2. Avoidance of the water logging phenomena in the study area through the following approaches:

- Flood irrigation methods should be stopped. Drip and Sprinkler irrigation methods are recommended.
- Improve the drainage systems by regular maintenance of the existing main and secondary drains to avoid any possible blocking of the water flow.

3. Untraditional methods for drainage should be applied in the area already deteriorated to lower the water level in this area.

4. Installation of suitable pumps in the secondary drains suffering from water stagnancy and pumping the drained water frequently to the main drain. This will accelerate the water movement helping to avoid the impact of water logging problem.

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