Egyptian J. Desert Res., **58**, No.1, 19-39 (2008)

EVALUATION OF GROUNDWATER RESOURCES IN EL GORA AREA AND ITS VICINITIES, NORTHEAST SINAI PENINSULA, EGYPT

Ismail, Y. L.; S. M. M. Ibrahim and S. A. F. Hawash
Hydrology Department, Desert Research Center, El Matariya, Cairo, Egypt.

In the frame of the governmental policy for desert development especially in Sinai Peninsula, the present research aims to evaluate the groundwater resources in El Gora area and its vicinities both quantitatively and qualitatively. Quantitatively, the water bearing formation in the area is evaluated by modulus contour map based on water level contour map and transmissivity distribution map. Qualitatively, the groundwater is evaluated by an iso-salinity distribution map. The hydraulic parameters of the water bearing formations were determined and evaluated through 12 pumping tests that were carried out on selected drilled wells. The alluvial aquifer reflects wide range of transmissivity (45 m^2/ day – 1787 m^2/ day), while the marine Kurkar aquifer shows narrow one (144 m^2/ day – 390 m^2/day). The ground elevation of the study area is illustrated by a Digital Elevation Model (DEM). The DEM map indicated that the investigated area lies within a low land area. Due to the depths of groundwater (46.1 m – 105 m from the ground surface, except few water points), the rainfall replenishment is nearly absent. This phenomenon reflects that the buried channels may have an essential role of water bearings recharge. Based on the resulting modulus contour map, the northern and northwestern portions are characterized by reasonable capacity in the frame of groundwater management. On the other hand, the eastern and southern portions reflect limited aquifer potentials.

Keywords: El Gora, groundwater, hydraulic parameters, quantitative evaluation, qualitatively evaluation.

This work is an approach to evaluate the groundwater conditions in El Gora area and its vicinities in the frame of a development project adapted by the Desert Research Center (DRC) in 2005. The investigated area occupies about 470 km^2 at northeastern portion of Sinai Peninsula (Fig. 1). This area lies between latitudes 31° 05' 00" and 31° 10' 00"N and longitudes 34° 06' 00" and 34° 15' 00"E.

Fig. (1): Location of the study area.

Meteorologically, the highest annual rainfall of about 300mm is observed at Rafah, while most of the study area lies under an arid condition. Most of the Sinai Peninsula receives precipitation less than 50 mm/year, but the northeastern part is characterized by a range of annual rainfall between 75 mm and 300 mm (Fig. 2). Shmida (1985) classified extreme deserts zone that having less than 70 mm/year, and semi deserts as receiving between 150 and 350 mm/year. This further supports the interpretation of the Sinai climate as desertic overall, with a transition to a semi desert climate in northeast Sinai.

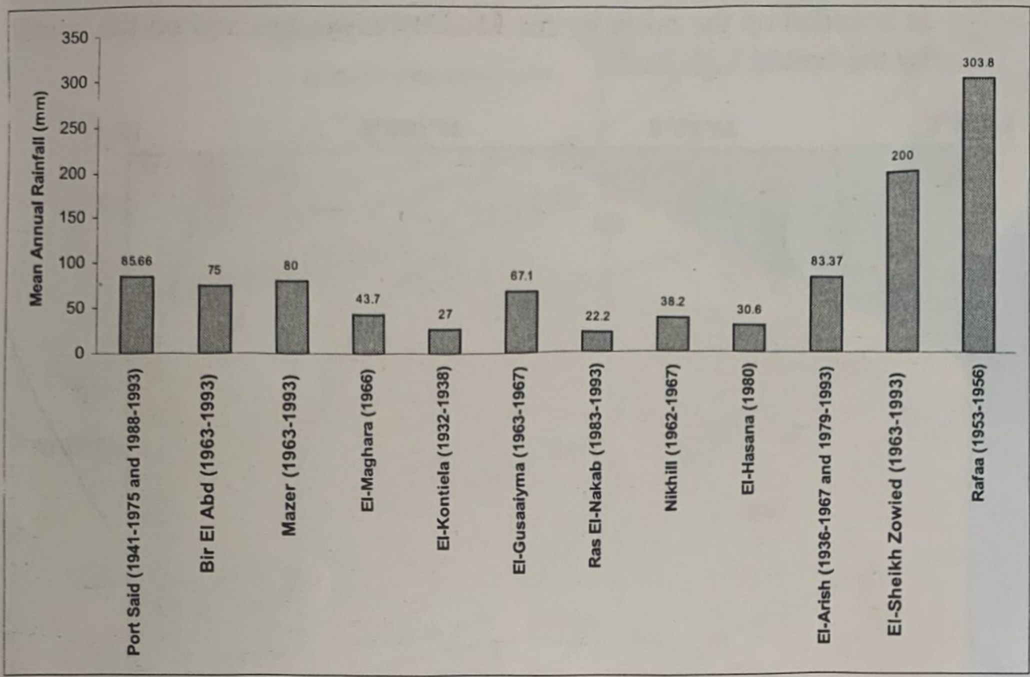

Fig. (2). Mean annual rainfall histogram, North Sinai, Egypt, (Records of meteorological stations, 1936 - 1993).

GEOLOGY AND DIGITAL ELEVATION MODEL (DEM)

Geologically, the study area is covered by Quaternary deposits which consists of sand dunes, old beach sand and calcareous sandstone (Kurkar Formation). The thickness of these deposits is about 80m to 100m (JICA, 1992).

The Kurkar Formation is distributed along the coastal plain and their genesis is present in the shallow marine environment. The old beach sand consists mainly of fine to coarse sand which is locally digenetic sandstone and intercalated with gravel and clayey layers. This is conformably overlying the Kurkar in some places which forms an unconfined aquifer (Fig. 3).

From the geomorphologic point of view, Sinai Peninsula includes the following main units (Fig. 4):

1. The southern mountainous region; which is composed of igneous and metamorphic rocks of Pre Cambrian age.
2. The central table lands; which include two plateaux:
   a) El Tih which is composed of Cretaceous limestones, with shales and sandstones at the base (Hammad, 1980).
   b) El Egma Plateau, that is composed of chalky carbonate rocks of Eocene age.
3. The Mediterranean coastal plain; where the investigated area lies within it and extends in the entire width of northern Sinai. This unit

is bounded on the north by the Mediterranean Sea and on the south by the central high lands.

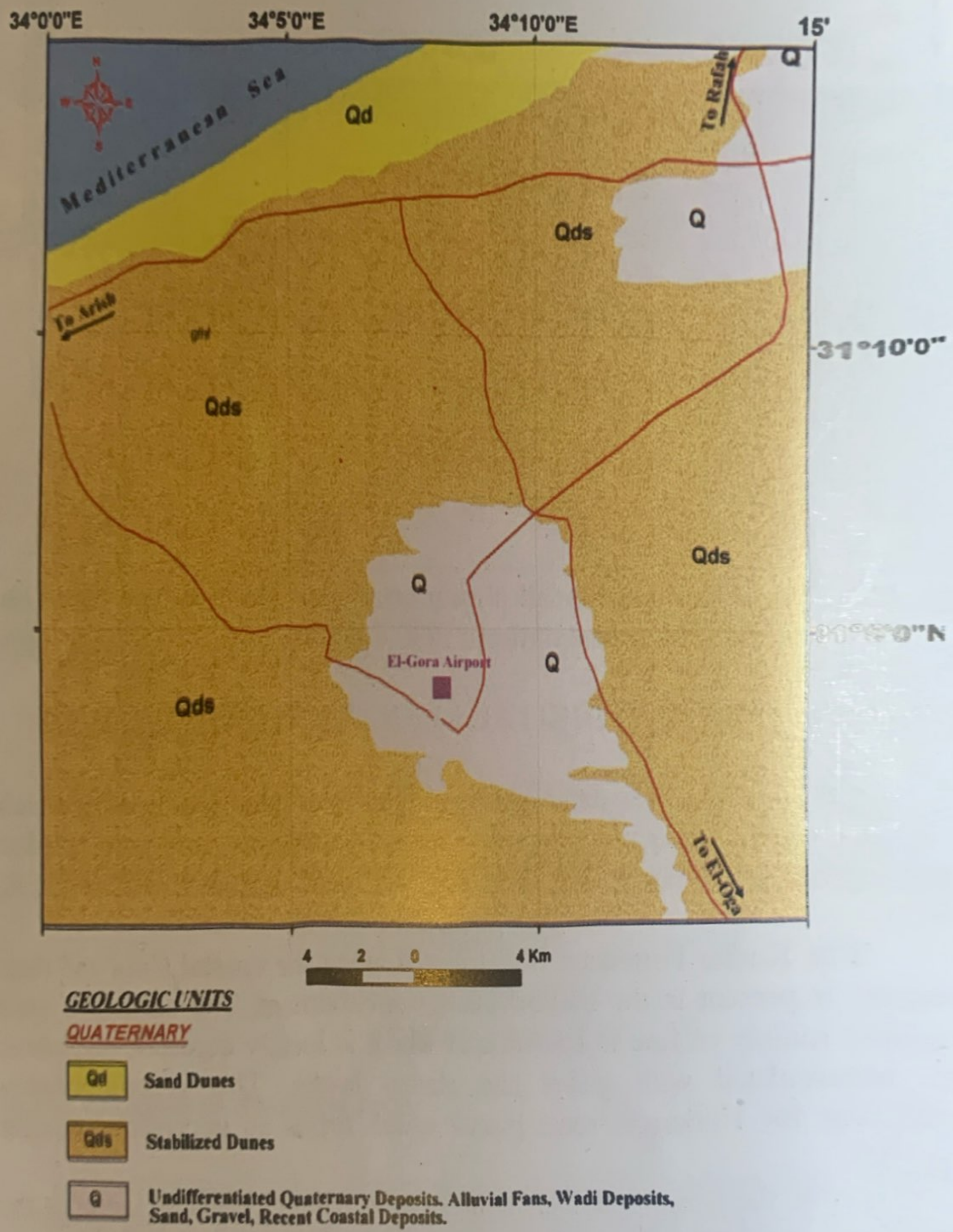

Fig. (3) Geological map of the study area and its vicinities.

The Digital Elevation Model of the study area (DEM) is created from the digitization of the elevation points on the topographic map of the study area. The DEM map (Fig. 5) is a raster map in which each pixel has digital number (DN) that indicates the ground elevation. So, it is easy to get the elevations of the undefined values in between the rasterized contour lines.

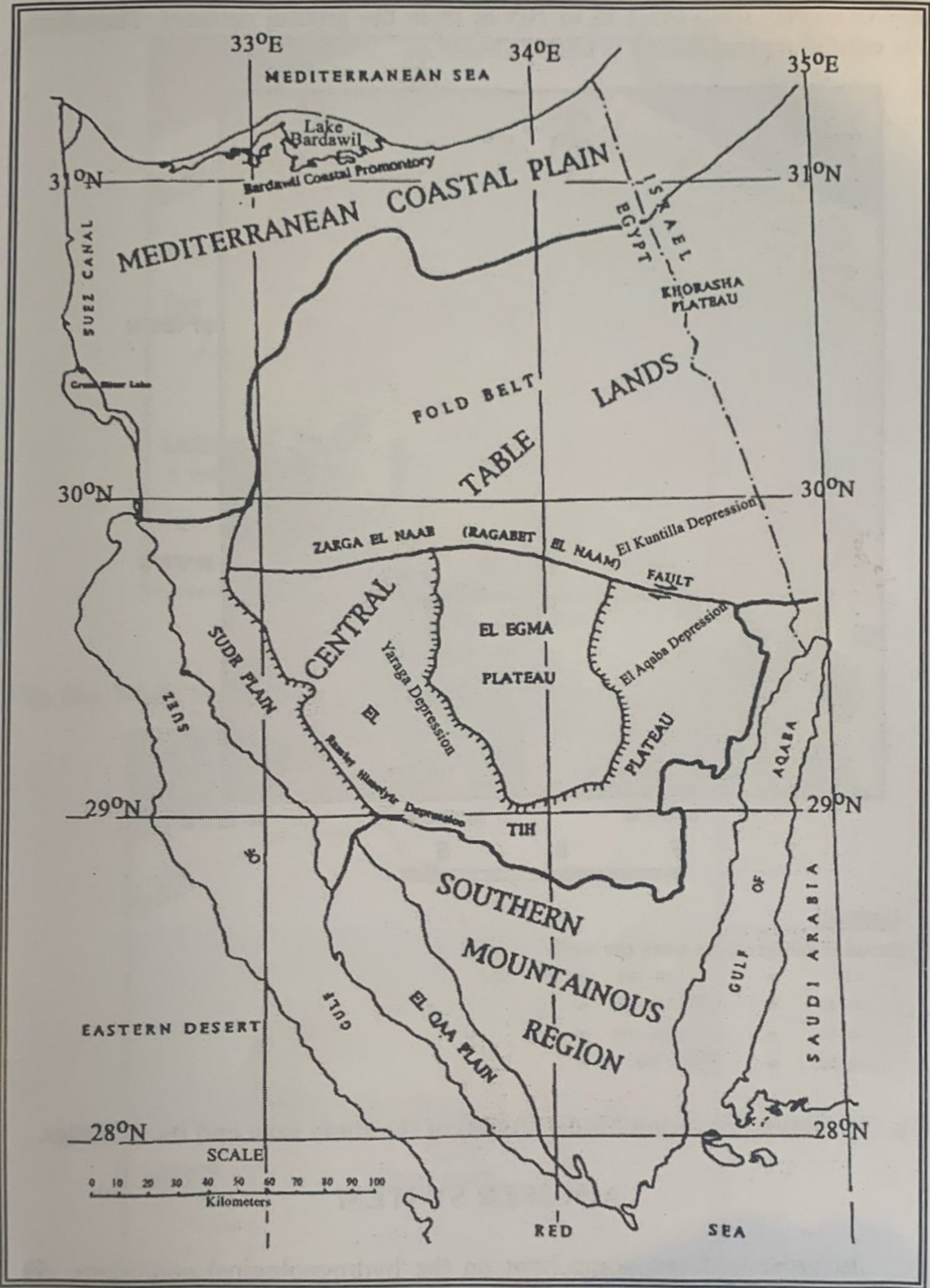

Fig. (4). Major geomorphic units of Sinai Peninsula, El Ghazawi (1989).

From the map (Fig. 5), the investigated area lies within a low land area which may reflect that the buried channels represent the main source of groundwater recharge, in addition to, that the depths to the groundwater are approximately deep (46.1 m to 105 m from the ground surface). Therefore the rainfall replenishment is nearly absent.

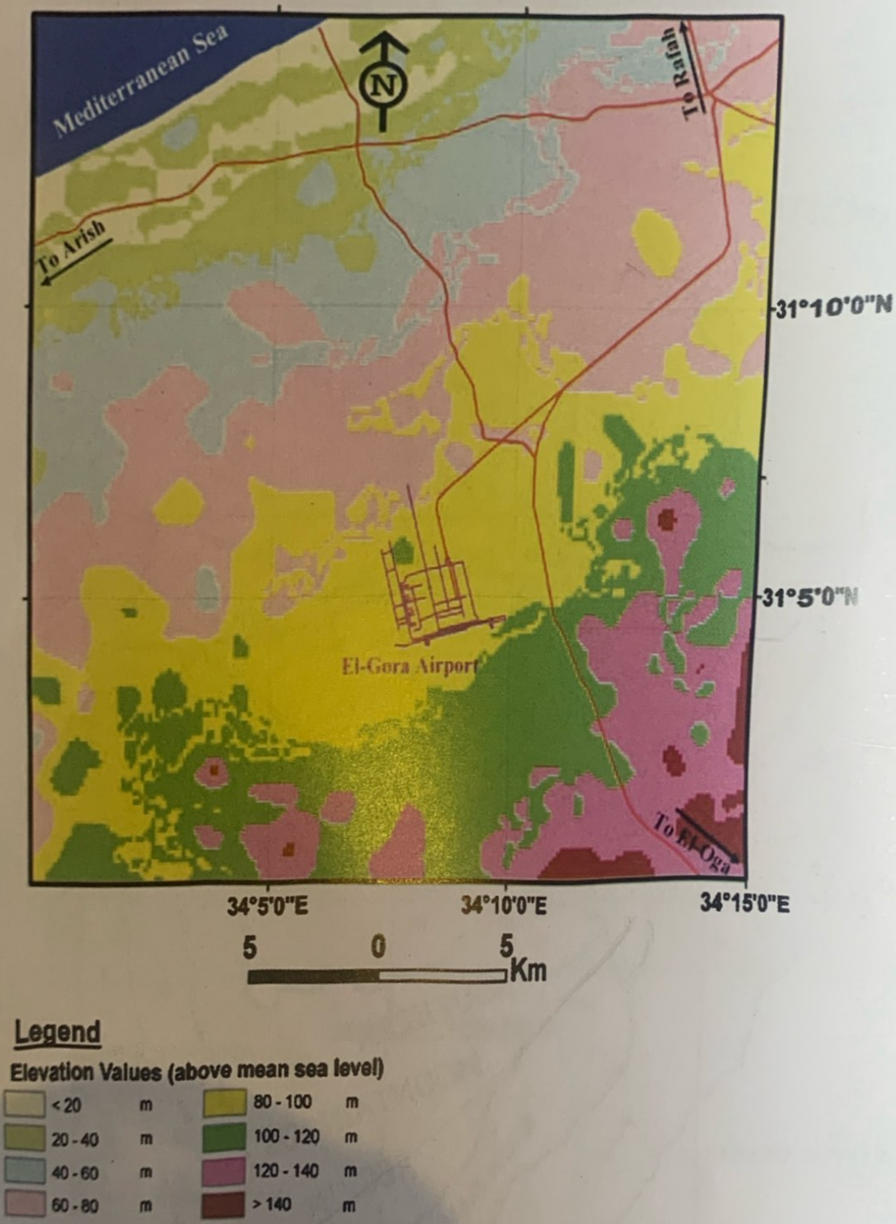

Fig. (5). Digital Elevation Model (DEM) of the study area and its vicinities.

AQUIFER SYSTEM

In order to focus some light on the hydrogeological conditions, 59 water points tapping two water bearing formations were collected as follow (Figs. 6, 7 and Table 1).

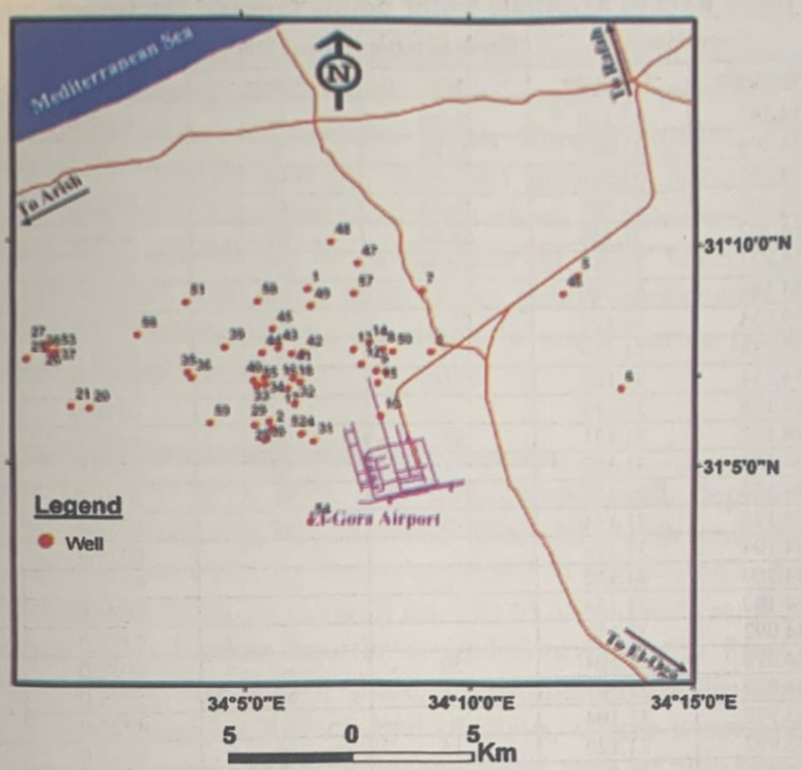

Fig. (6). Wells location at the study area.

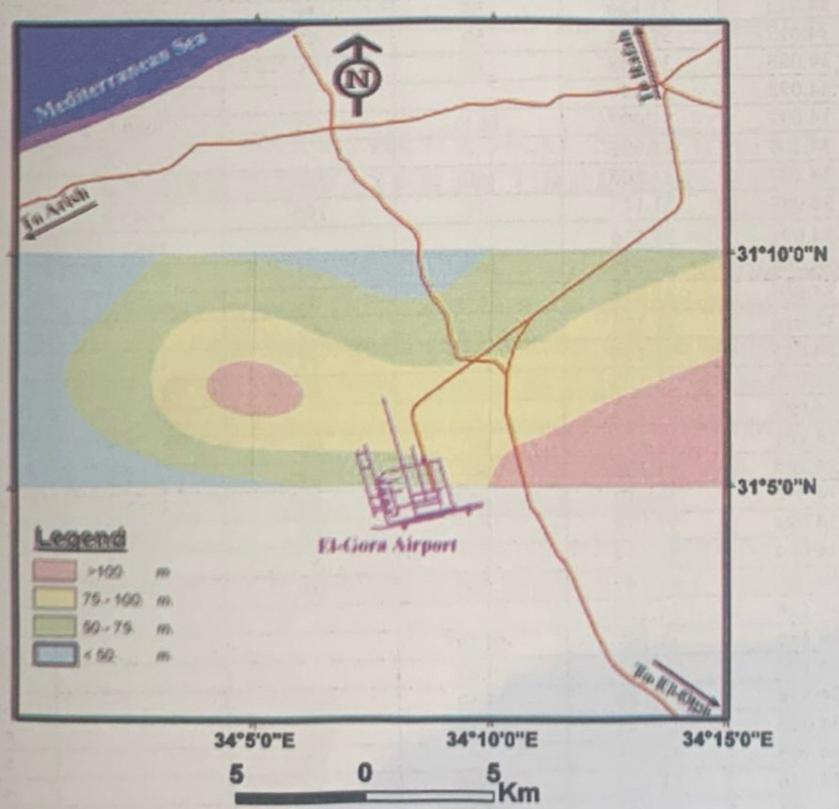

Fig. (7). Depth to water zonation of the study area (Alluvial aquifer).

Table (1). Basic data of available water points tapping the investigated aquifers.

Well No.	Coordinates		Depth to water	Total Depth	Salinity	Formation
	Longitude	Latitude	(m)	(m)	(ppm)	
1	34.107	31.149	59.50	90	6767.0	Kurkar F.
2	34.094	31.097	75.40	96	3200.0	Alluvium
3	34.153	31.126	-	92	-	Alluvium
4	34.105	31.095	76.97	93	5550.0	Kurkar F.
5	34.207	31.156	68.90	92	3050.0	Alluvium
6	34.223	31.113	104.50	117	2680.0	Alluvium
7	34.149	31.149	-	96	-	Alluvium
8	34.135	31.127	75.5	91	5978.0	Alluvium
9	34.132	31.119	-	-	6694.0	Kurkar F.
10	34.134	31.102	75.00	95	5453.0	Kurkar F.
11	34.136	31.118	-	-	6336.0	Kurkar F.
12	34.127	31.121	85	90	6688.0	Kurkar F.
13	34.124	31.127	-	95	5619.0	Alluvium
14	34.130	31.129	77	91	5485.0	Alluvium
15	34.133	31.114	75	92	6752.0	Kurkar F.
16	34.104	31.114	-	-	6234.0	Kurkar F.
17	34.100	31.112	-	-	4512.0	Alluvium
18	34.102	31.116	-	-	6093.0	Kurkar F.
19	34.092	31.113	-	-	4173.0	Alluvium
20	34.028	31.104	50	-	4032.0	Alluvium
21	34.022	31.105	-	65	5728.0	Alluvium
22	33.979	31.104	-	-	4922.0	Alluvium
23	33.992	31.120	15	60	5741.0	Alluvium
24	33.996	31.121	16	58	7488.0	Kurkar F.
25	34.005	31.122	58	72	5677.0	Alluvium
26	34.013	31.126	53	70	5626.0	Alluvium
27	34.013	31.128	50	57	4998.0	Alluvium
28	34.088	31.098	16	95	3251.0	Alluvium
29	34.093	31.099	-	-	2784.0	Alluvium
30	34.092	31.093	18.5	90	2989.0	Alluvium
31	34.109	31.092	-	-	5843.0	Alluvium
32	34.103	31.106	66	96	5325.0	Alluvium
33	34.089	31.113	71	105	3443.0	Alluvium
34	34.091	31.116	-	-	3462.0	Alluvium
35	34.064	31.118	62	80	3802.0	Alluvium
36	34.065	31.116	67	85	4224.0	Alluvium
37	34.016	31.125	-	65	-	Alluvium
38	34.015	31.124	50	70	4390.0	Alluvium
39	34.077	31.127	-	82	2822.0	Alluvium
40	34.088	31.115	-	-	3052.8	Alluvium
41	34.101	31.125	67	96	5907.2	Kurkar F.
42	34.105	31.125	64	84	6188.8	Kurkar F.
43	34.096	31.127	60	80	4442.0	Alluvium
44	34.091	31.125	75	81	3206.0	Alluvium
45	34.094	31.134	-	-	5261.0	Kurkar F.
46	34.201	31.149	70	91	3987.0	Alluvium
47	34.126	31.159	-	-	-	Alluvium
48	34.116	31.167	46.10	-	-	Alluvium
49	34.108	31.143	66.23	-	-	Alluvium
50	34.138	31.126	74.50	-	-	Alluvium
51	34.063	31.144	75.40	-	-	Alluvium
52	34.105	31.095	-	95	-	Alluvium
53	34.016	31.125	49.00	70	-	Alluvium
54	34.108	31.062	75.00	110	-	Alluvium
55	34.089	31.113	105.00	110	-	Alluvium

1- The alluvial Aquifer

The Alluvial aquifer is represented by two main lithologic facies, gravely sand and clayey sand. Both facies together with the old beach deposits constitute what we consider as an alluvial aquifer. Taha (1968) mentioned that the aquifer can be classified into two horizons; an upper horizon dominated by coarse gravel with interbeds of calcareous silt, and the lower horizon that proves to be water bearing. The water exists under unconfined conditions. The water table slopes gently northwards. During the recent inventory of water points, the depth to water varies from 46.1m to 105m from the ground surface.

2- The Calcareous Sandstone (Kurkar) Aquifer

Kurkar aquifer is a type of Calcareous sand deposits broadly distributed in the coastal plain between West El Arish and Rafah. This aquifer unit is characterized by being confined to semi-confined where the depth to water varies from 16 m (well no. 24) to 85 m (well no. 12) from the ground surface. The Kurkar aquifer is underlined by the Pre-Quaternary sediments that mainly consist of shale, sandstone, and/or limestone. Also, the Kurkar is overlined by a thick bed of clays, where a confined aquifer conditions are developed. It occupies the most part of the bottom of the Quaternary in the study area. However, where the extension of the clay bed is limited, the hydraulic connection between the Kurkar aquifer and the overlying aquifer is observed.

IMPACT OF THE STRUCTURAL SETTING ON GROUNDWATER OCURRENCE

The previous studies elucidated that the structural setting has a direct impact on the occurrence and flow direction of groundwater. In order to draw a general view of the hydrogeological setting of the study aquifer, two hydrogeological cross sections were drawn in figs. (8, 9 and 11). These sections displayed that the groundwater occurred into two zones. The upper one (Alluvial aquifer) composed of gravely sand with interbeds of calcareous silt. This aquifer seems to be unconfined one.

On the other hand, the lower one (Kurkar aquifer) consists of calcareous sandstone and it is overlained by thick clay bed. According to the occurrence and extension of clay layer, the Kurkar aquifer varies from unconfined to semi-confined.

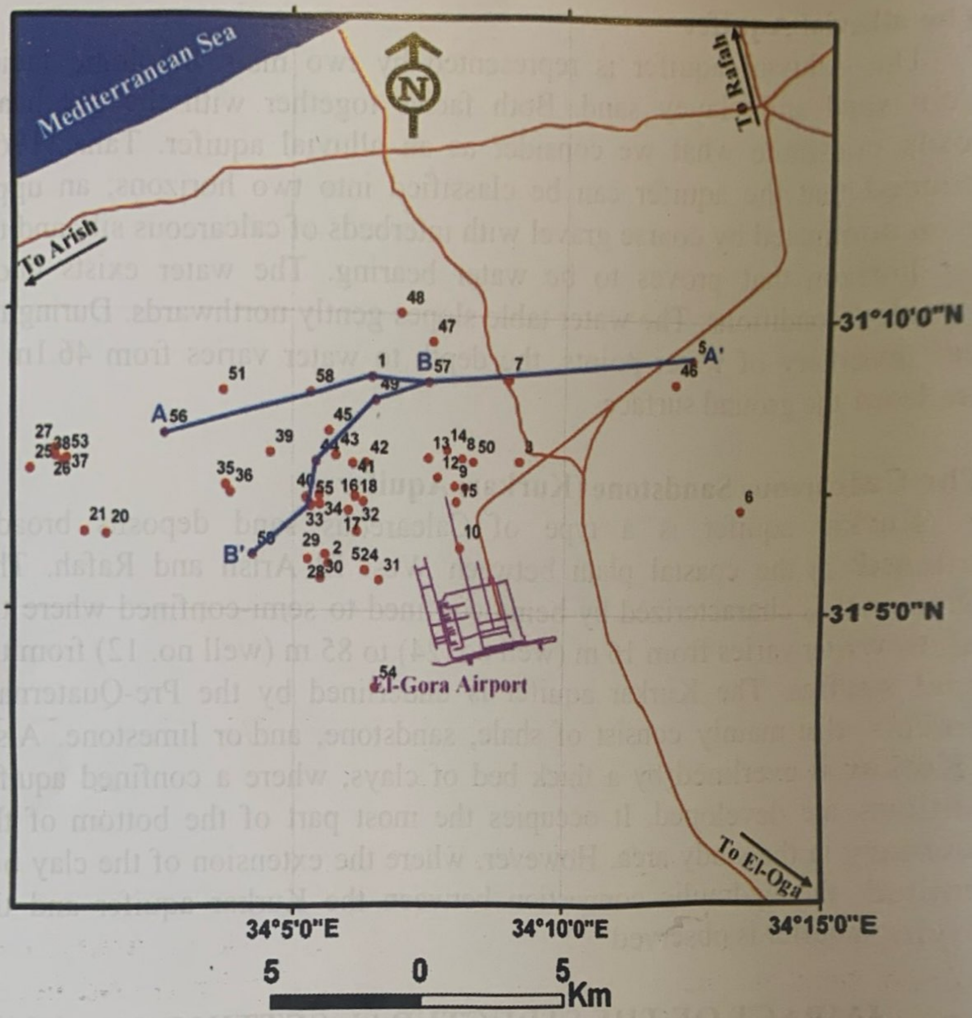

Fig. (8). Directions of the hydrogeological cross-sections in the study area.

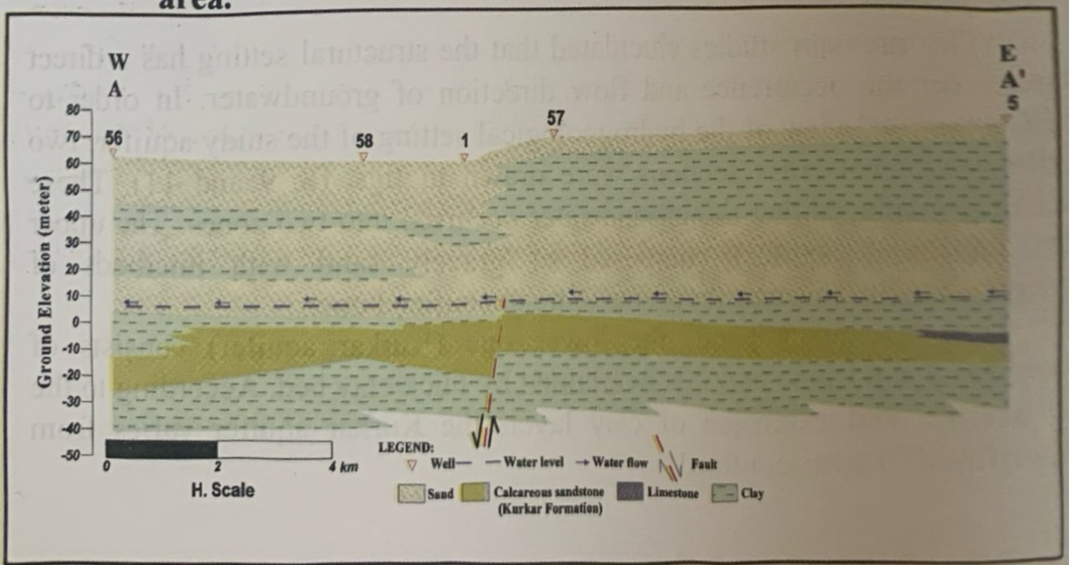

Fig. (9). Hydrogeological cross-section A-A'.

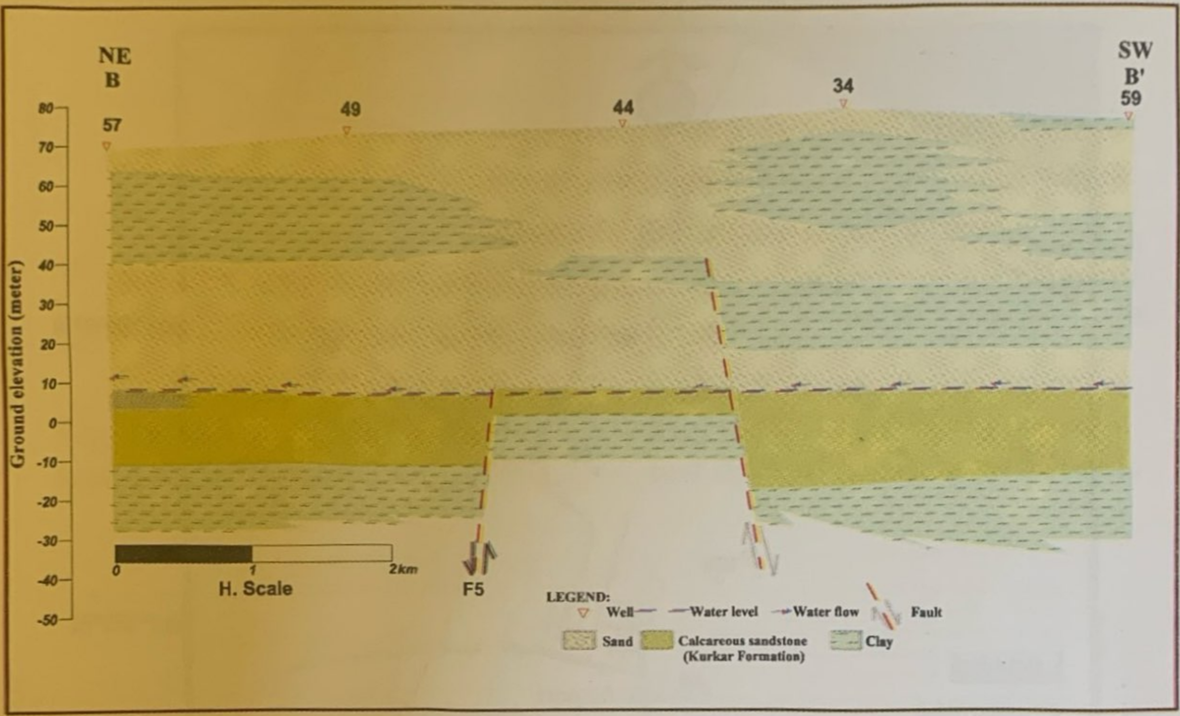

Fig. (10). Hydrogeological cross-section B-B'.

AQUIFER PARAMETERS

During the present work, an approach was made to determine and evaluate the hydraulic parameters of the water bearing formations. In order to achieve this goal, 12 pumping tests were carried out on selected drilled wells (Fig. 11). The calculated values were tabulated in table (2) and illustrated in figures (12 to 21). It is obvious that the alluvial deposits reflect wide range of transmissivity (45 m^2/day – 1787 m^2/day) while, the transmissivity of marine Kurkar aquifer shows narrow ones (144 m^2/day – 390 m^2/day). This phenomenon could be attributed to the impact of structural setting, variation of aquifer thickness and heterogeneity of aquifer sediments. It becomes clear that the water bearing formations in the northwestern and northern portions of the study area have reasonable capability to transmit water through it.

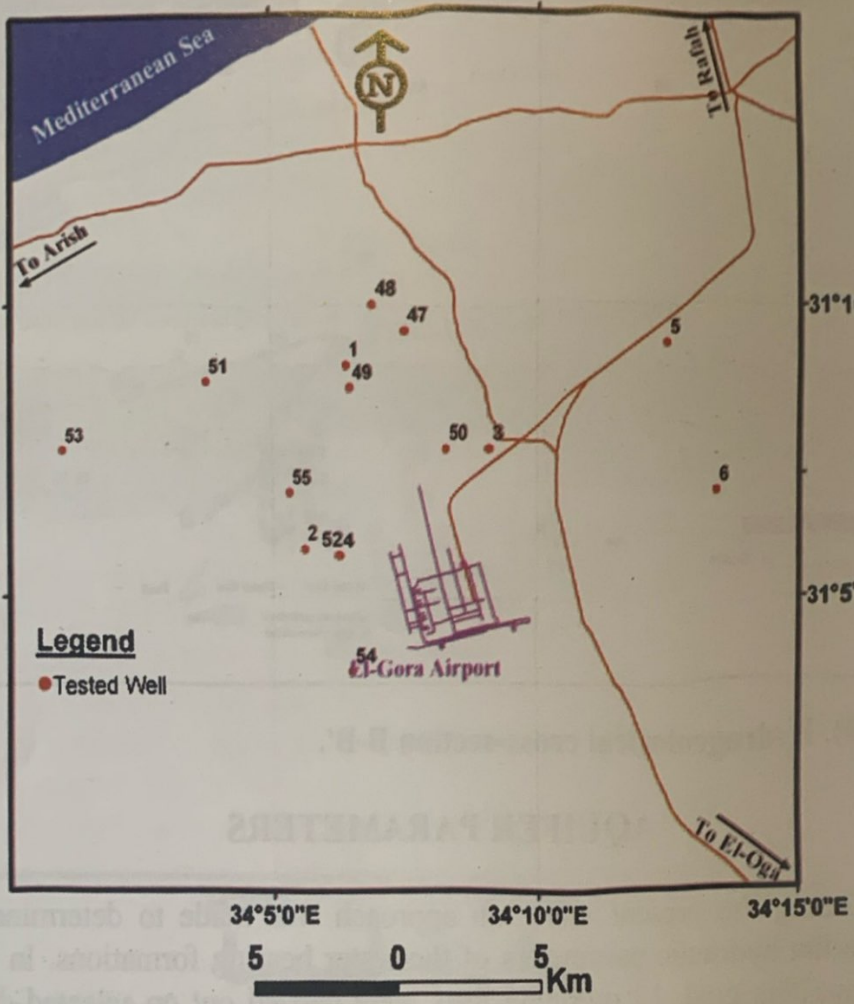

Fig. (11). Pumping test wells in the study area.

Table (2). The calculated values of hydraulic parameters of the investigated aquifers.

Well No.	Depth to water (m)	Pumping duration (min)	Total drawdown (m)	Transmissivity (m^2/ day)
1	59.5	720	4.62	390
2	75.4	840	5.87	202
3	74.45	600	5.30	248
4	73	600	7.79	144
5	68.9	600	5.03	303
6	104.5	720	4.06	45
52	75	360	4.50	185
53	48	360	2.00	1023
49	75	400	4.10	80
55	105	450		36.54
47				873
48	46.1			1787

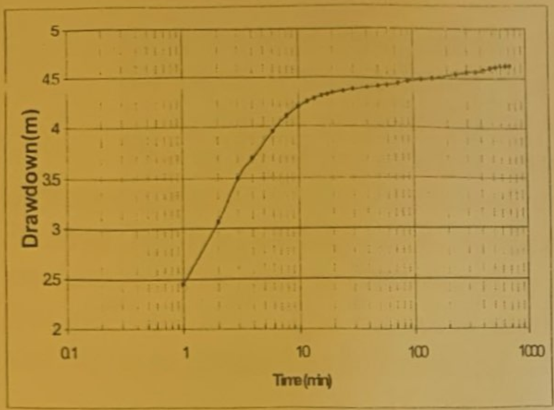

Fig. (12). Analysis of pumping test data of El Gora well No. 1.

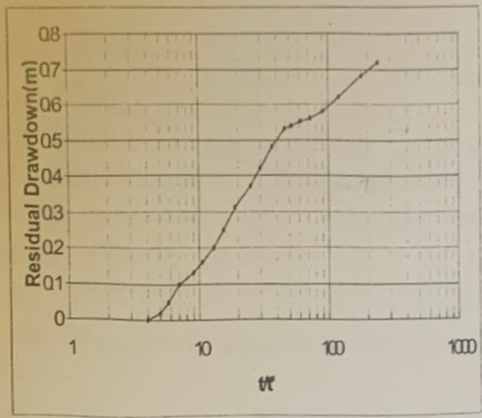

Fig. (13). Analysis of recovery test data of El Gora well No. 1.

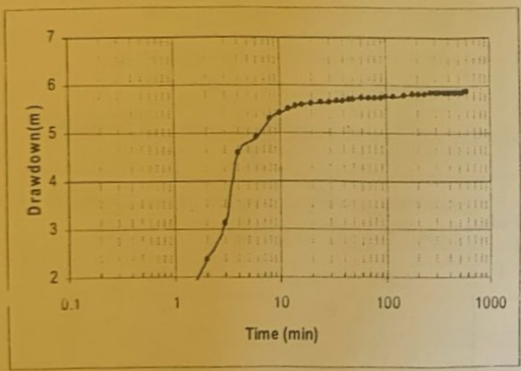

Fig. (14). Analysis of pumping test data of El Gora well No. 2.

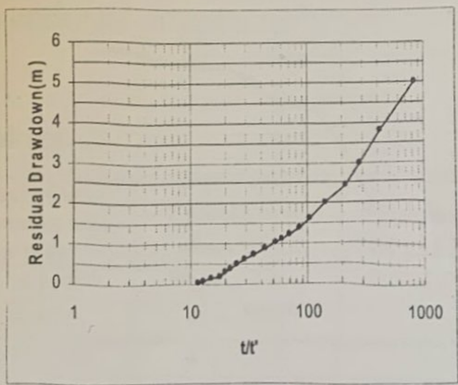

Fig. (15). Analysis of recovery test data of El Gora well No. 2.

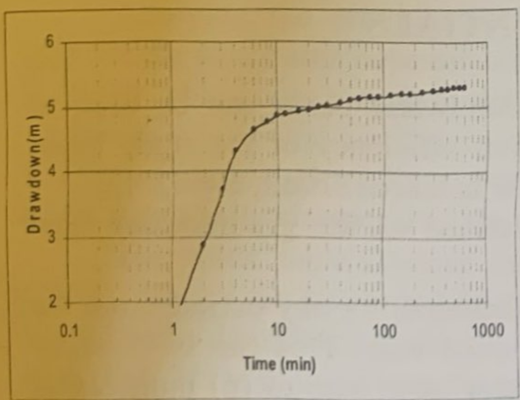

Fig. (16). Analysis of pumping test data of El Gora well No. 3.

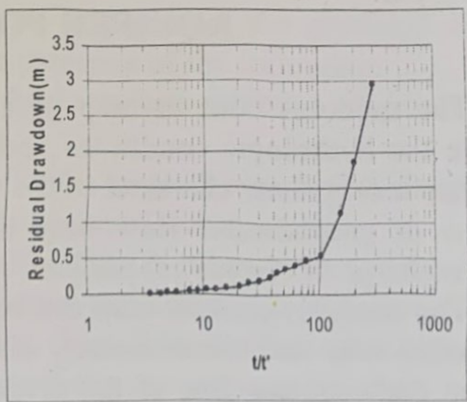

Fig. (17). Analysis of recovery test data of El Gora well No. 3.

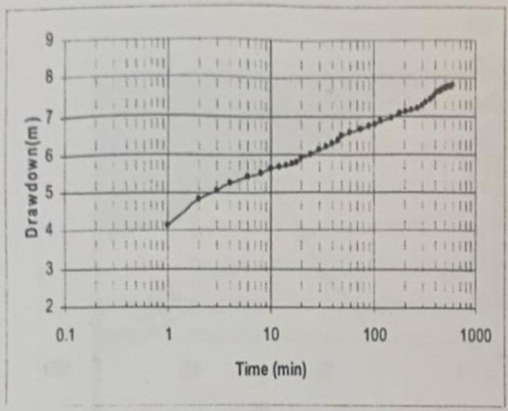

Fig. (18). Analysis of pumping test data of El Gora well No. 4.

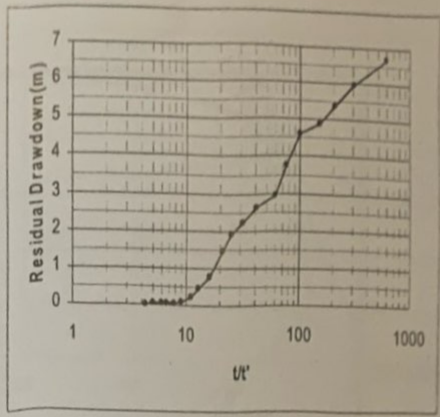

Fig. (19). Analysis of recovery test data of El Gora well No. 4.

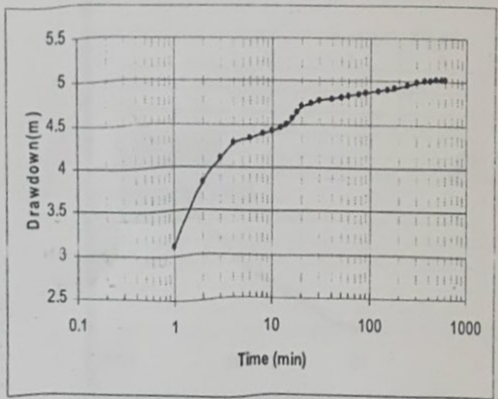

Fig. (20). Analysis of pumping test data of El Gora well No. 5.

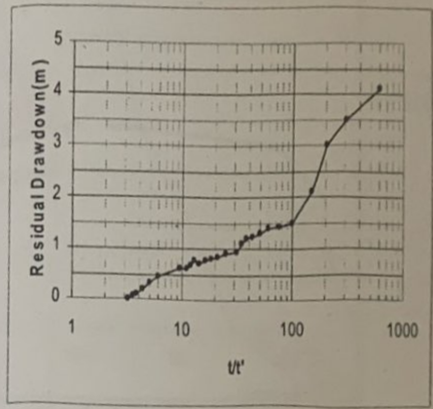

Fig. (21). Analysis of recovery test data of El Gora well No. 5.

AQUIFER POTENTIALS

The modulus contour map of a groundwater basin can be used to evaluate the hydrologic conditions and water efficiency of the study basin and hence it may show character of the water balance (Rofail, 1967). The modulus of groundwater flow may be defined as the groundwater flow (either recharge or discharge) per km^2.

The modulus contour map can be calculated, for any period, from the water table map and transmissivity distribution map. This can be done by dividing each contour line of the given water table map to (n) numbers of equal parts each of width (b) meters (Sewidan and Rofail, 1972). Discharge could then be estimated using Darcy's law. The total discharge for the total length of the contour line would then be:

$$Q = b \sum_{i=1}^{n} T_i l_i$$

Where:

Q: is the total discharge for the contour line (m^3/h),
T_i: value of transmissivity (m^2/day) at the sector (i),
I_i : hydraulic gradient (m/m) at the sector (i).

The value of the modulus groundwater flow can be calculated as the difference between the discharge values at any successive contour lines divided by the surface area between them (Table 3). The value of the modulus in this case is considered to be the mean values of the water gain or loss per unit area. The modulus coefficient M_{m-n} between two contours (*m*) and (*n*) is expressed as follows:

$$M_{m-n} = (Q_m - Q_n) / A_{m-n}$$

Where:

Q_m ; the natural discharge at contour m (m^3/day),
Q_n ; the natural discharge at contour n (m^3/day),
A_{m-n}; the surface area between contours m and n (m^2).

Table (3). Calculation of modulus values.

Water Level (m)	Discharge at upstream contour Q_m (m^3/day)	Discharge at downstream contour Q_n (m^3/day)	Surface area A_{m-n} (m^2)	Modulus value $(Q_m - Q_n) / A_{m-n}$
11 - 10	960041.7695	3891174.1691	78446170	- 0.037
10 - 9	3891174.1691	6166339.8928	99303820	- 0.024
9 - 8	6166339.8928	10404937.1345	47822870	- 0.085
8 - 7	10404937.1345	10689771.2072	42264660	- 0.008
7 - 6	10689771.2072	6483357.4986	44675140	+ 0.095

Applying the previous technique to construct the modulus contour map for the study area necessitates the presence of the following:

a. Water table contour map to detect the value and direction of groundwater flow,
b. Data of pumping tests for a group of wells to get the transmissivity (T),
c. An iso-salinity contour map for the purpose of water quality.

The water table contour map (Fig. 22) is taken after Abdel Azeem (2005). To get the transmissivity, pumping test analysis is carried out for 12 drilled wells distributed in the study area (Fig. 23). The iso-salinity zonation map (Fig. 24) is drawn using the salinity measurements for the water points.

The obtained values of modulus groundwater flow are used to construct a modulus contour map (Fig. 25). It shows that the study area is characterized by successive negative zones and one positive zone. The small changes noticed in the modulus contour values are due to the small storage capacity of the aquifer and poor groundwater flow as a result of low values of transmissivity average 239 m^2/day except wells No 48 and 53 have average of 1405 m^2/day.

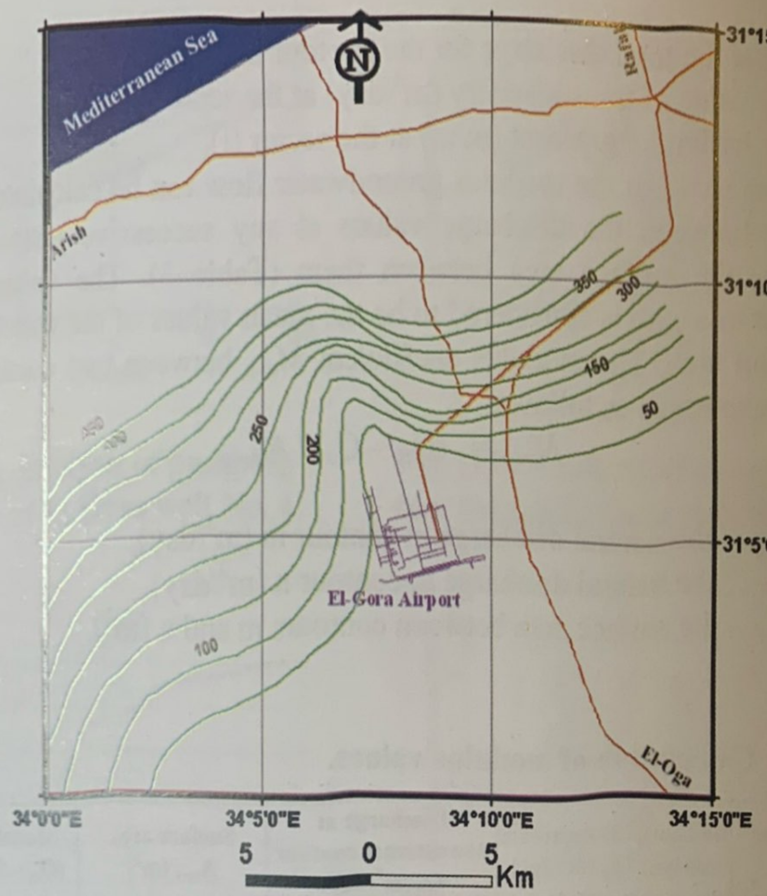

Fig. (23). Transmissivity contour map of alluvial aquifer

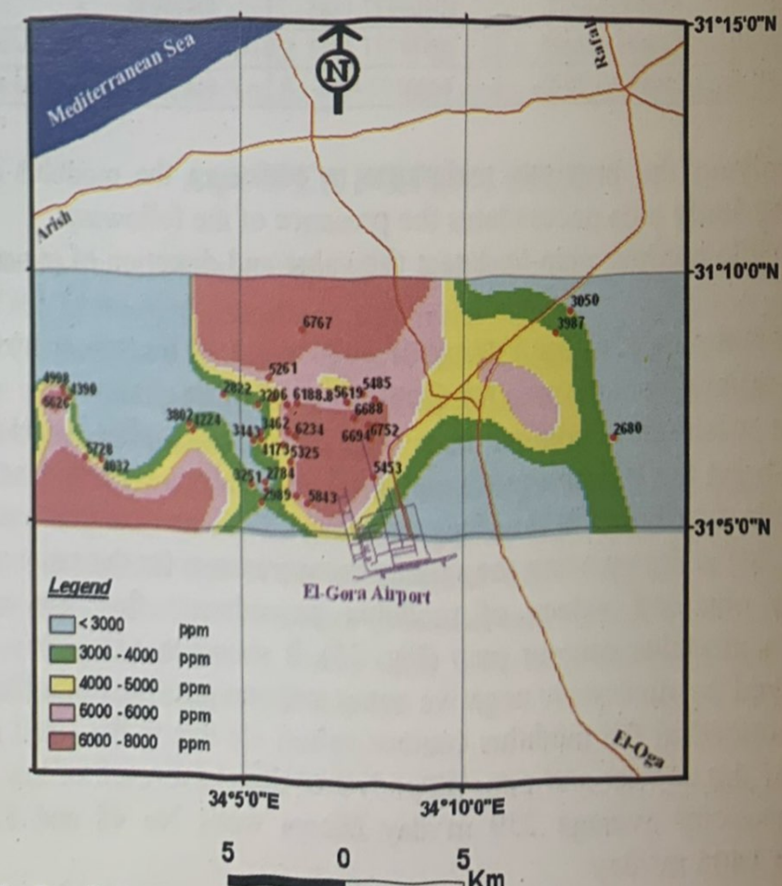

Fig. (24). Iso-Salinity zonation map the study area.

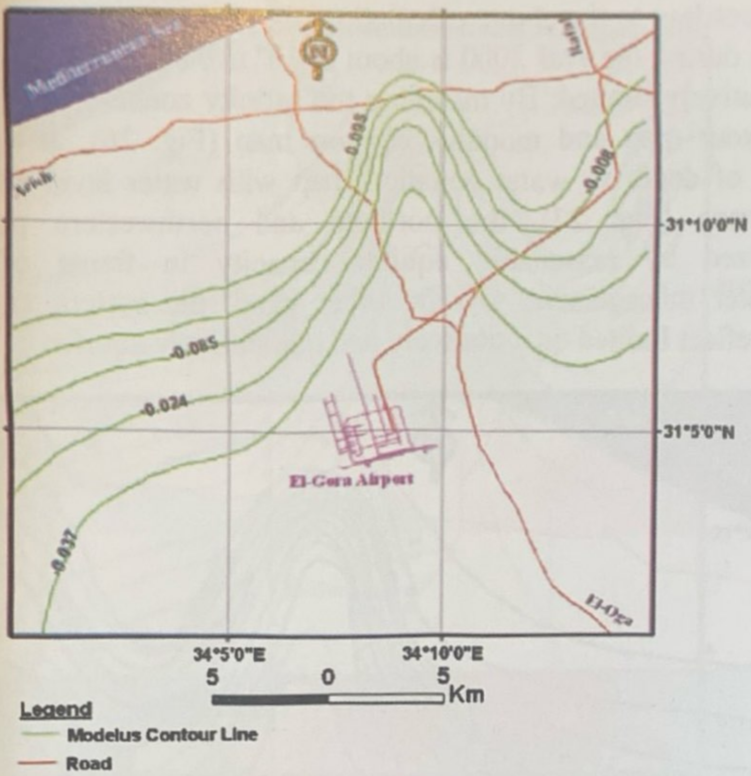

Fig. (25). Modulus contour map of the study area.

Negative modulus value zone means that the amount of subsurface recharge along the upstream contours is less than the amount of subsurface discharge along the preceding downstream contour. This is due to additional vertical recharge for the aquifer in the area between each successive two contours. This zone usually has high efficiency and considerable water replenishment.

Positive modulus value zone means that the amount of subsurface recharge along the upstream contours is more than the amount of subsurface discharge along the preceding downstream contours. This zone has medium efficiency and medium water replenishment.

The estimated quantity of recharge for the total area can be calculated by applying the following equation (Table 4):

$$\text{Total recharge} = \frac{\text{Recharge for the sub-area} \times \text{Total area}}{\text{Sub-area}}$$

Table (4) shows the calculations of the total amount of recharge to the study aquifer.

Table (4). Recharge calculation of the investigated area.

Discharge at the up-stream contour (m^3)	Discharge at the downstream contour (m^3)	Sub-area between The two contours (Km^2)	Recharge for the Sub- area (m^3)	Total area (Km^2)	Recharge for the total area (m^3)
(1)	(2)	(3)	(4) = (2) – (1)	(5)	(6)= (4)*(5)/(3)
960042	6483357	317	5523315	470	8189142

According to the above calculation, the recharge to the water bearing formation during the year 2000 is about 8×10^{6} m^{3}. It is clear that the aquifer is quantitatively limited. By matching the salinity zonation map with water level contour map and modulus contour map (Fig. 26), as well as, the matching of depth to water zonation map with water level and modulus contour map (Fig. 27), the northern and northwestern portions are characterized by reasonable aquifer capacity in frame of scientific groundwater management. On the other hand, the eastern and southern portions reflect limited quantitatively and qualitatively aquifer.

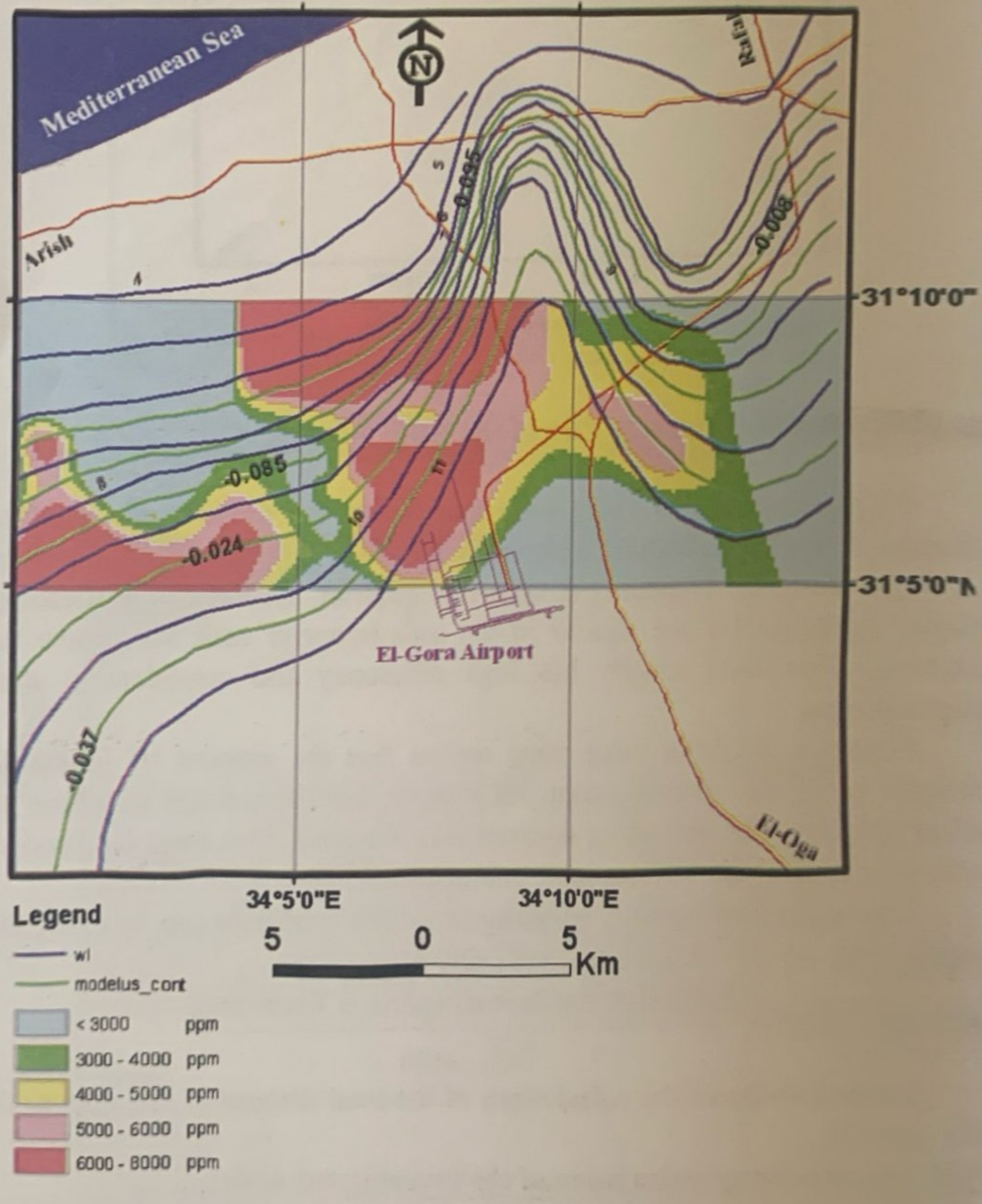

Fig. (26). Matching map of modulus and water level contour maps with salinity zonation map at the study area.

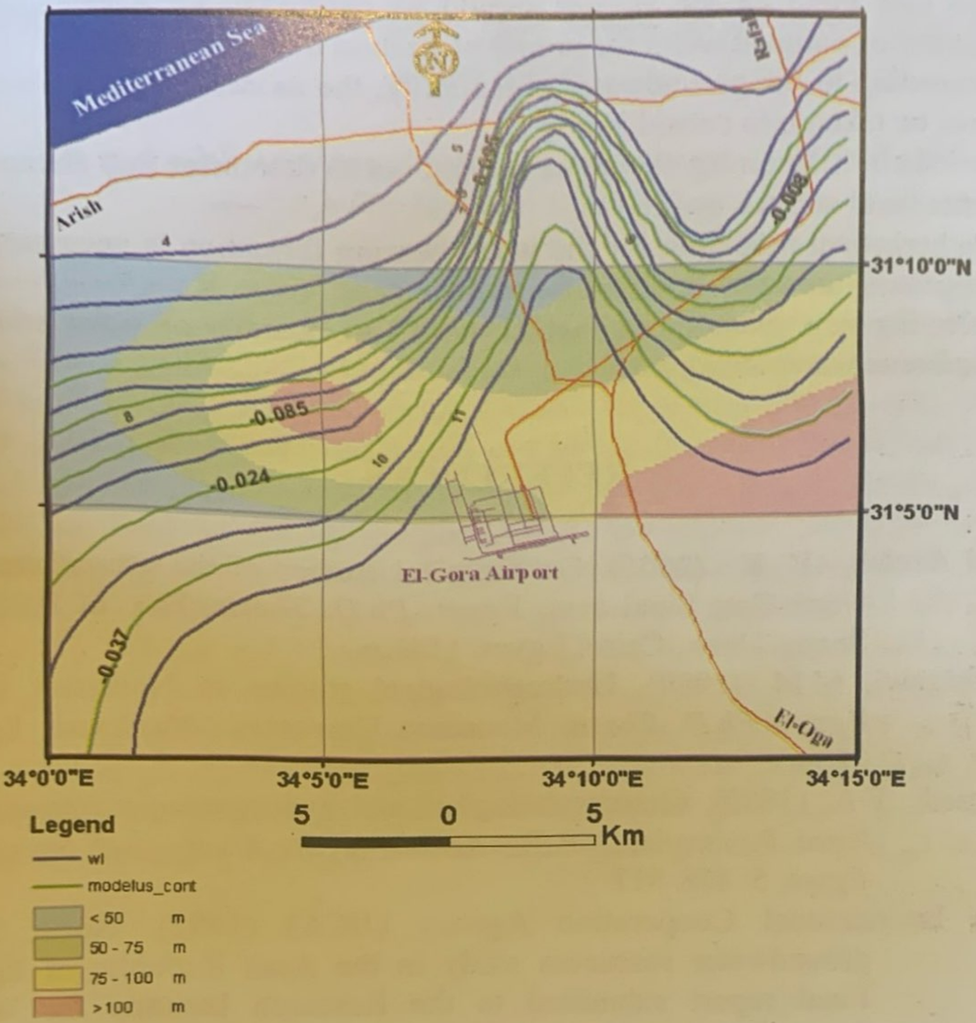

Fig. (27). Matching of modulus maps and water level contour maps with depth to water map.

CONCLUSIONS AND RECOMMENDATIONS

1. The hydraulic parameters of the investigated aquifer reflect wide range of transmissivity (45 m^2/day – 1787 m^2/day) for alluvial aquifer, while (144 m^2/day – 390 m^2/day) for Marine Kurkar aquifer.
2. The modulus contour map reflects that the northern and northwestern portions are characterized by a reasonable aquifer capacity in frame of scientific groundwater management, while the eastern and southern portions reflect quantitatively and qualitatively limited aquifer.
3. Due to the depths of groundwater (46.1m to 105m from the groundsurface), the rainfall replenishment is nearly absent. On the other hand, the buried channels may represent the main source of groundwater recharge.

4. The safe yield of the aquifer should be controlled by decreasing the number of pumped wells for proper utilization of groundwater.
5. According to the groundwater potentiality, the modern irrigation system must be taken into consideration.
6. Periodical monitoring should be carried out to determine any changes in water level and the quality.
7. Mathematical modeling for the water bearing formation is necessary for suggesting the suitable scientific management.
8. Selecting new plant species which need low quantity of water and can overcome water salinity.

REFERENCES

Abdel Azeem, Y. R. (2005). Geochemical studies of the groundwater in North-East Sinai area, Egypt. *Ph.D. Thesis*, Fac. of Sci., Ain Shams Univ., Cairo, Egypt. 1141 p.

El Ghazawi, M.M. (1989). Hydrogeological studies in Northeast Sinai, Egypt. *Ph.D. Thesis*, Mansoura University, Mansoura, Egypt. 290p.

Hammad, F.A. (1980). Geomorphological and hydrogeological aspects of Sinai Peninsula, A.R.E., *Annals of the Geological Survey of Egypt*, 5: 808-817.

Japan International Cooperation Agency (JICA) (1992). North Sinai groundwater resources study in the Arab Republic of Egypt. Final report submitted to the Research Institute for Water Resources, Ministry of Public Works and Water Resources, Cairo, Egypt, 207 pp.

Rofail, N.H. (1967). The groundwater modulus map on the Nile Delta, *High Technical Education Conference, Brne Czechoslovakia*, 1(2):145-149. .

Sewidan, A.S. and N.H. Rofail (1972). Groundwater modulus map of El Qasr area Western Desert, Mediterranean Coastal Zone. Proceeding 12th Arab Engineering Congress, Cairo, 8pp.

Shmida, A. (1985). Biogeography of desert flora: In "*Ecosystems of the World*", *Vol. 12A, hot Desert and Arid Shrublands*, (Evenari, M., Noy-Meir, I. and Goodall, D.W., eds.). Elsevier, Amsterdam, p. 23-77.

Taha, A.A. (1968). Geology of the groundwater supplies of EL Arish – Rafah. *M. Sc. Thesis*, Fac. of Sci., Cairo Univ., Giza, Egypt.

Received: 29/11/2006
Accepted: 13/12/2007

تقييم موارد المياه الجوفية بمنطقة الجورة ومايتاخمها- شمال شرق شبه جزيرة سيناء – مصر

يحيى لطفى اسماعيل – سوسن مصيلحى محمد – سعيد عبد العليم فرج حواش
قسم الهيدرولوجيا – مركز بحوث الصحراء – المطرية – القاهرة – مصر

فى إطار سياسة الحكومة للتنمية الصحراوية خاصة فى شبه جزيرة سيناء، يهدف البحث الى تقييم موارد المياه الجوفية كما وكيفاً بمنطقة الجورة وما يتاخمها بالجزء الشمالى الشرقى لشبه جزيرة سيناء على حدود مصر الشمالية الشرقية والتى تغطى مساحة حوالى ٤٧٠كم٢ وذلك من خلال اعداد خريطة محصلة لمعاملات الخزان الجوفي لدراسة الكفاءة الكمية للخزان نتيجة للسياسة المائية خلال هذه الفترة مع وضع توصيات للمناطق التى تمثل التوسع الزراعى والمناطق التى يلزم اعادة النظر فيها وقد أشارت النتائج الى أن المناطق الشمالية والشمالية الغربية تتميز بامكانيات مائية مقبولة فى إطار من الإدارة العلمية الجيدة بينما أظهرت المناطق الشرقية والجنوبية امكانيات محدودة للخزان الجوفى. كما أوضحت النتائج بأن المعاملات الهيدروليكية للخزانين الجوفيين تراوحت بين ضعيفة الى متوسطة حيث تراوح معامل الناقلية لخزان رواسب الوديان بين ٤٥ م٢/يوم الى ١٧٨٧ م٢/يوم بينما تراوح بين ١٤٤ م٢/يوم الى ٣٩٠ م٢/يوم لخزان الكركار البحرى وقد يرجع ذلك الى تباين رواسب الخزان الجوفى رأسياً وأفقياً وتأثير الظروف التركيبية على تواجد وحركة المياه. وقد أشارت النتائج بأن معدل التغذية للخزان الجوفى بلغ حوالى ثمانية ملايين متر مكعب خلال عام ٢٠٠٠ والذى يعكس امكانية محدودة للخزان الجوفى والتى تتطلب تقنيات علمية متطورة فى الاستغلال الامثل للخزان الجوفى بالاضافة الى نوعية النباتات التى تتحمل الملوحة العالية نسبياً ولا تحتاج الى كميات كبيرة من المياه.