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Estimation of Salt Balance in Salt-Affected Ecosystems in Arid Areas, Case Study: El Fayoum Depression, Egypt.

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Estimation of salt balance in salt-affected ecosystems in arid areas, Case Study: El Fayoum depression, Egypt

تقدير الميزان الملحي في الانظمة البيئية المتأثرة بالملوحة في المناطق الجافة "حالة دراسة :منخفض الفيوم- مصر"

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ملخص البحث:

تعاني معظم المناطق الزراعية بمحافظة الفيوم من مشكلة تدهور الإنتاج الزراعي كنتيجة طبيعية للمشاكل البيئية وأهمها إزدياد ملوحة قطاع التربة نتيجة لتبخر المياه الجوفية القريبة من سطح الأرض . وفي هذا البحث تم عمل ميزان ملحي لقطاع التربة للوقوف على أسباب وطرق حل هذه المشكلة البيئية. تبين من نتائج البحث أن كمية الأملاح التي تدخل قطاع التربة تصل إلى 2.48 مليون طن سنوياً بينما الكمية التي تفقدها التربة تصل إلى 3.8 مليون طن سنوياً مما يعكس وجود كمية أملاح بقطاع التربة تقلل من إنتاجية الفدان وتتسبب في تدهور الأرض الزراعية . وعليه توصي الدراسة بإتباع أساليب الصرف الحديثة لتقليل الأملاح الناتجة عن الصرف الزراعي بالطرق التقليدية.

Abstract

El Fayoum depression is a semi-closed depression located about 100 Km southwest of Cairo-Egypt It occupies an area of about 1200 Km^2. Due to the complex geological and hydrological conditions of that area, water logging problem and soil salinization affect great parts of the cultivated areas. The geological conditions are manifested in the rich content of clay in the Quaternary aquifer, the relative small aquifer thickness and the dominance of faulted and fractured limestone at the base and on the peripheries. On the other hand, the hydrological conditions include the occurrence of a thick net of irrigation system and presence of huge surface water bodies; e.g. Qarun lake and Wadi El Rayan lakes. Moreover, the groundwater depths vary from few centimeters below ground surface to 7.51 m which reflect a critical soil salt-affected problem. The present paper throws light on the salt balance of the groundwater regime. The estimation of the input and output components is carried out based on the field measurements during 2006. The estimated mean annual salt influx reaches 2.05 million tons. The Output component includes the salt efflux through the drainage network, subsurface groundwater flow and the salinity losses due to plant uptake. The estimated annual mean value of salt efflux from these three components reaches 3.8 million tons. The average annual storage component is estimated to be -1.75 million tons. The estimation of salt balance shows that the groundwater or/and soil water receive an excess of annual salt content of 1.75 million tons due to leaching process of evaporites and clay lenses during its flow from the upstream till it reaches the downstream area (Qarun Lake). Mitigation of imbalanced salt load through minimizing the losses from drainage network and using low consumed cop pattern is highly recommended.

Keywords:

Hydrogeology- Water logging-Salt influx-Salt efflux-El Fayoum depression

1. Introduction

The concerned area is located southwest of Cairo city by about 100 km and northwest of Beni Suef by about 30 km (Fig. 1). It is limited between latitudes 29° 00\ and 29° 30\ North and longitudes 30° 20\ and 31° 10\ East with an area of about 1200 km^2. This area is characterized by arid climate. The mean temperature records 36 °C in summer and 20 °C in winter. Rainfall is relatively low. The mean annual rainfall depth is 10

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mm. The maximum mean evaporation intensity reaches 306 mm (in July).

Geomorphological setting

Geomorphologically, three geomorphic units characterize the surface of El Fayoum depression and its vicinities. El Fayoum depression is bounded by tablelands from east, south and west, separating the depression from the Nile Valley and Wadi El Rayan depressions (Tamer 1968). These tablelands include Gisr El Hadid (50 masl) and Gebel El Lahun- Gebel El Naalun (150 masl).The morphtectonic depressions include Nile Valley depression (25 masl), El Fayoum depression (-45 masl) and Wadi El Rayan depression (-60 masl). The great monoclinal edge (Gebel Qatrani 400 masl) bounds El Fayoum depression from north and northeast (Abdel Baki 1972). It is characterized by dry shallow wadies directed towards Qarun Lake (QL). The depression surface is characterized by dense network of irrigation and drainage canals besides the great natural QL while sand sheets and artificial lakes distinguish Wadi El Rayan depression.

Geological setting

Geologically, El Fayoum depression and its vicinities are occupied by a surface sedimentary section of about 484 m thick belonging to Tertiary and Quaternary rocks (Said 1962; Tamer 1968; Tamer et al. 1975; Awad 1984). Tertiary rocks include Eocene, Oligocene, Miocene and Pliocene rocks (Fig. 1). They form the surrounding walls of El Fayoum depression and sometimes appear in the bottom of the deep grooves inside the depression. These rocks consist mainly of limestone, marl and shale with basalt and sandstone in the northern, western and southern margins of the depression while Quaternary deposits develop into the form of aeolian, nilotic and lacustrine deposits. Sand and clay facies are dominating most of the depression area. Folding and faulting are the common structural elements in the study area. NE-SW surface anticlines were detected in Wadi El Rayan and north QL. In addition, NW-SE faults (Clysmic trend), NE-SW faults (Aqaba trend) and E-W faults (Mediterranean trend) are recognized at the depression (Tamer et al. 1975).

Hydrogeological setting

The hydrogeological conditions of El Fayoum depression were the object of many studies such as (Abdel baki 1972; El Hakeem 1977; Himida and Abdel Baki 1980; El Diftar 1983; Desert Research Institute 1986; Dahab 1986; Tamer and Faheem 1987; Diab and Shided 1999; El Sheikh et al. 2008). Based on these studies, there are three aquifers in El Fayoum area, the Quaternary Aquifer of El Fayoum Depression (QAFD), Fissured Eocene aquifer and Nubia sandstone aquifer. The QAFD is dissected by a network of irrigation canals and drains. The total length of the irrigation canals reaches 1306 km and transports 2680 million m^3/year (El Sheikh 2005). In addition, drainage canals consist principally of two large drains (El Wadi and El Bats drains) besides a group of short drains. The total length of these drains reaches 154 km and transports 963 million m^3/year of drainage water to both QL and Wadi El Rayan lakes. Surface water constitutes the main recharging source for groundwater due to both the dense of irrigation canals and flood irrigation system. The QAFD is generally composed of sand with rich content of clay (Fig. 2).

However, it is more gravelly at west. Towards east four layers are well recognized, silty clay layer at the top and sandy clay layer in the middle, while sand and clay intercalations characterize the bottom with high fossil content. The clay facies increase towards QL and become calcareous in the lower part. The clay-rich content sediments in the northern and eastern directions decrease the vertical movement of seepage water and consequently water logging creation in addition to the Eocene marl and limestone which form the base of the QAFD. The maximum thickness of QAFD is present in the center of the depression (Sanhour-Ibshiway area) where it reaches 40m while the minimum thickness is present along the peripheries due to local faulting. QAFD is characterized by low transmissivity values all over the depression area (from 13 to 84 m^2/day, El-Hefnawy et al. 2006). These values indicate low groundwater potentiality of the QAFD. The water balance of the QAFD during the hydrologic year 2004/05 shows an imbalance between the outflow components and the inflow components by 70.2 million m^3 which may be attributed to the upward leakage from the deep aquifer through fault zones (El-Sheikh 2005).

In the other hand, the fissured Eocene limestone aquifer extends under the QAFD. It is composed of limestone marl and clay. Groundwater of this aquifer appears as springs issued in some places. In addition, the Nubia sandstone aquifer is composed of sandstone and shale of Cretaceous age. It is not exposed in the area of study but reported in the subsurface succession at Wadi El Rayan. The Nubia formations are generally characterized by relatively high hydrostatic pressure (Himida and Abdel Baki 1980). The mineral springs of Wadi El Rayan are flowing at a dynamic level of 25 masl where their water are originated from the Nubia sandstone aquifer. Their water salinity ranges between 3500 to 8000 ppm (Faiad 2000). Nowadays QL level continuously rises causing the formation of strip of water logged area parallel to its southern shoreline. *The mathematical solution of the general equation of the salt balance for any hydraulic closed system is used in this paper to mitigate the soil water salinization and water logging problems in the QAFD.*

2. Materials and methods

The materials used in this paper were collected through carrying out four field trips in El Fayoum depression area during the period 2005-06. During these field trips, a network of 21 observation wells penetrating the QAFD was constructed. Among them, 18 piezometers were drilled during the year 2005 by Desert Research Center, while the rests were drilled by the stockholders. The location of these observation wells was given in (Fig. 1). Periodic depth to groundwater level was recorded in 18 observation wells during Oct. 2004 and July 2006 (Table 1) and characteristics of soil water salinity problem and its spatial and temporal variation, as well as its future behavior, was thoroughly investigated by periodic chemical analysis of collected water samples.

The methodological approach used in this paper is based on the mathematical solution of the general equation of the salt balance for any hydraulic closed system. The salt balance of the soil water zone in any irrigated lands depends on the assumption that, all salts are soluble and not precipitate. The general equation for salt balance estimation can be written as;

Soil water salt influx = Soil water salt efflux + Change in soil water salinity

All components that comprising salt influx and efflux depend on the quantities of water entering and flowing out from the soil zone multiplied by its salinity. Accordingly, the equation for the estimation of salt balance in an irrigated area can be expressed as (ILRI 1994);

$$I.C_i + E.C_i + R.C_r + G.C_g = ET_c . C_i + D.C_d + P.C_p + \Delta S \quad \ldots\ldots 1$$

Where;

I, E, R, G, ETc, D and P are the quantity of water due to irrigation, evaporation, rainfall, upward flow, evapotranspiration, subsurface flow and deep percolation, respectively (L^3T^{-1}). C is the salinity of water (ppm) and the suffix i, r, g, d and $_p$ refer to salinity of irrigation water, rain water, groundwater, drainage water and deep percolation water, respectively. $I.C_i$ and $E.C_i$ represent the salt influx due to irrigation and evaporation from the shallow water table or surface water bodies. $R.C_r$ and $G.C_g$ are the salt influx resulted from rainfall and upward flow of groundwater. Due to the scarcity of rainfall and presence of impermeable beds beneath the soil zone in QAFD, both elements can be neglected. $ET_c .C_i$ and $D.C_d$ are the salt efflux due to plant evapotranspiration and subsurface flow to the drains. $P.C_p$ is the salt efflux due to deep percolation from the soil zone. For the studied area, the $P.C_p$ element is excluded (Gad and Abdel-Baki 2002).

Δ S is the change in the soil salt storage.

3. Results and discussion

According to the groundwater level measurements (Table 1), water table maps at Oct.2005 and July 2006 were constructed (Fig. 3). These maps show that the groundwater flows generally from south to north and northwest directions. The groundwater levels decrease from south and southeast towards west and northwest i.e. from 15 masl and 20 masl to – 40 masl close to QL. The curvature of contour lines relative to the directions of the irrigation network indicates that the canal network acts as influent streams (recharge areas) in southern part, while it operates as effluent streams (discharging areas) in the northern part. Moreover, there is a remarkable rise in groundwater levels in the western part of the depression area indicated by the concentric contour lines. This local rise may result either from the downward seepage from the irrigation water or the upward leakage from underlying fractured limestone aquifer (Gad and Saafan 2006). According to (Saafan et al. 2009) QAFD receives about 56 million m^3/year of return flow after irrigation and/or upward leakage from underlying aquifers, causing the continuous rise in the groundwater levels. The fissured Eocene limestone aquifer; extending under the QAFD inside the depression, considers the source of upward leakage since its groundwater appears as springs issued in some places as mentioned before. In addition, viewing ILRI's equation and neglecting the non-represented components, the salt balance equation for the soil zone of QAFD can be written as follows (Gad and Abdel Baki 2002):

$$(I.\ C_i) - (D.C_d + GW.C_g + ET_c .\ C_i) = \Delta S \quad \ldots 2$$

Estimation of mean salt influx ($I.\ C_i$)

As mentioned before, the main salt influx enters the QAFD from the irrigation water network (Fig. 4-left map). The irrigation canals in El Fayoum depression have a total length of about 1306 Km, transferring about 2680 million m^3/year of the Nile water to the depression that serving an area of about 399677 feddan of cultivated land (Table 2). This amount enters El Fayoum depression through Bahr Yousef, the main channel across El Lahun regulator at the southeast. Referring to (Table 2) and (Fig. 4-left map), the old cultivated land of QAFD comprises the presence of 399677 feddan that consume 2680 million m^3/year through 347 canals. A part of this amount infiltrates to the soil zone, from which the subsurface inflow component takes place. The other part seeps directly to the lakes through drainage network. Concerning the average salinity of irrigation water C_i that equals 768 g/m^3 (Table 3); so

The mean salt influx ($I. C_i$) = 2860 x 10^6 (m^3/year) x 768 g/m^3 = 2058240 x 10^6 g/year that means 2058240 tons of salts enters the QAFD.

Estimation of mean salt efflux

The main salt efflux includes the fluxes due to drainage water, subsurface outflow (groundwater seepage to QL) and plant evapotranspiration. The estimation of every component is given in the following.

1-Estimation of mean drainage water salt efflux ($DW. C_d$)

The drainage network consists principally of two large drains, El Bats and El Wadi drains besides a group of short drains (Fig. 4-right map). The drainage network transports 962 million m^3/year both to QL and Wadi El Rayan depression at west, resulting of huge lakes. The total length of El Fayoum drains attains 154.37 Km, serving an area of 433435 feddan (Table 4). Referring to (Table 4) and (Fig.4-right map), the old cultivated land of QAFD comprises the presence of 155 km of open drains transferring a quantity of drainage water estimated as 963 million m^3/year (El sheikh 2005). The salinity of these drains ranges between 1713 mg/l to 3601 mg/l with an average value about 2583 mg/l. Concerning the average salinity of drainage water C_d that equals 2583 mg/l or 2583 g/m^3, the mean salt efflux resulted from the drainage water can be estimated as follow;

($DW. C_d$) = 963 x 10^6 (m^3/year) x 2583 g/m^3 = 2487429 x 10^6 g/year

This means that 2487429 tons of salts eliminated from the soil of the QAFD and enter Qarun and Wadi El Rayan lakes causing intensive salinity rise problem.

2- Estimation of mean groundwater salt efflux ($GW. C_g$)

QL borders the QAFD from north forming a natural discharging area. Groundwater seeps to the lake by gravity. Darcy's equation is applied to estimate the quantity of groundwater recharges the lake.

$Q = KAI$ …………………....3

Where; Q is the quantity of water (m^3/day), K is the hydraulic conductivity (m/day), A is the front area (m^2) and I is the hydraulic gradient (dh/dl). A groundwater level contour map is constructed to estimate the average hydraulic gradient against the QL (Fig. 5). The hydraulic gradient is estimated as 0.0039. The hydraulic conductivity and the front area are equal to 3.3 m/day and 400,000 m^2 respectively (Elsheikh 2005). Therefore, the amount of groundwater seeps to QL from the QAFD is estimated as 1.879 million m^3 through the measurement year. According to the average salinity of groundwater in the area adjacent to the QL as estimated from the chemical analysis of the collected groundwater samples from the adjacent piezometers (Fig. 6 and Table 5), the average salinity of the groundwater ranges from 13248 to 45100 mg/l with an average value of about 32037 mg/l. Considering the quantity of groundwater seeps out from the QAFD to QL as 1.879 million m^3/year. As a result, the mean salt efflux resulted from the groundwater seepage can be estimated as follow;

($GW. C_g$) = 1.9 x 10^6 (m^3/year) x 32037 g/m^3 = 3870.3 x 10^6 g/year

This means 3870 tons of salts eliminated from the soil of the QAFD and enter QL causing intensive salinity rise problem of the lake.

3-Estimation of mean evapotranspiration salt efflux ($ET. C_{et}$)

The third component concerning the salt efflux is the evapotranspiration ($ET_c . C_i$). Due to the dense cultivation of El Fayoum depression, huge quantity of water is discharged from the QAFD by means of evapotranspiration. The mean evapotranspiration of the crop unit in QAFD was estimated depending on Penman-Montith method (Smith 1992).

The mean value of the consumptive use of each crop is multiplied by its cultivated area to give the total consumptive use of this crop (Table 6). Accordingly, the total crop unit consumptive use of the QAFD was estimated as 1715.59 x 10^6 m^3/year. As a result, the mean salt efflux resulted from the evapotranspiration can be estimated as follow;

(ET. C_{et}) = Total crop unit consumptive use x salinity of irrigation water = 1715.59 x 10^6 (m^3/year) x 767.9 g/m^3 = 1317401.6 x 10^6 g/year

This means 1.3 million tons of salts eliminated from the soil of the QAFD by the different cultivated crops in the depression.

Estimation of storage parameter (∆ S)

The difference between salt influx and efflux equals the storage factor. The estimated net result of the salt influx and the salt efflux of the old cultivated lands during hydrologic year 2005/2006 refer to;

Mean annual salt storage= Mean annual salt influx - Mean annual salt efflux = 2.48 million tons - 3.8 million tons = -1.75 million tons

Accordingly, the estimated salt balance of the soil water in the QAED shows that the annual mean of the salt influx reaches 2.48 million tons while the annual mean of the salt efflux reaches 3.8 million tons with an annual average storage of magnitude 1.75 million tons. These figures mean that every feddan in the studied area losses about 4.378 tons of salts every year (mainly sodium chloride) neglecting the effect of salt load increase due to upward of saline water from the underlain Eocene fractured aquifer. This decreases the sharp deterioration problem for these cultivated areas. Moreover, the probable decrease of salt load per feddan in winter than that in summer may attribute to the intensive agriculture activities in summer more than in winter. So, the change in crop unit may use in decreasing the deterioration problem. It is obvious that the system is imbalanced concerning salt loads where the output exceeds the inputs with more or less than twice. This imbalance may be attributed to the excess salt loads resulting from groundwater leaching process, dense drainage network and salt water encroachment from upward leakage from Eocene aquifer through fractures.

4. Conclusion and recommendations

The estimation of the salt balance in the soil water of the old cultivated land in QAFD (399677 Fed. with total water requirements 2.86 milliard m^3/year) during the hydrologic year 2006 exhibits that the average quantity of water entering the soil zone during the year 2006 reaches 2.86 milliard m^3, with average annual salt influx of magnitude 2.05 million tons. While the mean annual salt efflux from the soil water reaches 3.8 million tons. Accordingly, the following is recommended to mitigate the imbalance of salt loads:

1- The drainage network system must be changed to modern drainage system to minimize the losses and consequently, decrease the salt efflux since the mean salt efflux due to the drainage system (2.48 million tons) represents twice the mean salt efflux due to the evapotranspiration (1.3 million tons).

2- The crop unit must be changed into low consumed plants to decrease the salt efflux required for salt balance.

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Table 1: Ground elevation (masl), total depth of the observation well (m) and the groundwater levels (masl) in the QAFD during the period Oct. 2004-July 2006

ID	Locality name	Location		G. elev. (masl)	T.**D** (m)	October 2004*		October 2005		July 2006	
		Lat.	Long.			DTW (m)	WL (masl)	DTW (m)	WL (masl)	DTW (m)	WL (masl)
P1	Sobeh	29 24 29	30 31 31	-41.64	3	0.95	-42.59	0.60	-42.24	0.77	-42.41
P2	Rawashda	29 23 34	30 36 44	-18.21	4	0.76	-18.97	0.62	-18.83	0.93	-19.14
P3	Hana habib	29 20 39	30 34 01	8.23	6	0.55	7.68	0.45	7.78	0.61	7.62
P4	AboGabal	29 20 02	30 37 04	6.71	4	1.25	5.46	1.12	5.59	1.38	5.33
P5	Miqrani	29 16 54	30 38 47	-1.66	5	0.98	-2.64	0.78	-2.44	1.03	-2.69
P6	Abo Gandir	29 15 03	30 40 09	5.23	7	0.31	4.92	0.30	4.93	0.44	4.79
P7	Al -Prince	29 09 54	30 37 16	8.95	7	2.54	6.41	2.48	6.47	2.89	6.06
P8	Al-Hagar	29 08 04	30 38 41	9.2	4	0.70	8.50	0.80	8.4	0.95	8.25
P9	Tatoun	29 09 10	30 47 50	14.35	7.6	0.42	13.93	0.41	13.94	0.56	13.79
P10	Al-Wabor	29 11 47	30 45 28	14.83	2.5	0.03	14.80	0.10	14.73	0.41	14.42
P11	Al-Azab	29 15 11	30 50 33	20.03	3.7	1.15	18.88	----	----	0.95	19.08
P12	El-Khatib	29 18 11	30 44 19	17.52	3	0.42	17.10	0.50	17.02	0.51	17.01
P13	Tobhar	29 18 19	30 49 08	21.34	5	0.38	20.96	----	----	0.42	20.92
P14	Ibshiway	29 21 38	30 40 32	0.25	7	1.68	-1.43	1.14	-0.89	2.1	-1.85
P15	El-Celein	29 22 40	30 47 23	15.65	44	7.30	8.35	7.20	8.45	7.98	7.67
P16	Oberge	29 28 01	30 46 32	-42.2	6	1.72	-43.92	1.33	-43.53	1.48	-43.68
P17	Tadrus	29 28 40	30 51 29	-33.15	5.5	0.70	-33.85	----	----	0.78	-33.93
P18	El-Kaabi	29 22 03	30 51 54	17.8	6	0.55	17.25	0.45	17.35	0.57	17.23

G. elev. = Ground elevation (masl), DTW = Depth to groundwater (m), WL = Absolute groundwater level in masl, October 2004* = The source data from (El Sheikh, 2005)

Table 2: Numbers and lengths of the irrigation canals in El Fayoum depression

Locality	Depression part	Canals		
		number	Length (Km)	Area service (Feddan)
El Fayoum	Middle part	62	269.50	73794
Sinnuris		54	207.42	54732
Tamia	Eastern part	44	157.25	75325
Ibshiway	Western part	116	416.84	97344
Etsa	South part	71	255.31	98482
Total		347	1306.32	399677

Table 3: Salinity of irrigation canals of El Fayoum depression

Canal name	pH	Total dissolved solids (mg/l)
B.Yousef	7.1	373
B.Hassan Wasef	7.5	503
B.El-Nazla	7.8	428
B. Qasr El-Banat	7.5	484
B.Wahby	6.9	472
B.Shalat	7.7	336
B.Arus	7.7	396
B.Sanhur	7.2	491
B.Rafaa	7.8	1647
B.MishiIk	7.8	1181
B.Awlad Mahmou	7.2	580
B.Feddmin	6.9	526
B.Ibshiwy	7.3	544
End-Nazla	7.3	1206
Tirit El-Gomhorya	7.5	2037
B.Qouta	7.2	1950
B.Tersa	7.4	772
B El-Gharaq	7.1	516
B.El-Kaabi	7.5	556
B.Shahla	7.5	360
Average		767.9

Table 4: Salinity, lengths and area served of drainage canals in El Fayoum depression

Drain name	Down stream	Length (Km)	Area served (Fadden)	Ph	Salinity (mg/l)
El Batts	Qarun lake	50.848	136800	7.5	1556
El Wadi	Qarun lake	48.51	17500	7.4	2207
Abu Harawa	Qarun lake	7.550	2500	7.4	2987
Batts Said	Qarun lake	4.754	800	7.4	1713
Abu Tarfaya	Qarun lake	6.270	1600	7.10	2137
Hurr El Hitan	Qarun lake	3.810	1363	8.2	3025
Hodoud Tersa	Qarun lake	9.700	1200	7.3	4436
El Sheikh Allam	Qarun lake	7.631	8600	7.3	3142
Hodoud Ibshiway	Qarun lake	9.400	3300	7.2	3601
El Misharrik	Qarun lake	7.123	2000	6.5	2325
Al Eslah	Qarun lake	8.560	629	8.2	3025
El Hamam	Qarun lake	4.265	2500	7.7	2287
Battn Ihreet	Qarun lake	8.910	6000	7.10	2137
Quta drain	Qarun lake	8.358	1160	6.9	2083
Wadi El Rayan	Wadi El Rayan lakes	15.80	-	6.9	2083
Total		154.73	433435		
Average					2582.9

Table 5: Piezometers used to measure the salinity of groundwater near Qarun lake

Serial No.	Locality name	pH	Salinity (mg/l)
P1	Sobah	7.2	17408
P2	Rawashda	8.2	52392
P16	Oberge	6.3	45100
P17	Tadrus	7.2	13248
Average			32037

Table 6: Total crop unit consumptive use in the QAFD (After Elsheikh 2005)

Crop type	Season	Crop unit consumptive use (m^3/feddan) (Penman - Montith method, Smith 1992)	Crop area (feddan)	Annual crop unit consumptive use (million m^3)
Wheat	Winter	2060	46000	94.76
Broad bean	Winter	1862	60000	111.72
Berceem	Winter	2308	144892	334.42
Medical & aromatic	Winter	1719	7177	12.34
Barley	Winter	1730	13183	22.81
Fenugreek	Winter	1254	3550	4.45
Beat Sugar	Winter	2265	7367	16.69
Vegetables	Winter	1041	34150	35.55
Onion & Garlic	Winter	1758	70136	12.37
Cotton	Summer	3800	25000	95.00
Sycemum	Summer	2597	4739	12.31
Ground Nuts	Summer	3093	1325	4.10
Medical & aromatic	Summer	3487	7202	25.11
Maize	Summer	2729	45000	122.81
Sunflowers	Summer	3118	13430	41.88
Sorghum	Summer	3042	60000	182.52
Vegetables	Summer	2644	134818	356.46
Rice	Summer	5391	15000	80.87
Sun flowers	Nili	3118	1010	3.15
Maize	Nili	1947	3893	16.34
Sorghum	Nili	2097	1075	2.25
Vegetables	Nili	1520	43276	65.78
Citrus trees	Annual	2662	22203	59.10
Sugar Cane	Annual	8249	343	2.83
Total				1715.59

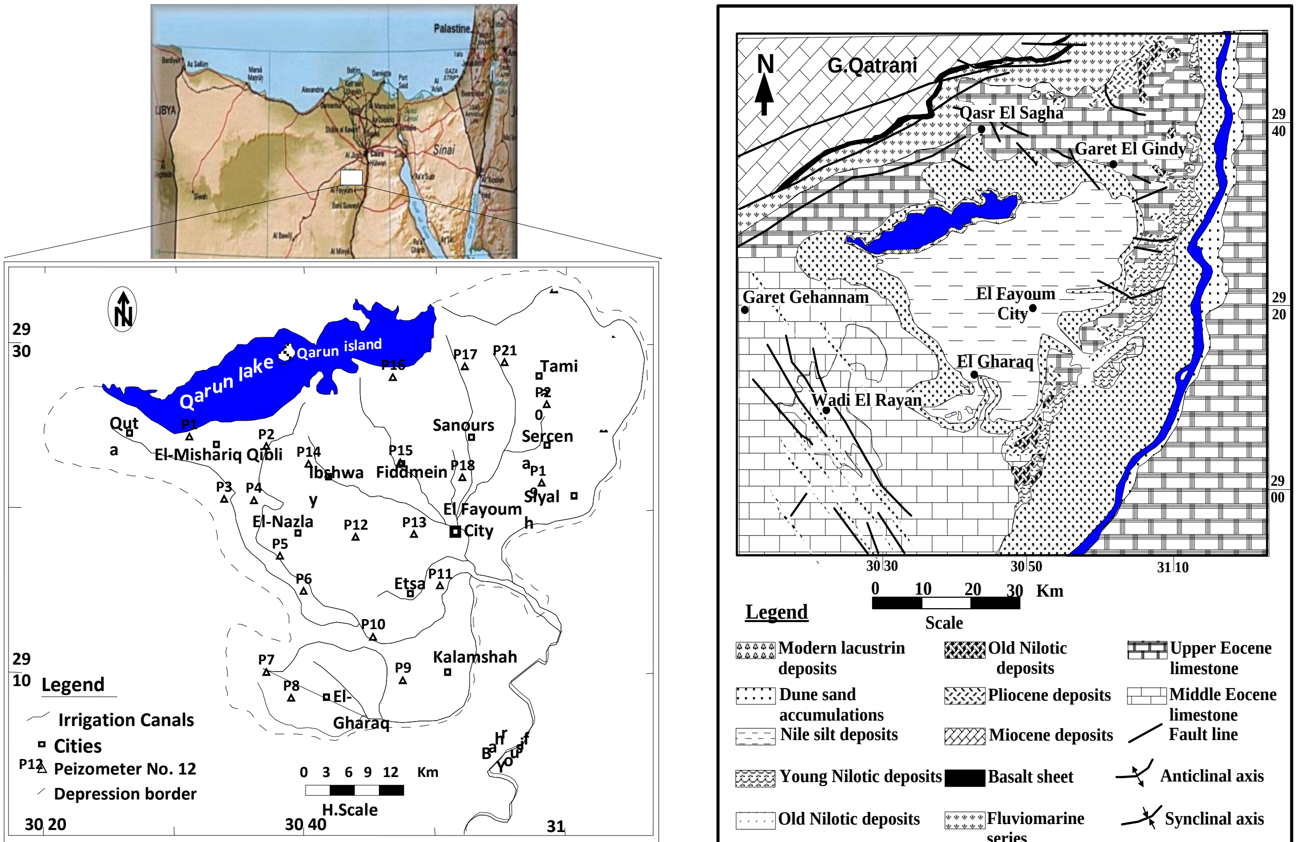

Fig.1: Key map showing the irrigation system and the location of the drilled observation wells (left map) and the Geological setting of the study area (right map)

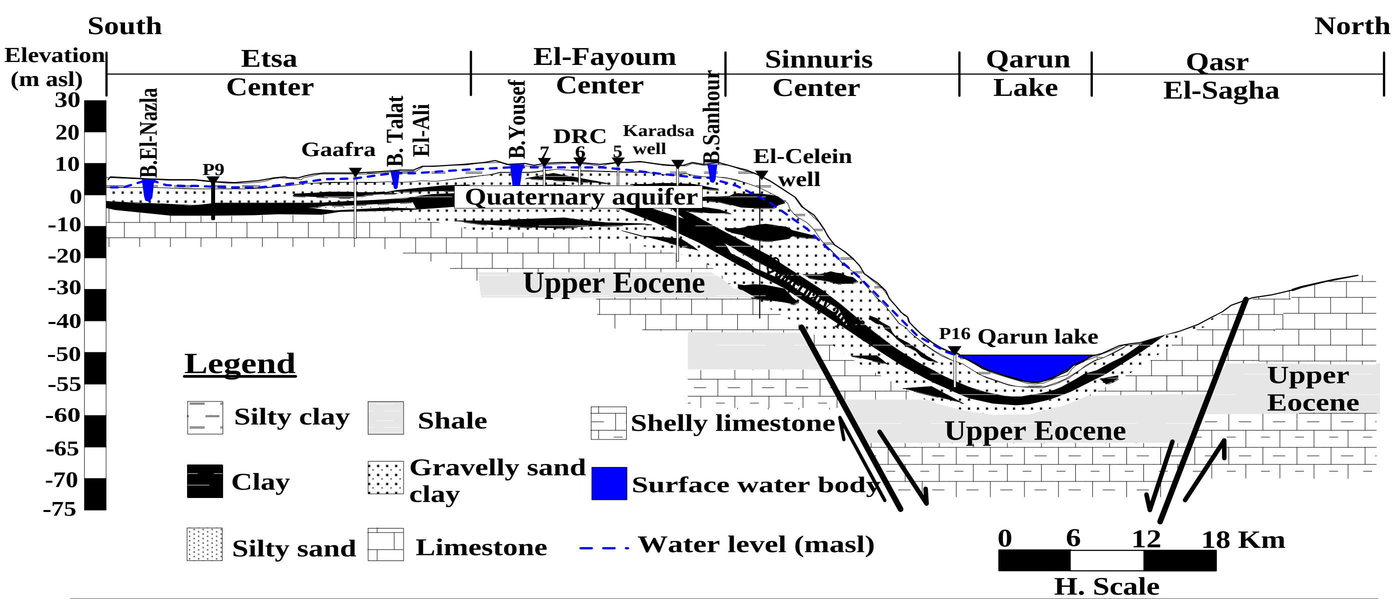

Fig. 2: Hydrogeological cross section in N-S direction along the QAFD (after El Sheikh, 2004)