SALINIZATION OF SHALLOW WATER AQUIFER IN EL- QAA COASTAL PLAIN, SINAI, EGYPT

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ABSTRACT:

El-Qaa coastal plain Quaternary aquifer lies on the eastern coast of the Gulf of Suez and represents the only source of fresh water in this arid region. This aquifer has good storage capacity and receives appreciable recharge. It discharges along a narrow strip that is open to the sea, either to the coastal sabkha or as underflow to the Gulf of Suez. The concentrated natural discharge keeps balance and prevents seawater intrusion. Hydrochemical mapping of natural and actual conditions showed four natural zones and two grades of salinization in the shallow ground water at seaside part of the aquifer. The variations of salinity among natural zones are caused by variations in recharge conditions, intensity of flow and lithology. The fresh water zone is extending along the best recharge and hydraulic conductivity conditions.

The conventional hydrogeological methods, hydrochemical indicators and ratios as well as stable isotope have been used to identify the source of salinization. Salinization is affected mainly by the changes in the ground water flow system and hence dissolution of salts and leaching of stagnant old saline water in the coral reefs body. Seawater intrusion has limited contribution to salinization. It is observed clearly only in one well, which is situated about 150 meters from the seashore. The hydrochemical indicators and ratios in this well are similar to that of seawater, and its isotope composition refers to recent recharge. We propose drilling new test boreholes to clarify the aerial distribution of lithology and the variations of salinity with depth. These information are necessary to propose new network of monitoring wells to monitor the changes in ground water quality and protect the aquifer from further deterioration.

INTRODUCTION AND OBJECTIVES

El-Qaa plain Quaternary aquifer lies on the eastern coast of the Gulf of Suez, South Sinai, Egypt. The high Pre-Cambrian crystalline basement terrain bounds it from the East (fig. 1). It consists mainly of alluvial deposits of high storage capacity and receives appreciable amounts of recharge from the surrounding eastern mountains. This aquifer is the only source of low cost fresh water in the region. The main well field that supplies El-Tor and Sharm El-Sheikh Cities by drinking water lies in the fresh water zone and at about 5 to 10 km from the seashore.

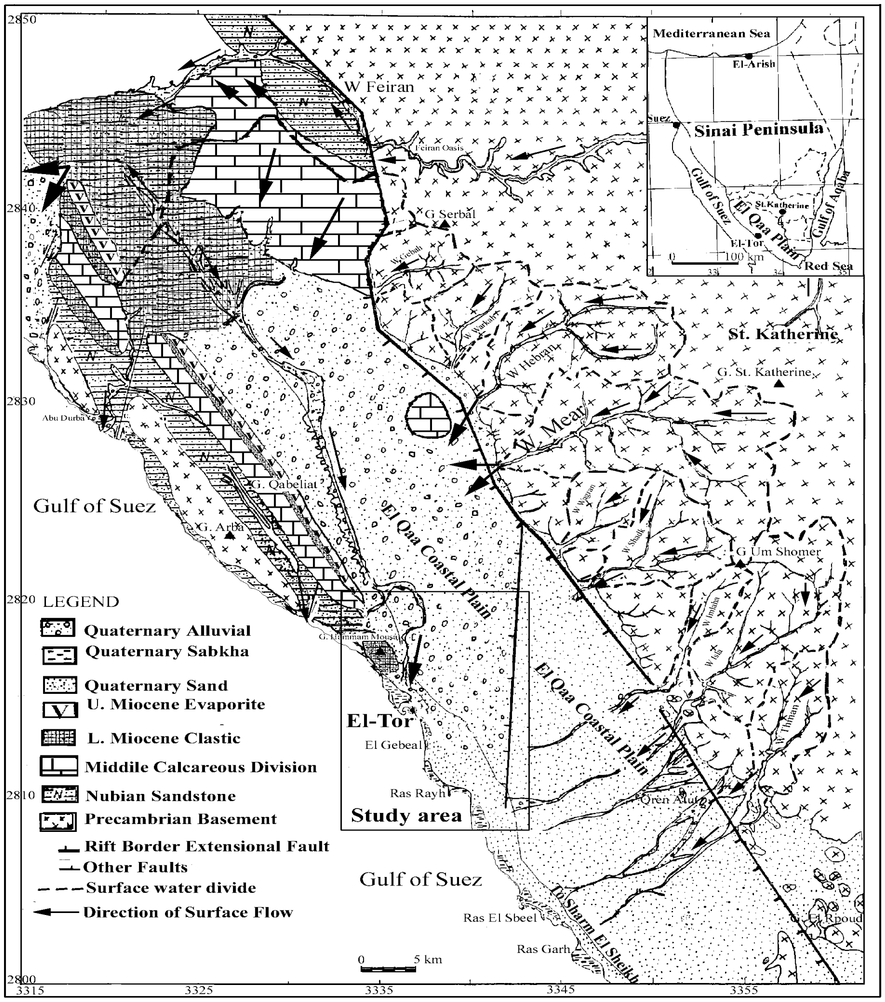

Figure 1: Location and geologic map of the study area (geology modified after EGSMA, 1993)

Moreover, it sustains the agricultural projects and other activities in the region by their water needs.

Recently we observed salinization (increase in the concentration of the dissolved salts in water than their initial values given by Gilboa 1972) of the aquifer especially near the Gulf of Suez. This article is concerning with the salinization of the seaside part of the shallow aquifer in El-Qaa coastal plain. These results are part of comprehensive study concerning with management and protection of ground water resources in the whole aquifer. The main objectives of this piece of work are to show the aerial extension of the initial salinity and salinization zones, identification of sources of salinization and recognition the relations between hydrochemistry and ground water flow system.

The area of interest (seaside) is occupied by El-Tor City and is developed mainly by dug wells. These wells are randomly distributed without systematic network of monitoring. Absence of observation wells and Uncertainty of measuring water level in exploitation wells. The aquifer lithology consists mainly of marine sandstone, limestone, coral reefs, and clay alternating with continental sabkha and alluvial deposits. Because of the above factors we relied mainly on the hydrochemical approach to tackle the problem.

GEOLOGY AND REGIONAL HYDROGEOLOGY

El- Qaa plain is bounded from the East by high mountainous Pre-Cambrian crystalline basement complex that is a part of the Arabian-Nubian shield. The basement complex has high relief of elevations range from 300 to about 2641-m amsl at St.Katherine Mount. The area has arid climatic conditions with scarce precipitation. The direct rain over the outcrops of El- Qaa plain Quaternary aquifer is about 10 mm/y and reaches about 60 mm/y over the high surrounding basement rocks with heavy storms producing floods every few years. There are about ten main wadis (dry rivers) dissecting the basement terrain and draining their water via El-Qaa plain.

The Gulf of Suez is the north-western arm of the Red Sea rift system. The rift is bounded by major border extensional fault (Said 1990). El-Qaa plain is a secondary rift basin accompanied the main rift system in the Gulf of Suez. Most of the wadis dissecting the basement complex are straight, narrow of steep wall indicating structural control (fig. 1). Continuous subsidence in El-Qaa basin have been caused the accumulation of more than 1000 m of post Miocene deposits of alluvial facies. The region has four aquifer and three aquitard units (fig. 1). The aquifer units are Quaternary alluvium, Pre-Cambrian fractured basement, Lower Miocene clastics and Nubian Sandstone successively according to their importance in El-Qaa region. The aquitard units are Massive Basement, Middle Calcareous Division, and Upper Miocene Evaporites. The precipitation that falls on the fractured basement represents the main source of recharge for the Quaternary aquifer. The rainwater infiltrates through the fracture systems to the wadis that act as local discharge channels.

The wadis eventually transfer both surface and subsurface water to El-Qaa plain. Lower Miocene rocks outcrop near El-Tor. They bound the Quaternary aquifer from the West. These rocks consist mainly of anhydrite, gypsum and halite. Therefore, groundwater discharge near El-Tor City has high salinity (salinity of Hammam Musa spring is about 8000 mg/L).

SAMPLING AND METHODS

About thirty-two water samples were collected on two times in Jan. 1999 and Apr. 2000 from the whole aquifer. In the first run, we sampled for performing a complete chemical analysis of the major ions and trace elements. The results of the first run oriented us in the second run to collect samples representative for the different hydrochemical zones and performing analyses for specific indicators as well as sampling for isotope analyses. The measured variables were the following: electrical conductivity (EC), pH, temperature, and alkalinity (measured in the field); the major cations (Ca, Mg, Na, and K), the major anions (SO_4, and Cl), and the total dissolved solids (TDS). The following indicators N-NO_3, F, Br, B, Li, and Sr. as well as stable isotopes of oxygen and hydrogen, the ^{18}O and deuterium (D) were measured for selected water points.

In order to process and interpret the results, we used the traditional graphical methods (mapping and hydrogeologic cross-sections) as well as hydrochemical and stable isotope indicators. The indicators Cl, Sr, Li, B and the ratios Cl/Br, B/Cl, Na/Cl, Mg/Ca,

SO_4/Ca, Sr/Ca, $Na/(Na+Ca)$, $Cl/(Cl+HCO_3)$ and BEX were used. Strontium (Sr) is geochemically similar to calcium (Ca), the concentrations in most ground water of both Strontium (Sr) and Boron (B) range between 0.01 and 1.0 ppm, whereas Lithium (Li) concentrations range between 0.001 and 0.5 ppm, higher concentrations for Sr, B, and Li are expected in drier conditions (Davis and DeWiest, 1966). The ratios Cl/Br, B/Cl, Na/Cl, Mg/Ca, SO4/Ca, Sr/Ca, Na/(Na+Ca), Cl/(Cl+HCO3) were previously identified to differentiate between sources of salinization (Starinsky et al 1983; Richter et al 1990; Vengosh and Rosenthal 1994; Davis et al 1998). The Base EXchange index, BEX, was defined as follow: BEX= {(Na+K+Mg in meq/L) – 1.076 Cl in meq/L} (Stuyfzand 1993 cited in Stuyfzand 1999). Significantly positive sign of BEX indicates freshening and significantly negative sign indicates salinization and value near zero occurs at equilibrium (Stuyfzand 1999).

HYDOGEOLOGIC SETTING OF THE QUATERNARY AQUIFER

The Quaternary aquifer extends along El-Qaa plain. It is bordered from the East by Pre-cambrian crystalline basement that acts as recharge boundary along the wadi outlets and no flow boundary from the rest (fig. 1). The aquifer is bounded from the south by fault barrier (no flow boundary) and from the northwest with Gebel Qabiliate (no flow boundary) and from the southwest with the Gulf of Suez (constant head boundary). The aquifer is developed mainly by dug wells along the seaside part and drilling wells in the eastern part. Distribution of wells is shown in figure 2. The rate of groundwater extraction is increasing, it was about 500 m^3/d in1930 extracted from three shallow wide aqueducts and few Bedouin dug wells (Attia 1930). It increased to about 3000 m^3/d in 1972 (Gilboa 1972) and becomes 26000 m^3/d in year 2000.

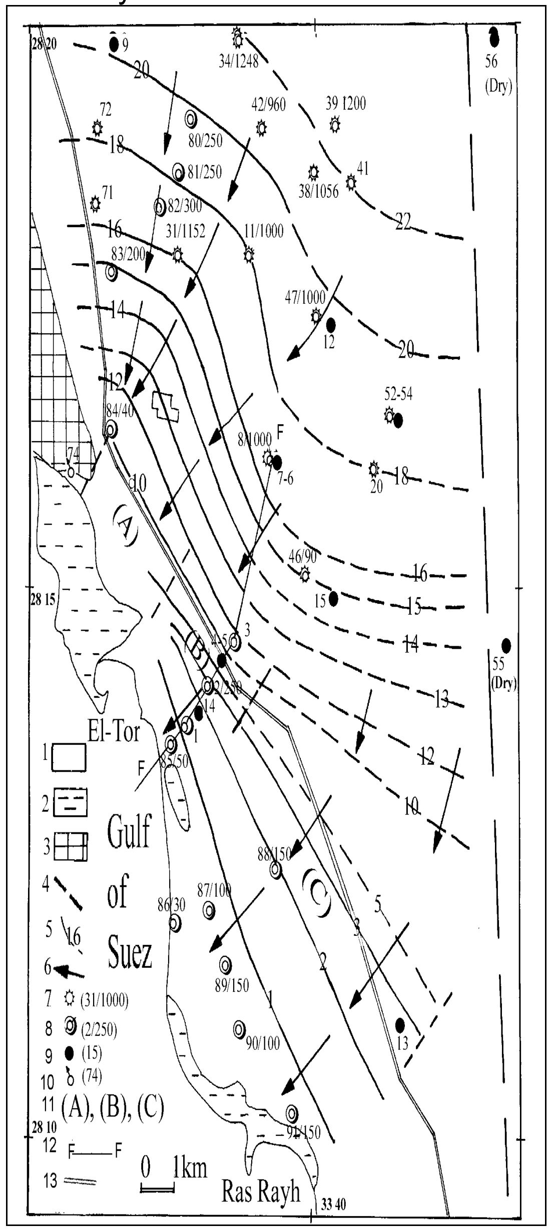

Figure. 2: Hydrogeologic map of the seaside part of the Quaternary aquifer.

1: Quaternary Aquifer, 2: Quaternary Sabkha, 3: Lower Miocene Clastic, 4: Fault boundary, 5: Equipotential lines (m amsl) as of 1972 dashed when it is interpolated, 6: direction of ground water flow, 7: drilled well (identification number/actual yield in m3/day), 8: dug well, 9: test borehole (identification number), 10: spring 11: natural discharge zones, 12: line of cross-section, 13: main road.

The eastern margin of the aquifer consists of sandy gravel and gravely sand that are typical for alluvial fan deposits of high hydraulic conductivity (about 50 m/day). While the sea-side margin is occupied by parallic sediments which consists mainly of limestone, coral reefs, and clay alternating with continental sabkha and alluvial deposits of lower hydraulic conductivity (about 5 m/day) (fig 6). The thickness of the aquifer is varied from about 100 to 400 meters in the East and decreases to about 30 meters in the West. The specific yield for this unconfined aquifer is about 0.2 for sandy gravel. The storage capacity of the aquifer is calculated for area of about 600 km^2 and average thickness 100 m to be about 12-milliard m^3.

The potentiometric map shows the ground water potentiometry and directions of ground water flow (fig. 2). In the discharge area there are three distinct zones of different hydraulic gradient. These are A, B and C of hydraulic gradient about 0.00395, 0.006 and 0.000775 successively (fig. 2). The hydraulic gradient is gentle in the northeast and become steeper near discharge at El-Tor City. The direction of ground water flow is from northeast to southwest. The flow lines have been discharging either to the coastal sabkha or as under-flow to the Gulf of Suez (fig. 2). In the discharge zone, hydraulic conductivity (k) is about 5 m/d and the thickness of the aquifer is about 30 meters. The natural discharge along 13-km front is calculated of about 6000 m^3/day. Gilboa 1972 calculated it in the same area for 10-km width of about 5500 m^3/day. Ground water level measurements show that the aquifer is under steady state where there is no distinct change in the static water level since 1972 till now and hence recharge is more than total discharge (32000 m^3/d).

HYDROCHEMICAL ZONES

The hydrochemical map was prepared using mainly the hydrochemical data given by Gilboa, (1972) and other initial data since drilling time as well as our data. Four initial hydrochemical zones and two zones of salinization were established (fig. 3). The initial hydrochemical zones were classified according to their total dissolved solids (TDS) into four classes: fresh, fairly fresh, brackish, and saline water zones. The aerial distribution of these classes is shown in figure 3. It is worth to mention that according to Piper definition of water types (Piper, 1944 cited in Macioszczyk 1987) all of these classes occupy the same location on his diagram and have NaCl-$CaSO_4$ type (ionic). Sodium (Na) and chloride (Cl) are the dominant cation and anion and both Ca and SO_4 accounts more than 20% of total equivalent concentration. In contrary according to water types using Sulin classification (cited in Macioszczyk 1987), they have Na_2SO_4, $MgCl_2$, and $CaCl_2$ types (genetic). Herein we will use ionic and genetic to differentiate between these two types. In the following is a description of the main characteristics of each class.

Class I (fresh water)

This class has low salinity, TDS range from 400 to 800 mg/L. It has NaCl-$CaSO_4$ ionic type and of Na_2SO4 and $MgCl_2$ genetic types respectively according to its abundance. It extends along the flow lines from the main recharge area (wadi Mear) until its natural discharge area (El-Tor). This means it receives higher amounts of recharge than other zones. Moreover, it is associated with alluvial fan facies of high hydraulic conductivity and hence relatively higher velocity of flow and good conditions for flushing of salts than other zones.

Class II (fairly fresh water)

The TDS of this class range from 800 to 1500 mg/L. It has NaCl-$CaSO_4$ ionic type and Na_2SO_4 and $CaCl_2$ genetic types respectively according to its abundance. It is diffusion zone between fresh and brackish water zones. Salinity is connected with low rate of recharge in the North and lithological variations in the South where it is associated with marine facies of relatively low hydraulic conductivity and high ratio of soluble salts.

Class III (brackish water)

The TDS of this class range from 1500 to 3000 mg/L. It has NaCl-$CaSO_4$ ionic type and Na_2SO_4 and $CaCl_2$ genetic types respectively according to their abundance. It is close to the saline water zone. Salinity is due to low rate of recharge and association in playa deposits that have lenses of clay and evaporites of soluble salts.

Class IV (saline water)

The TDS of this class has more than 3000 mg/L. New crystallized halite exists on the surface of its sabkha. They have NaCl- (Ca, Mg) SO_4 ionic type and of $MgCl_2$ genetic type. It is close to the Miocene evaporites. Salinity is rendered to low rate of recharge, lithology (derived mainly from the older evaporites) and presence of sabkha and playa deposits.

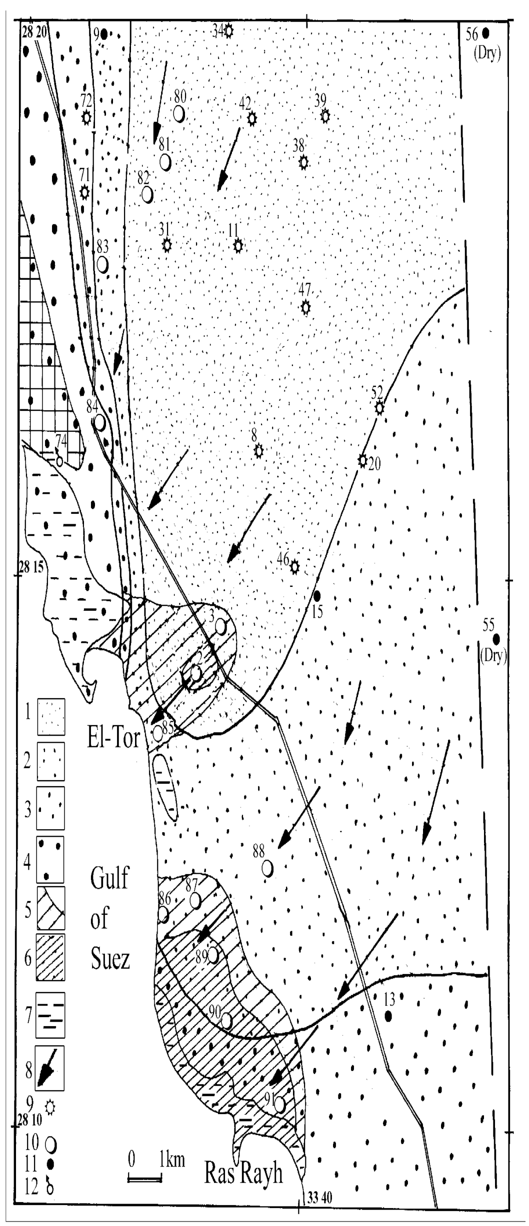

Figure 3. Hydrochemical map showing initial and salinization zones

1: fresh water TDS < 800 mg/L, 2: fairly fresh water TDS 800 – 1500 mg/L,3: brackish water TDS 1500 – 3000 mg/L, 4: saline water TDS > 3000 mg/L,5: zone of increasing salinity, 6: zone of sever salinization, 7: sabkha,8: direction of ground water flow, 9: drilled well, 10: dug well, 11: test borehole, 12: spring.

SOURCES OF SALINIZATION

We observed two grades of salinization in the seaside part of the aquifer (fig. 3). The zone of salinization (ZS) where the concentration of dissolved salts is increasing and the zone of severe salinization (ZSS) where the increase is four times the original value given by Gilboa (1972). These zones are close to the sea (Gulf of Suez), associated with coral reefs and evaporite deposits, in contact with sabkha deposits, and covered by El-Tor City. Therefore, we supposed that the probable sources of salinization include: (1) seawater intrusion, (2) dissolution of salts and old saline water from the stagnant zone in the coral reefs and sabkha, (3) Pollution from leakage in sewage system and septic tanks as well as agricultural refuse and (4) upward flow from deeper saline aquifer. In order to identify the main source of salinization hydrochemical compositions, ratios, stable isotopes of oxygen (^{18}O) and hydrogen (deuterium), lithology and ground water flow system we could.

The saline samples vary in their chemical and isotope compositions relative to fresh water (e.g. 78), sea water (GS) and Hammam musa water (HM) reflecting different sources of salinization (table1, fig. 4 and fig. 5). In all samples, there are high correlation between sodium and chloride. The fresh ground water (e.g. 78) and seawater (GS) form the end members of the Na-Cl trend and the saline samples are located in the middle. The equivalent Na/Cl ratio is varying from about 1 (halite ratio) in samples number 89 and 2 and about 0.86 (seawater ratio) in number 86 and less than 0.86 (0.77 to 0.6) in numbers 91, 90, 87, and 85. The influence of the sea as a main source of salinization is limited and clear only in well number 86. It has NaCl ionic type and $CaCl_2$ genetic type. Its Na/Cl and B/Cl ratios as well as Sr and Li compositions are similar to that of the sea and their BEX has significantly negative sign referring to salinization (table 1 and fig. 4). It is relatively enriched in both oxygen and deuterium (fig 5). This means there is recent recharge from the sea. It is worth to mention that this well is about 150 meters from the present day shoreline.

The other saline samples that have Na/Cl ratio about one or less than 0.86 as well as their Sr and Li compositions are higher than that of seawater and have positive BEX. They should have other source of salinization (table 1 and fig. 4).

Parameters	GS	No.2	No. 89	No. 86
TDS mg/l	44496	4189	10940	4720
Ca mg/l	512	521	864	228
Mg mg/l	1535	33	226	104
Na mg/l	13850	1050	2950	1290
K mg/l	420	5.5	59	44
SO4 mg/l	3384	885	1090	370
Cl mg/l	24663	1680	4800	2380
F mg/l	1.3	1.88	3.8	3
Br mg/l	84	7.5	13	10.2
B mg/l	4.5	0.96	1.82	0.5
N-No3 mg/l		12	5.4	12
Li mg/l	0.17	0.5	0.71	0.2
Sr mg/l	10	10.2	22.5	7.8
Cl/Br mg/l	293.6	224	369	233.3
B/Cl meq/l	0.0018	0.006	0.004	0.002
Na/Cl meq/l	0.86	0.96	0.948	0.836
Mg/Ca meq/l	4.94	0.1	0.43	0.75
SO_4/Ca meq/l	2.76	0.71	0.53	0.68
Sr/Ca meq/l	0.0103	0.0103	0.0137	0.018
Na/(Na+Ca) meq/l	0.96	0.67	0.77	0.85
Cl/(Cl+HCO_3) meq/l	0.99	0.96	0.98	0.94
BEX meq/l	-5.89	-2.24	3.36	-6.13
^{18}O %0 SMOW	1.1 to 1.7	-5.15	-5.79	-4.84
D %0 SMOW	5.0 to 9.0	-32.4	-40.2	-26.6

Table 1: Chemical and stable isotope composition of selected saline samples and Gulf of Suez (Gulf of Suez (GS) analysis after Mazore et al., 1973)

This could be dissolution of salts and leaching of saline stagnant water in coral reef deposits. These samples are relatively depleted in both oxygen and deuterium (fig 5). They are close in their hydrochemical and isotope composition to Hammam Musa of known origin of salts (dissolution of evaporite deposits). The dissolution of salts is the main source of salinization in samples numbers 89 and 2 that have NaCl ionic type and $MgCl_2$ genetic type.

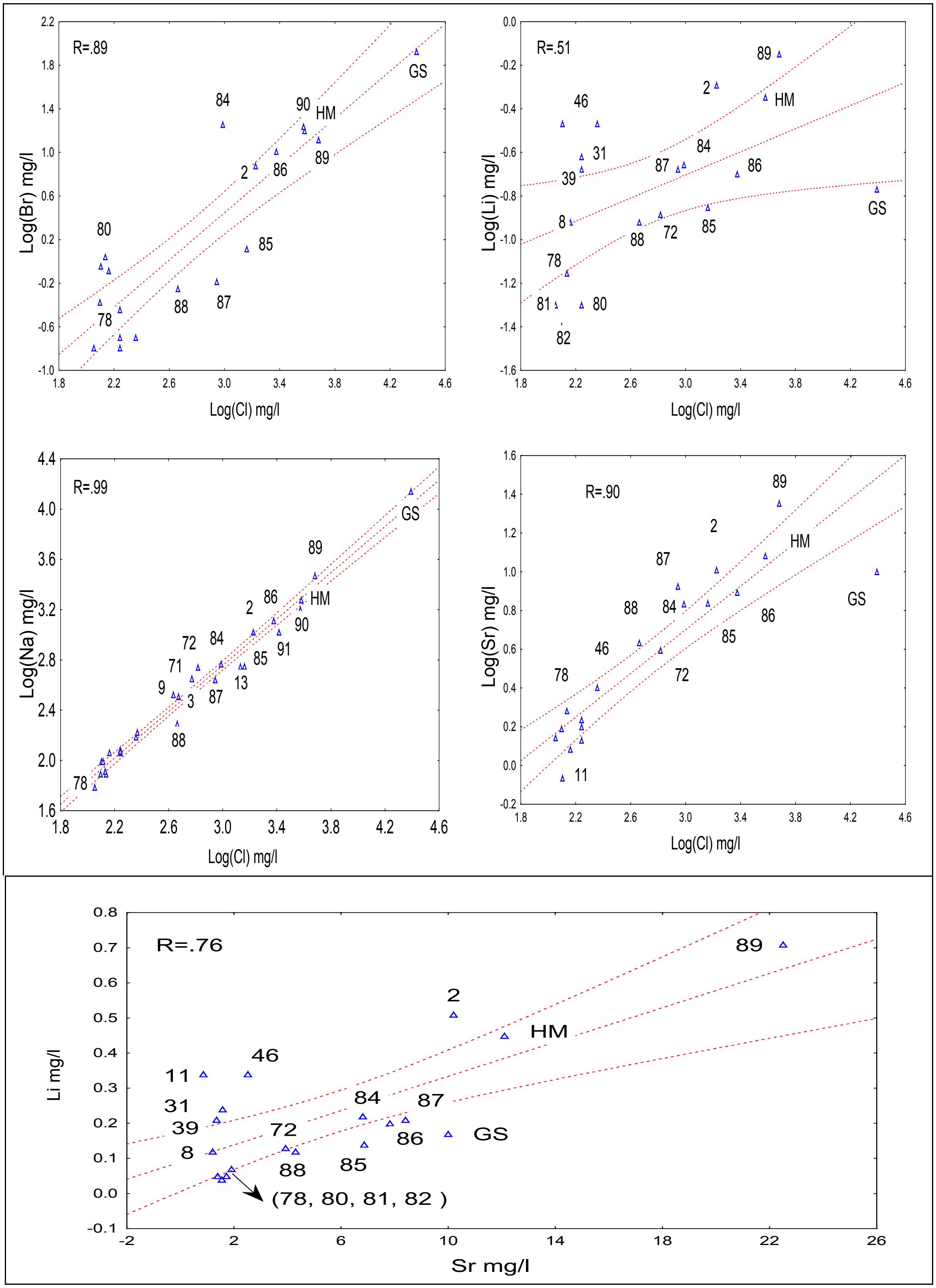

Figure 4 Variation of Sodium (Na), Bromide (Br), Strontium (Sr), and Lithium (Li) with Chloride (Cl) concentration and variation of Li and Sr in saline wells relative to fresh water (e.g. 78), seawater (GS) and Hammam Musa (HM).

The Na/Cl ratio in these two samples is about one. Moreover they are associated with coral reefs. Whereas the leaching of saline stagnant water is the main source of salinization in the sample numbers 91, 90, 87, and 85. They have NaCl ionic type and $CaCl_2$ genetic type and their Na/Cl ratio vary from 0.77 to 0.6 and have relatively high Sr and Li concentrations (fig 4). Vengosh and Rosenthal (1994), referred to similar factor of salinization in Gaza coastal plain aquifer formed with formation of the sabkha during the glacial periods in which the sea retreated and the coastal shelf becomes exposed. This source is considered the main factor causing salinization in the study area. The main agent that activates these processes is the ground water flow system. In natural conditions and even in early stages of exploitation the ground water flow was horizontal and avoiding to flow through the coral reefs and its associated salts and stagnant old saline water. In early stages of exploitation the ground water flow was supplying enough fresh water to the shallow dug wells (fig 6 a). After heavy exploitation the fresh water stressed to flow upward through this stagnant body and leaching the residual old saline water and dissolve the salts causing salinization (fig. 6 b). There is also possibility that the upward flow from deeper saline aquifer share in the salinization process but we have not enough data about deeper aquifers to recognize this source (fig. 6 b). Salinization due to pollution is local and not severe. Some water points have high values of Nitrates about 12 mg/l as Nitrogen and Boron ranges from 0.5 to 1.82 mg/l. This may be due to leakage from septic tanks and sewage system as well as agricultural activities.

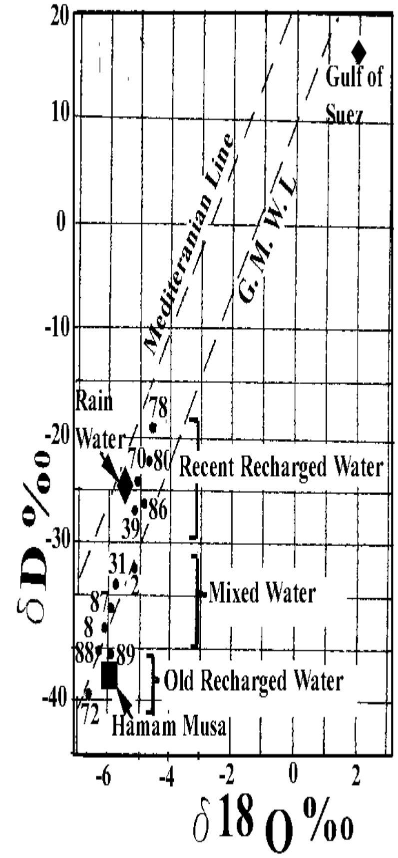

Figure 5: Stable isotope composition of water from different hydrochemical zones with three reference points (Gulf of Suez (GS), Rain Water, and Hammam Musa from Mazor et al 1973; and Gat and Issar 1974).

CONCLUSION AND RECOMMENDATIONS

The salinity of water in El-Qaa plain under natural conditions is differentiated because of variations in recharge conditions, intensity of flow and lithology. The fresh water zone (TDS up to 800 mg/l) extends along the best recharge and hydraulic conductivity conditions. After severe abstraction by dug wells in the seaside area with parallic deposits salinity increased from about 1000 to 10000 mg/l.

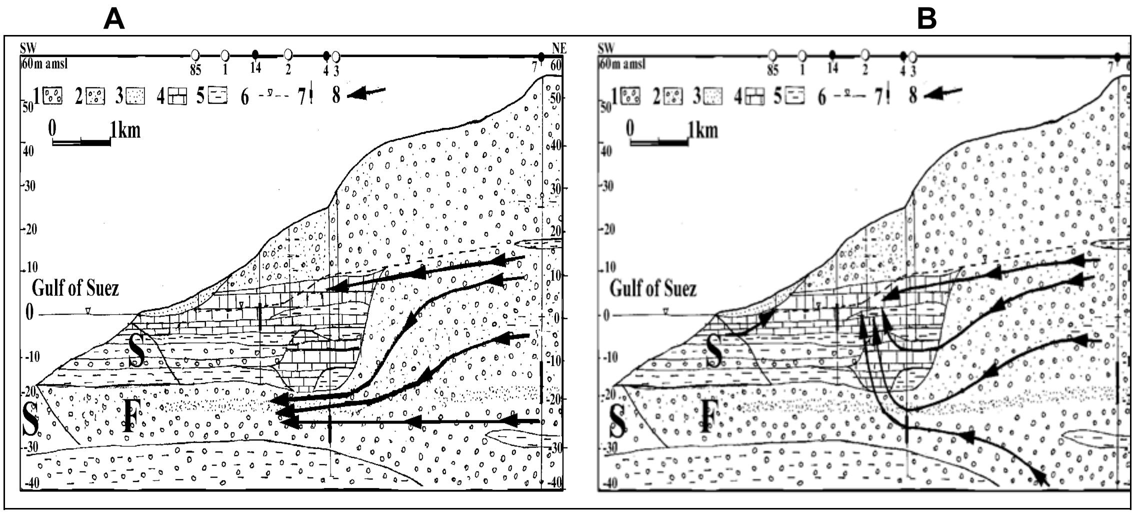

Figure 6 (a & b): Hydrogeologic cross section (F-F) extending NE-SW showing ground water flow in natural (A) and exploitation (B) conditions. Explanation: 1: gravel, 2: sandy gravel, 3: sand, 4: limestone and coral reefs, 5: clay, 6: groundwater level, 7: screen interval, 8: ground water flow line, F: fresh water, and S: saline water

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Salinization is mainly caused by changes in ground water flow system and hence dissolution of salts and leaching of saline stagnant water in coral reef deposits. Seawater intrusion is of limited effect. Strontium (Sr) and Lithium (Li) are effective hydrochemical indicators to identify the source of salinization in similar environment. Further studies are required to test these two indicators based on more data.

We recommend the following measures to protect the fresh water zone from salinization. (1) Reducing the abstraction from the shallow aquifer near El-Tor and relocating it outside the coral reef deposits. (2) Drilling of new test boreholes to clarify both the lithology and variation of salinity with depth. (3) Installation network of monitoring wells.

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