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## **WATER SALINITY, TOTAL, TEMPORARY AND PERMANENT OF THE PLEISTOCENE AQUIFER SAMPLES IN EL-SADAT AREA.**

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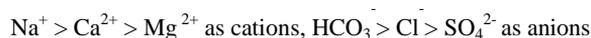
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### **Abstract**

From the arithmetic mean values of different ions that predict the most effective ions affecting the salinity level, the obtained data of Pleistocene aquifer show that the effective ions that cause an increase of water salinity are in the orders:



As a result of cation exchange processes, the increase of  $\text{Na}^+$  concentration and decrease in  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in solution, lead to a considerable decrease in salts causing temporary and permanent hardness in form of  $\text{CaMg}(\text{HCO}_3)_2$  and  $\text{CaMgSO}_4$  salts, respectively.

While causing a considerable increase in water salinity but no change in pH and  $\text{HCO}_3^-$  content because each mole of  $\text{Ca}^{2+}$  or  $\text{Mg}^{2+}$  adsorbed is replaced by 2 moles of  $\text{Na}^+$ . The loss of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  decreases the degree of water saturation with respect to both carbonate and gypsum minerals in Pleistocene aquifer. The total and permanent hardness increase with increasing water salinity and vice versa in case of temporary hardness.

On the other hand the leaching and dissolution and cation exchange processes. Both processes lead to the increase in soluble salts ( $\text{NaCl}$  and  $\text{Na}_2\text{SO}_4$ ) which is more than that of hardness salts  $\text{MgSO}_4$ ,  $\text{CaSO}_4$ ,  $\text{MgCl}_2$ ,  $\text{CaCl}_2$ ,  $\text{Mg}(\text{HCO}_3)_2$  and  $\text{Ca}(\text{HCO}_3)_2$ .

### **Introduction**

Recently, an attention has been paid to the protection of the environment by different governments in the entire world and to support the economic development for both the present and future generations. Accordingly, there is a need for a system where by negative effects of development can be identified and controlled at the national level<sup>(1)</sup>.

El Sadat area (Menoufiya Governorate) is undergoing great development comprising a lot of economical industrial projects that need essentially the presence of water resources. Ground water represents the main resource for these projects. El-Sadat area is located in the west of the Nile Delta and eastern side of the Cairo-Alexandria desert road from kilo 85 to 109, i.e accessible through Cairo-Alexandria desert road and El-Khatatba-El-Tahrir road. The present ground water supplies in El-Sadat are generally insufficient to meet the expected increases in water

demands<sup>(2)</sup>. The area under study is characterized by a long hot summer and a short warm winter, low rainfall rates (50 mm/ year) and high evaporation rates (more than 2000 mm/year)<sup>(3)</sup>.

Most information available is on the geology, hydrology, hydrogeology and hydrogeochemistry of El-Sadat and its surrounding was treated by Wassel et.al.<sup>(4)</sup>

Xing et.al<sup>(5)</sup> has pointed out that the thickness of the Pleistocene and the Pliocene deposits together nearly 335 m, based on the record data from drilled wells. The author<sup>(6)</sup> has revealed that the ground water of wadi El-Natron represent a mixture of meteoric and old formation waters from Nubian sandstone. He has recognized three types of water containing NaCl, Na<sub>2</sub>SO<sub>4</sub> and NaHCO<sub>3</sub>.

In literature<sup>(7)</sup> the author studied the electrical prospecting on the ground water in the area west of Cairo- Alexandria desert road (between El-Natron and Nasr canal).

## **Experimental**

The study includes 46 ground water samples (Pleistocene aquifer) during November, 2011.

### **1-Carbonate and bicarbonate constituents:**

Carbonate (CO<sub>3</sub><sup>2-</sup>) and bicarbonate (HCO<sub>3</sub><sup>-</sup>) constituents are determined titrimetrically against sulfuric acid by neutralization method.

### **2-Calcium and magnesium constituents:**

Calcium (Ca<sup>2+</sup>) and magnesium (Mg<sup>2+</sup>) concentrations are determined titrimetrically against (Na<sub>2</sub>H<sub>2</sub>EDTA) by complexometric method, calcium is determined by using murexid indicator while magnesium is estimated by subtracting the calcium value from the total hardness value after determining them using Eriochrome Black T in presence of suitable buffer solution.

## **Results And Discussion**

### **1.Areal distribution of water salinity of the Pleistocene aquifer:**

From iso-salinity distribution map (Fig.1) of the Pleistocene aquifer, it is obvious that, there is one general direction of water salinity which increases from the East, to the West along the study area.

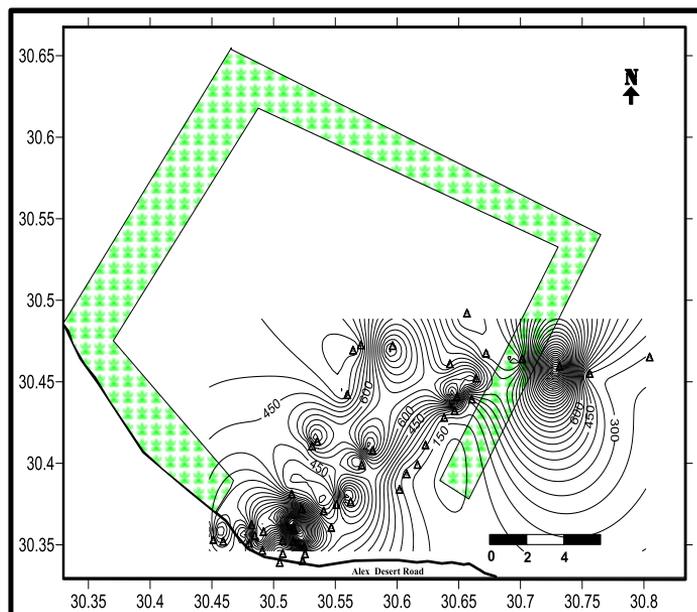
### **2. Distribution of total water hardness:**

The solubility of calcium and magnesium salts in natural waters is responsible for forming the so-called water hardness. Hardness in water is caused by divalent

cations including calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), iron ( $\text{Fe}^{2+}$ ), strontium ( $\text{Sr}^{2+}$ ), zinc ( $\text{Zn}^{2+}$ ) and manganese ( $\text{Mn}^{2+}$ ). Calcium ( $\text{Ca}^{2+}$ ) and magnesium ( $\text{Mg}^{2+}$ ) are usually the only ions present in significant concentrations. Therefore, hardness is generally considered to be a measure of the calcium and magnesium in water.

Actually, the total hardness in the natural water occurs due to different types of salts. The phenomenon of leaching and dissolution and the occurrence of some gypsum deposits are the principal reasons of ground water hardness in the area of study. Generally, hardness is measured as  $\text{CaCO}_3$  of total hardness (TH). carbonate hardness (CH), or temporary hardness is equivalent to the bicarbonate and carbonate (alkalinity). If the total hardness exceeds the alkalinity in milliequivalent per million (epm), the excess is termed non-carbonate hardness (NCH), or permanent hardness.

When TH is less than or equal to alkalinity, all hardness is carbonate hardness <sup>(8)</sup>. i.e., the difference between the total hardness and carbonate hardness is negative, then  $\text{NCH} = \text{zero}$ , where the permanent hardness is the non-carbonate hardness (NCH), temporary hardness is the carbonate hardness = alkalinity (CH).



**Fig. (1) Iso-salinity contour map of ground water of the Pleistocene aquifer El-Sadat city area (Nov.2011).**

The temporary hardness can be removed by heating where  $\text{CaCO}_3$  precipitates and the permanent hardness can be removed by adding sodium carbonate ( $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$ ), where the calcium carbonate precipitates too. From the obtained

data (Table1), of Pleistocene aquifer, it is clear that the mean value of total, temporary and permanent hardness reached, 324.4, 178.9, 133.8 mg/l, respectively, in the fresh ground water samples of Pleistocene aquifer and 663.4, 177.9 and 648.1 mg/l of Pleistocene aquifer respectively, in the brackish ground water samples.

These data indicate an increase in total and permanent hardness with increasing water salinity and vice versa in case of temporary hardness, where the temporary hardness is the dominant which reflects the effect of a meteoric origin as in (Table 2and3).

With regard to the total, temporary and permanent hardness relative to water salinity (TH/TDS, CH/TDS and NCH/TDS)% in the Pleistocene aquifer, the obtained ratios are 62%, 45.5% , 17.4% respectively, in the fresh ground water samples aquifer and 43.3%, 21%, 22.3% respectively, in the brackish ground water samples of Pleistocene aquifer (Table 1) and (Table 4and5).

This means that the total and temporary hardness percent of TDS decrease according to the change of water type from fresh to brackish and vice versa in case of permanent hardness. This is due to the increase in soluble salts of brackish ground water samples (56.7% for Pleistocene aquifer) more than that of fresh ground water samples (38%).

This is mainly attributed to the effect of leaching and dissolution of salts, leading to the increase of hardness with particular importance to the effect of NaCl concentration

**Table (1) Average and relative values of total, temporary and permanent hardness compared to the water salinity of ground water in the Pleistocene aquifer (El Sadat city).**

Water salinity classes of Pleistocene aquifer								
Freshwater (TDS <1500mg/l)								
TDS mg/l	TH mg/l	CH mg /l	NCH mg/l	(TH/TDS)%	(CH/TDS)%	(CH/TH)%	(NCH/TDS)%	(NCH./TH)%
645	324.4	178.9	133.8	62	45.5	69.5	17.4	30.5
Brackish water (TDS = 1500-5000 mg/l)								
TDS mg/l	TH mg /l	CH mg /l	NCH mg/l	(TH/TDS)%	(CH/TDS)%	(CH/TH)%	(NCH/TDS)%	(NCH./TH)%
1984	663.4	177.9	648.1	43.3	21	52	22.3	48
Water salinity in Pleistocene aquifer in E-l Sadat (TDS =1500-5000 mg/l)								
TDS mg/l	TH mg /l	CH mg /l	NCH mg/l	(TH/TDS)%	(CH/TDS)%	(CH/TH)%	(NCH/TDS)%	(NCH./TH)%
687.3	325.3	169	157	57	41	71	17	29

1- Carbonate hardness or temporary hardness relative to water salinity (CH% of TDS) =  $(Mg(HCO_3)_2 + Ca(HCO_3)_2)$  salts as percent.

2- Non-carbonate hardness or permanent hardness relative to water salinity (NCH% of TDS) =  $(MgSO_4 + CaSO_4 + MgCl_2 + CaCl_2)$  salts as percent.

(effect of ionic strength) on increasing solubility of  $Ca^{2+}$  and  $Mg^{2+}$  in water <sup>(9)</sup>.

This does not exclude the contribution of  $CO_2$  and longer residence time and the influence of salty water and cation exchange process. Therefore, the increase in water salinity of Pleistocene aquifer is due to the increase of soluble salts (59% of TDS) which is more than that of temporary salts (41% of TDS), and the permanent salts (17% of TDS) i.e.,  $(NaCl + Na_2SO_4, 59\%) > Mg(HCO_3)_2 + Ca(HCO_3)_2, 41\%) > \{(MgSO_4 + CaSO_4 + MgCl_2 + CaCl_2, 17\%)\}$ , respectively.

**Table (2) Water salinity, total, temporary and permanent hardness of the Pleistocene aquifer samples in El-Sadat city area.**

Sample No.	Salinity mg/l	Total hardness mg/l as $CaCO_3$	Temporary hardness as mg/l as $CaCO_3$	Permanent hardness mg/l as $CaCO_3$
1	230	170.88	170.00	0.88
2	1125	549.77	164.15	385.62
3	929	542.84	167.04	375.80
4	240	169.99	154.56	15.43
5	306	184.34	161.45	22.88
6	259	157.78	133.11	24.67
7	218	179.12	160.07	19.05
8	215	179.12	171.07	8.05
9	234	167.91	144.66	23.25
10	283	181.85	148.30	33.55
11	987	407.85	182.06	225.79
12	489	263.07	194.19	68.88
13	337	223.87	186.82	37.05
14	1083	335.85	309.97	25.88
15	1013	235.07	192.36	42.71
16	706	352.62	192.56	160.06
17	713	324.64	184.01	140.63
18	353	145.54	119.02	26.52
19	996	495.57	176.32	319.25
20	365	209.12	183.88	25.24
21	596	291.06	176.32	114.74
22	295	195.91	181.57	14.34

**Table (3) Water salinity, total, temporary and permanent hardness of the Pleistocene aquifer samples in El-Sadat city area.**

Sam	Salinity	Total	Temporary	Permanent hardness
23	2349	1108.22	216.04	892.18
24	1615	688.44	193.03	495.41
25	427	139.94	106.92	33.02
26	849	235.08	193.36	41.72
27	354	128.75	91.13	37.62
28	1286	591.02	131.35	459.67
29	1261	686.72	172.35	514.37
30	272	170.89	148.03	22.86
31	455	167.92	148.09	19.83
32	799	332.14	115.59	216.55
33	1306	503.22	158.26	344.96
34	534	271.97	183.88	88.09
35	1020	402.99	178.62	224.37
36	870	335.83	205.54	130.29
37	290	167.92	149.97	17.95
38	245	173.51	168.12	5.40
39	298	190.28	167.94	22.34
40	304	202.57	147.75	54.81
41	572	328.65	147.74	180.90
42	395	221.54	166.45	55.08
43	334	214.77	161.84	52.93
44	1989	750.00	193.36	556.63
45	337	210.76	165.82	44.94
46	293	189.16	161.85	27.31

**3-Water-rock interaction:**

To understand the chemical changes that can occur in water as it moves through the ground, the chemistry of the water and aquifer materials and the interactions between them should be examined. One aspect of such geochemical interactions is the dissolution and precipitation of minerals along flow paths in the ground water system. The saturation indices (SI) are a measure of the departure from equilibrium of the water with respect to various minerals phases.

When the saturation indices of minerals are equal to zero, the solution is considered saturated with these minerals. Positive values indicate super-saturation with minerals (precipitation is possible) and negative values indicate under-saturation conditions (dissolution of the mineral is possible).

Making use of the chemical equilibrium of natural waters model provided by Plummer et al., which depends on the thermodynamic speculation of inorganic ions and complex species in solution as input parameters, the saturation indices of carbonate and non-carbonate minerals were computed by WATEQ program, <sup>(10)</sup>.

According to this program, the interaction between natural water and carbonate minerals in an aquifer can be expressed by the following equations:-

$$K_{H_2CO_3} = [H^+] [HCO_3^-] / [H_2CO_3]$$

$$P_{CO_2} = [H_2CO_3] / K_{CO_2}$$

Where;

1-The brackets mean ionic activity.

2-The  $[H^+]$  is the ionic activity of hydrogen (which can be determined from the pH by definition);

$K_{H_2CO_3}$  is an equilibrium constant =  $10^{-6.35}$  at 25 °C;

$P_{CO_2}$  is the carbon dioxide partial pressure expressed in bar.

The calcite and dolomite saturation indices,  $SI_c$  and  $SI_d$ , respectively, are the logarithms of the ratios  $K_c \text{ obs.} / K_{cal.}$  and  $K_d \text{ obs.} / K_{dol.}$ , respectively. The terms  $K_{cal.}$  and  $K_{dol.}$  are equilibrium constants of calcite and dolomite, respectively, and are as follows;

$K_{cal.} = 10^{-8.4}$  and  $K_{dol.} = 10^{-17}$  at 25°C in pure water and one bar total pressure.

The calculation of  $K_c \text{ obs.}$  for calcite is based on the actual concentration of  $Ca^{2+}$ , the calculated concentration of  $CO_3^{2-}$ , and on the pH and temperature values where  $K_c \text{ obs.}$  for calcite is:

$$K_c \text{ obs.} = [Ca^{2+}] [CO_3^{2-}]$$

Saturation indices for the water samples were calculated using the aqueous speculation model WATEQF, <sup>(10)</sup>.

$$SI = \log (IAP/K_T) \text{ or } \log (IAP/K_{SP})$$

Where;

IAP = Ion activity product of the mineral calculated from analytical data.

$K_T$  = Thermodynamic equilibrium constant at the measured temperature of the water samples.

$K_{SP}$  = Solubility product constant.

This value of  $(\text{CO}_3^{2-})$  is calculated from the ionic activity value of  $\text{HCO}_3^-$  and the pH using the dissociation equation for  $\text{HCO}_3^-$ , assuming that the involved chemical species exist in the solution in equilibrium with each other:

$$K_{\text{CO}_3^{-2}} = (\text{H}^+) (\text{CO}_3^{2-}) / (\text{HCO}_3^-)$$

**Table (4) Absolute and relative values of total, temporary and permanent hardness compared to the water salinity of ground water in the Pleistocene aquifer samples in El-Sadat city area.**

Sample No	TDS	(TH/TDS)%	(CH/TDS)%	(NCH/TDS)%	(CH/TH)%	(NCH./TH)%
1	230	74.0	74	0	100	0
2	1125	55.0	17	38	31	69
3	929	65.0	21	44	32	68
4	240	73.0	68	5	93	7
5	306	64.0	57	7	89	11
6	259	63.0	58	5	92	8
7	218	80.0	73	7	91	9
8	215	80.0	78	2	98	3
9	234	73.0	63	10	86	14
10	283	65.0	65	0	100	0
11	987	47.0	21	26	45	55
12	489	59.0	44	15	75	25
13	337	70.0	58	12	83	17
14	1083	34.0	34	0	100	0
15	1013	27.0	22	5	81	19
16	706	55.0	21	34	38	62
17	713	50.0	30	20	60	40
18	353	45.0	41	4	91	9
19	996	56.0	21	35	38	63
20	365	63.0	54	9	86	14
21	596	56.0	35	21	63	38
22	295	69.0	51	18	74	26
23	2349	53.0	11	42	21	79

**Table (5) Absolute and relative values of total, temporary and permanent hardness compared to the water salinity of ground water in the Pleistocene aquifer samples in El-Sadat city area.**

Sample No	TDS	(TH/TDS) %	(CH/TDS) %	(NCH/TDS) %	(CH/TH)%	(NCH./TH) %
24	1615	49.0	14	35	29	71
25	427	37.0	37	0	100	0
26	849	33.0	27	6	82	18
27	354	40.0	40	0	100	0
28	1286	53.0	13	40	25	75
29	1261	61.0	16	45	26	74
30	272	64.0	64	0	100	0
31	455	41.0	41	0	100	0
32	799	49.0	21	28	43	57
33	1306	45.0	15	30	33	67
34	534	57.0	39	18	68	32
35	1020	46.0	20	26	43	57
36	870	44.0	27	17	61	39
37	290	61.0	61	0	100	0
38	245	73.0	70	3	96	4
39	298	69.0	59	10	86	14
40	304	71.0	53	18	75	25
41	572	64.0	29	35	45	55
42	395	61.0	47	14	77	23
43	334	68.0	53	15	78	22
44	1989	44.0	12	32	27	73
45	337	68.0	55	13	81	19
46	293	68.0	60	8	88	12

The equilibrium constant,  $K_{\text{HCO}_3^-}$ , has a value of  $10^{-10.33}$  at 25°C in pure water and one bar total pressure.

On the other hand, the calculation of  $K_d$  obs. for dolomite depends on the same variable plus actual concentration of  $\text{Mg}^{2+}$  where  $K_d$  obs. for dolomite is:

$$K_d \text{ obs.} = (\text{Ca}^{2+})(\text{Mg}^{2+}) (\text{CO}_3^{2-})^2$$

The values of ionic activities are usually calculated from observed ionic concentrations, expressed in moles, multiplied by the activity coefficient which, in turn, is calculated using the well-known Debye-Hückel equation:

$$\text{Log } f_i = \text{AZ}_i^2(\text{I})^{0.5} / 1 + \text{Ba}_i(\text{I})^{0.5}$$

Where  $f_i$  is the activity coefficient of charged ion pairs. A and B are constants that depend on the dielectric constant, density and temperature of the solvent,  $Z_i$  is the charge on the ion. I is ionic strength ( $I = \frac{1}{2} \sum m_i Z_i^2$ , where  $m_i$  is the molality of the ion), and  $a_i$  is the ion size parameter. As a general rule, the Davies equation:

$$\text{Log } f_i = -\text{AZ}_i^2 ((\text{I})^{0.5} / 1 + (\text{I})^{0.5} - 0.31)$$

The Davies equation is probably accurate when ionic strength is less than 0.5 while Debye-Hückel equation is more accurate when ionic strength is less than 0.1. Activity coefficients of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  are always calculated from the extended Debye-Hückel equations of Truesdell and Jones.

The usual reason for doing the calculation is to obtain saturation indices for minerals and partial pressures of gases which whether minerals or gases should dissolve or precipitate in the solution.

The program needs a complete chemical analysis of the major elements ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Na}^+$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{Cl}^-$ , alkalinity, minor and trace elements ( $\text{Fe}^{3+}$ ,  $\text{Mn}^{2+}$ ,  $\text{B}^{3+}$ ,  $\text{K}^+$ ,  $\text{CO}_3^{2-}$ ) and field pH to make the calculation.

When the saturation indices of carbonate minerals are equal to zero, the solution is considered saturated with carbonate minerals for a given temperature and  $\text{CO}_2$  partial pressure. Positive values indicate super – saturation with carbonate minerals and negative values indicate under – saturation conditions. Other indices of different minerals are calculated in the same manner.

The obtained data, it reveals that all of the ground water samples of the Pleistocene aquifer were supersaturated with respect to dolomite  $\text{CaMg}(\text{CO}_3)_2$ , calcite ( $\text{CaCO}_3$ ), aragonite ( $\text{CaCO}_3$  and magnesite ( $\text{MgCO}_3$ ). This is due to ion activity products (IAP) which are more than that of the solubility product constant ( $K_{\text{sp}}$ ) in these samples.

i.e., these ground water samples precipitate the carbonate minerals during the flow from recharge area to the discharge one.

This indication confirms either the presence of relatively high marine carbonate deposits that were transported after weathering from the catchment area or during transgression by old sea water or through heavy local precipitation, leading to leaching and dissolution of carbonate minerals from catchment area and the aquifer matrices in this particular area.

The rest ground water samples were unsaturated with respect to the carbonate minerals, referring to IAP is less than  $K_{sp}$ , i.e. these ground water samples dissolve the carbonate minerals during the recharge route from catchment area to the discharge one.

Saturation and super-saturation conditions of carbonate minerals are usually associated with:

1-Increase in  $Ca^{2+}$  or  $Mg^{2+}$  and  $HCO_3^-$  concentrations and pH value. The increase in these concentrations are directly proportional to NaCl concentration in water that is affected by dissolution and evaporation.

In other words, the increase in NaCl concentration is accompanied by a relative increase in carbonate concentration, and therefore, leading to saturation or super-saturation by carbonate minerals.

This is based on the effect of NaCl on increasing both ionic strength and solubility product of carbonates. Worth-mentioning that, NaCl solubility could be encountered at any stage of water circulation within the aquifer. As dissolution of carbonate minerals takes place, pH,  $Ca^{2+}$  or  $Mg^{2+}$  and  $HCO_3^-$  in water increased along the evolution paths for specified  $P_{CO_2}$  values.<sup>(11)</sup>

2-Lowering of  $P_{CO_2}$  causes higher carbonate saturation condition and vice versa, loss of  $CO_2$  from the system enhanced more carbonate saturation.<sup>(12)</sup>

3-The slow diffusion flowing system normally allows a longer contact between ground water and the carbonate material in the aquifer matrix or surface carbonate rock or recharge areas, which leads to saturation or super-saturation with  $Ca^{2+}$  or  $Mg^{2+}$ , or both, and  $HCO_3^-$ .<sup>(12)</sup>

4-The solubility product is strongly dependent on temperature, the solubility-temperature relationship for these minerals shows that solubility occurs at lower temperature because of the relatively high content of  $CO_2$  and because the values of equilibrium contents for carbonate minerals is larger at lower temperatures. All

other minerals (non-carbonate minerals) have the reverse relationship since they are more soluble at higher temperature <sup>(11)</sup>.

5-The ground water is significantly super-saturated with carbonate minerals. This is caused by dissolution of trace amounts of gypsum and that the condition of super-saturation is maintained by an imbalance in rates of gypsum dissolution relative to precipitation rates of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  carbonates (the common-ion effect). <sup>(13,14)</sup>

Attributed this condition of disequilibrium (under saturation or super-saturation) to the combined influence of temperature change, degassing, cation exchange and common-ion effect caused by gypsum dissolution.

The solution equilibrium reaction of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  carbonates, which contributed to temporary hardness, is influenced by  $\text{H}_2\text{CO}_3$  ( $\text{CO}_2$  and  $\text{H}_2\text{O}$ ) in percolating rainwater,  $\text{P}_{\text{CO}_2}$ , pH values and water temperature. This is generally reflected on the temporary hardness in the Pleistocene aquifer which contain  $\text{CaCO}_3$  and  $\text{MgCO}_3$  materials from the chemical weathering at catchment areas and aquifer matrices. In other words, the temporary hardness is significant in Pleistocene aquifer where temporary hardness is 41%.

The permanent hardness is enhanced by longer residence time and influences of salty water, sulfates and chlorides of calcium and magnesium increase in ground water, i.e. permanent hardness of Pleistocene aquifer (17%) is less than temporary hardness in the samples, as in Table (1).

#### **4-Areal distribution of total hardness:**

The areal distribution of total hardness is shown in Figure (2). In the ground water samples of the Pleistocene aquifer in El Sadat area, the total hardness follows, more or less, the water salinity distribution.

The total hardness of Pleistocene aquifer increases from East to West directions and the highest values of total hardness are 641 mg/l as  $\text{CaCO}_3$  as evidenced in.

Such low values of total hardness of Pleistocene aquifer (141mg/l as  $\text{CaCO}_3$ ) are mainly due to the dilution effect caused by seepage of water from canals and drains while the high values of total hardness are due to the effect of the recharge of ground water to this aquifer as well as over pumping activity.

#### **5-Areal distribution of non-carbonate hardness or permanent hardness (NCH):**

The areal distribution of permanent hardness of Pleistocene aquifer are shown in Figure (3), from which, it is clear that;

In the ground water samples at El-Sadat city area, the permanent hardness distribution follows, more or less, that of total salinity (TDS) and total hardness (TH). The permanent hardness distribution mainly increases from the East to West where the permanent hardness distribution tends to increase with increasing ground water salinity.

The low values of the permanent hardness distribution (1 mg/l for Pleistocene aquifer) are mainly due to the dilution increase water from canals and drains while the high values (917 mg/l for Pleistocene aquifer, as  $\text{CaCO}_3$ ).

This is due to leaching and dissolution of permanent hardness salts in the aquifer matrices as a result of ground water flow from the recharge route to aquifer matrices and over pumping activity.

#### 6- Areal distribution of carbonate hardness or temporary hardness (CH):

Based on Nov., 2011 ground water sampling, the iso-temporary hardness distribution in Pleistocene aquifer in El Sadat area shown in Figure (4). From these figure, it is clear that the temporary hardness distribution follows, more or less, that of total salinity (TDS), total hardness (TH) and permanent hardness (NCH).

The temporary hardness as  $\text{CaCO}_3$  distribution increases from East to West within the range of 91 to 310 mg/l Pleistocene aquifer in El Sadat area. This behavior of temporary hardness can be explained on the basis of increasing solubility of carbonate minerals from aquifer matrices as well as the effect of fresh water from recharge of the canals where  $\text{HCO}_3^-$  species is the dominant.

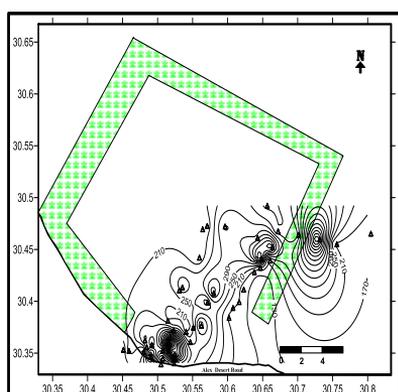


Fig. (2) Iso-contour map of total hardness (mg/l as  $\text{CaCO}_3$ ) of ground water of the Pleistocene aquifer in El-Sadat city Area (Nov.2011).

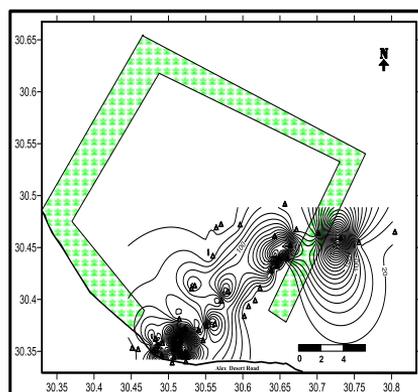
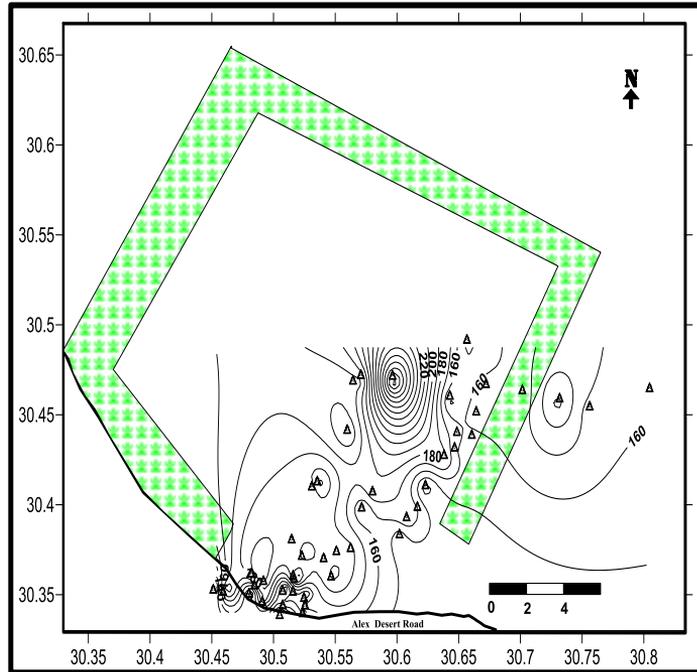


Fig. (3) Iso-contour map of permanent hardness (mg/l as  $\text{CaCO}_3$ ) of ground water of the Pleistocene aquifer in El-Sadat city Area (Nov.2011).



**Fig. (4) Iso-contour map of temporary hardness (mg/l as  $\text{CaCO}_3$ ) of ground water of the Pleistocene aquifer in El-Sadat city Area (Nov.2011).**

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