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GROUNDWATER CHEMISTRY OF THE SHALLOW AQUIFER, EL-TUR AREA, SOUTH SINAI, EGYPT

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Twenty groundwater samples were collected and analyzed from several hand-dug wells at El-Tur City, South Sinai, Egypt. The results of chemical analyses indicate that the water types are Na_2SO_4 of meteoric genesis, $MgCl_2$ of marine genesis and $CaCl_2$ of old marine genesis. The saturation indices with respect to minerals were calculated by the use of the hydrochemical program WATEQ and used to elucidate the rock-water interactions. The results point to the occurrence of 18 minerals that reflect the chemical characteristics of the shallow aquifer. A multivariate statistical analyses shows that a grouping exists. The suitability of the water for irrigation and potable purposes falls within five classes.

INTRODUCTION

Several workers have studied the hydrogeology of the El-Qaa plain, among them Issar and Gilad (1982), El-Refaei (1984), Dames and Moore (1985), and WRRI and JICA (1999). The study area lies on the eastern side of the Gulf of Suez, between Lat. 28º10' and 28º20' N and Long. 33º34' and 33º40' E on the Sinai Peninsula (Figure 1). The scope of these studies was not the rock-water interactions; their focus was the relatively deep aquifers. The area of study is the shallow Quaternary aquifer bounded on the east by the El-Qaa plain, on the northwest by Gebel Hamam Saidna Musa, and on the west by the Gulf of Suez. It is composed of terrace gravel deposits, alluvial fans and wadi deposits.

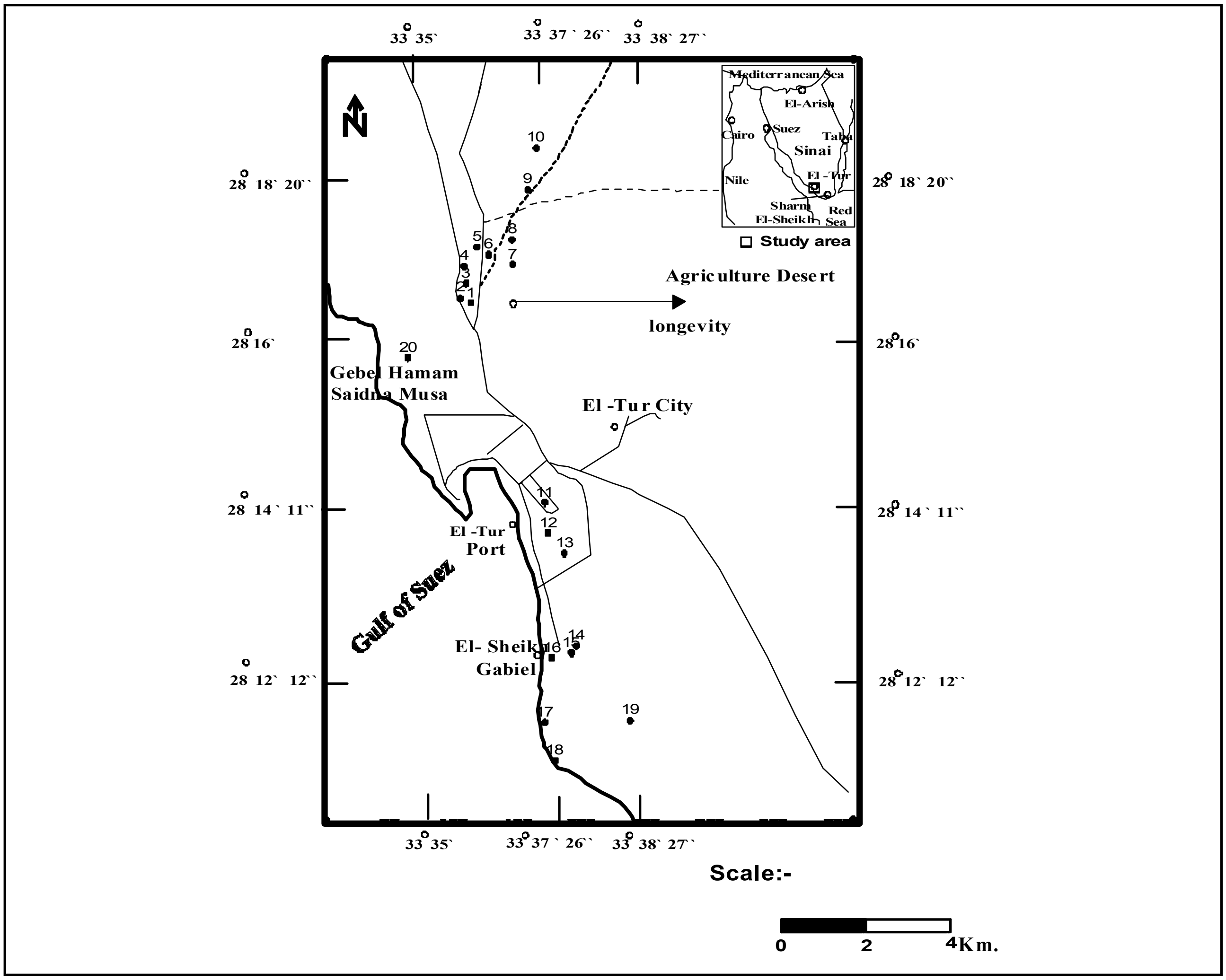

Figure 1. Location map of the study water wells.

The southeastern part, the El-Sheik Gabiel area, is composed of wadi sediments and old coral reefs. Two faults exist at the northwestern corner of the study area (EGSMA, 1994) with azimuths 304º and 318º and direction NNW-SSE. The total lengths of these faults reaches up to 4 km (Figure 2).

The unconfined aquifer occurs in the El-Wadi and El-Sheikh Gabiel villages. The direction of groundwater flow in the north takes a southeast direction, but in the south takes the direction from east to west to the Gulf of Suez (Figure 3).

The Quaternary sediments are of a clastic nature, since they are made up of the erosional products of the wadi surface drainage basin, where its drainage net dissects different sediment varieties and

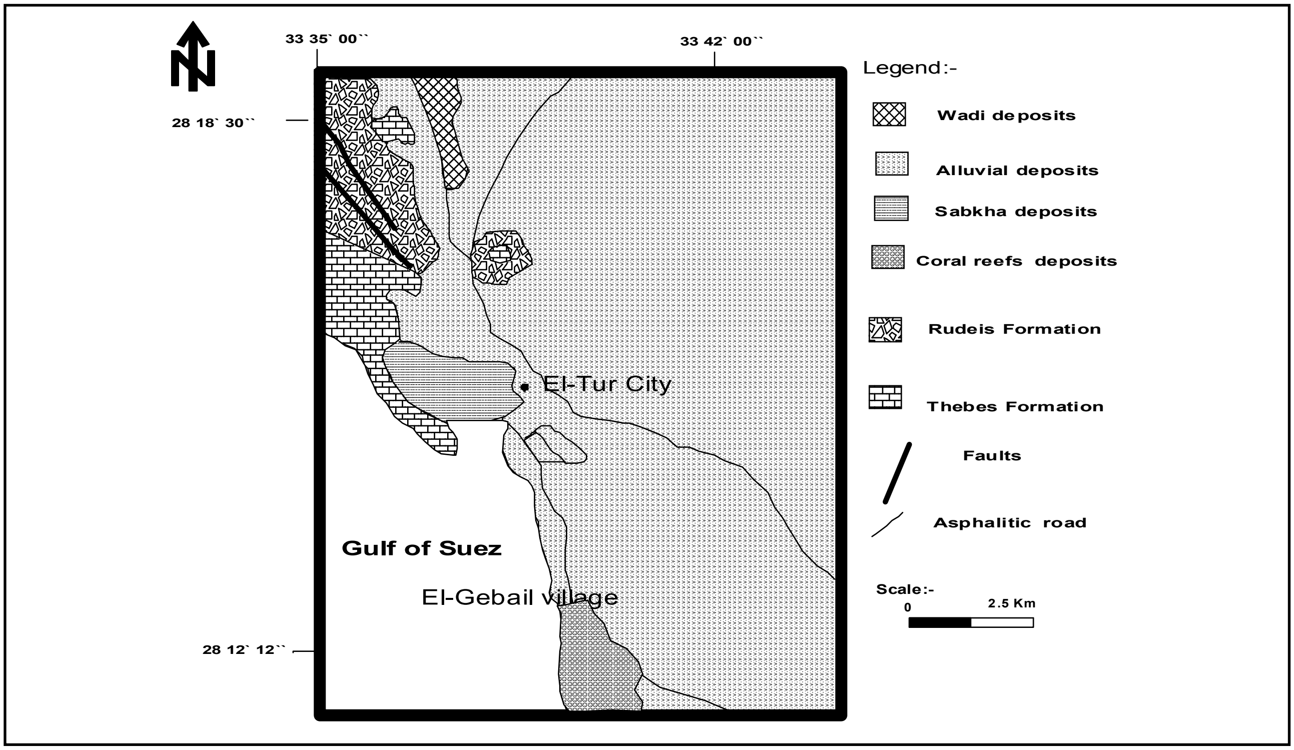

Figure 2. Geological and structural map of the study area (after EGSMA, 1994).

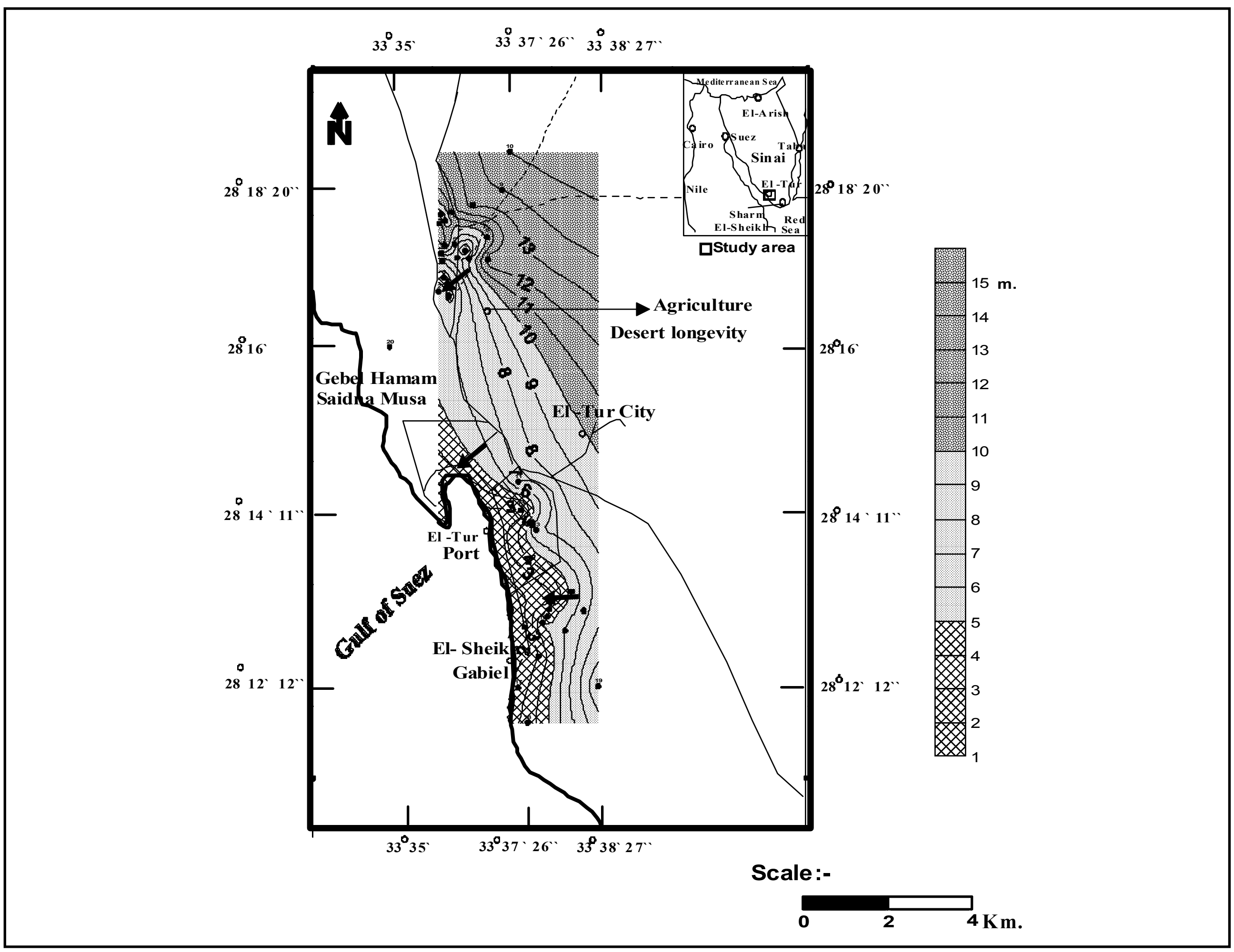

Figure 3. Water table map.

basement rocks. The groundwater samples were collected from the unconfined Quaternary aquifer. There are two types of wells in the area of El-Tur City; shallow wells and hand-dug wells with a depth to water ranging from 1.6 to 18.7 m.

MATERIAL AND METHODS

Twenty water samples were collected from the El-Tur area in November 2002 after stopping pumping for 24 hrs. Some measurements were carried out in the field such as temperature, pH, electrical conductivity, and the latitude and longitude of each well. The determination of the major elements was carried out in the laboratory of the Ministry of Agriculture in the Mansoura Governorate. This study provides the hydrochemical characteristics of the shallow aquifer in El-Tur City.

The study also aims to determine the types and origin of the aquifer water, to classify the productive water bearing horizons by multivariate statistical analyses, and elucidate the hydrochemical relationships among the wells by using the Sulin and Piper diagrams, and the saturation levels by the WATEQ program. In addition, the study determines the suitability of water for irrigation purposes.

RESULTS AND DISCUSSION

The results of the chemical analysis are tabulated in Table 1.

Table 1. Chemical Analyses of the Studied Water Wells

Well No.	pH	TDS	K	Na	Mg	Ca	HCO_3	Cl	SO_4	Zn	Pb	Fe	Mn
1	7.8	6231	19.55	1287.9	208	615	146.43	2670.2	1282.4	0.04	0.14	0.01	0
2	7.5	4362	125.1	625.6	143.5	487	292.9	794	1891.5	0.02	0.08	0.02	0
3	7.8	2187	14.07	335.8	33.6	368.95	119.59	929.1	384.25	0.02	0.1	0.01	0
4	7.9	3395	9.38	688.8	130.84	292.7	133.01	1198.6	941.4	0.02	0.07	0	0
5	7.9	738	5.47	105.8	15.81	106.04	166.57	212.77	125.36	0.03	0.05	0.01	0
6	8	1061	3.127	143.28	40.856	110.64	152.5	301.4	201.7	0.01	0.1	0.09	0
7	7.7	2334	3.9	324.75	154.9	263.9	106.16	1028.4	451.97	0	0.09	0	0
8	7.9	731	1.56	164.67	15.807	55.42	119.59	209.2	163.78	0.01	0.08	0.4	0
9	7.7	534.91	3.13	104.88	4.38	59.42	119.59	127.66	115.75	0	0.07	0.01	0
10	7.8	566.03	3.909	137.07	7.78	38.22	133.01	177.31	68.68	0.02	0.14	0.1	0
11	7.9	4183	5.08	1030.4	35.14	368.15	61.01	1268.8	1414	0.02	0.12	0.03	0
12	7.9	1280	5.47	275.99	41.46	92.04	67.72	331.9	464.94	0.01	0.06	0.03	0
13	8	1826	5.47	469.18	24.68	116.05	81.15	479.43	649.4	0.01	0.09	0.02	0
14	7.8	2043	10.56	459.98	43.65	172.07	54.3	604.96	696.93	0.03	0.05	0	0
15	8	4067	21.11	938.36	77.58	280.11	94.57	663.83	1990.9	0.03	0.1	0.03	0
16	8	2279	17.98	616.37	38.79	100	94.57	612	799.23	0.02	0.13	0	0
17	8.1	7054	26.19	1398.3	220.09	730.3	183.04	2636.9	1859.3	0	0.06	0	0
18	8.3	3799	12.12	1002.8	31.128	280.11	81.15	1298.8	1122	0.01	0.07	0	0
19	8.4	1214	5.08	220.79	21.89	146.06	54.3	269.15	497.12	0.18	0.05	0	0
20	8.1	8173	5.86	1793.9	345.94	590.04	98.23	3466.67	176.37	0.04	0.02	0.01	0.02

A brief discussion of these results follows.

Salinity content

The salinity of the groundwater ranges from 534.91 ppm to 8173 ppm. According to the Chebotarev (1955) classification, the groundwater of the aquifer is classified into the following types (Figure 4):

a - Fresh water (less than 1000 ppm) is found in the northern and northeastern parts of the study area.

b - Brackish water (1000-3000 ppm) is found from the northwest to the east and southeast portion of the study area.

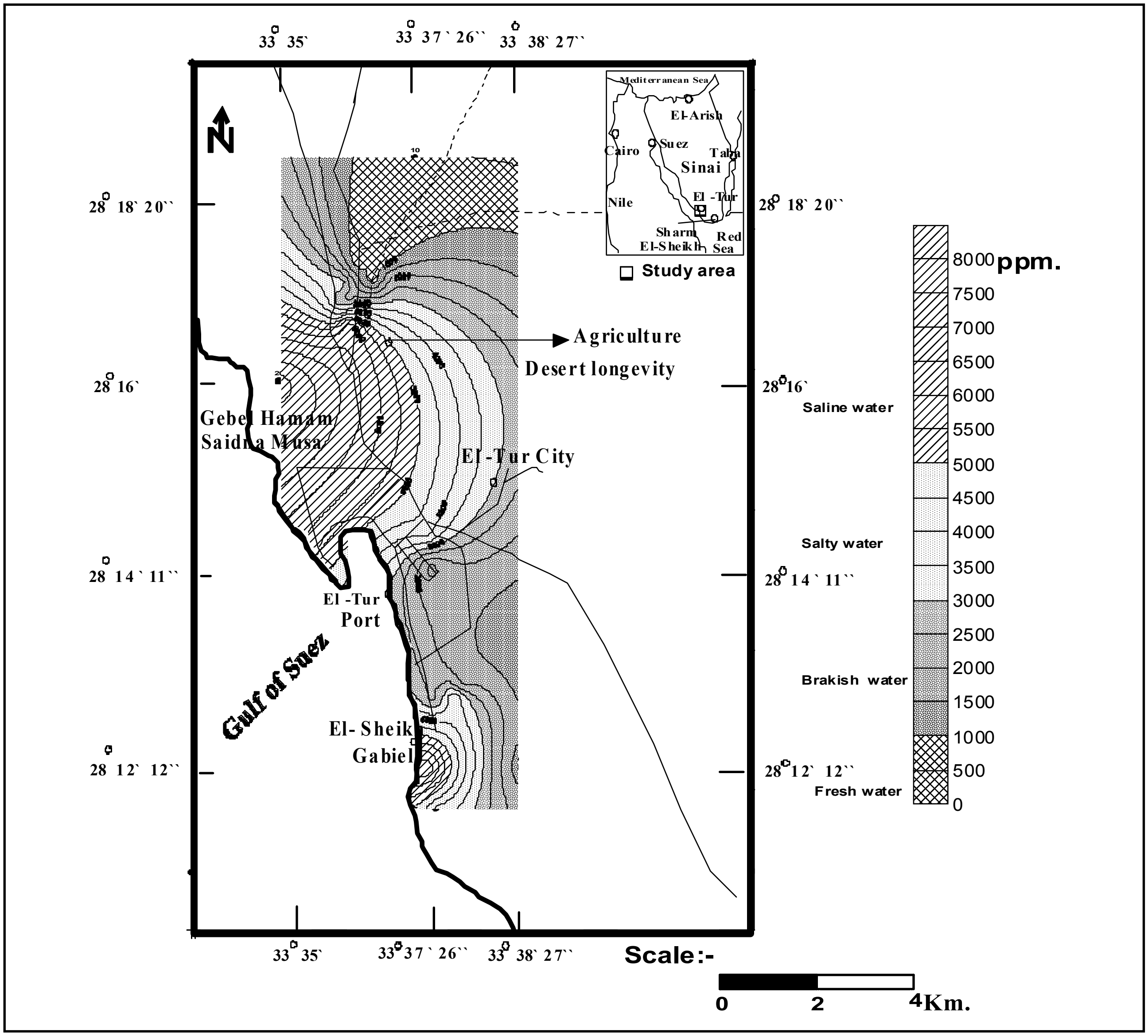

Figure 4. Iso-salinity contour map.

c - Salty water (3000-5000 ppm) is found in the northwest from the middle to the west. It is also found as an area in the southwest.

d - Saline water (5000-10000 ppm) is found in the west and southwest in small areas.

The salinity of the groundwater generally increases with the increase of pH due to increasing K and Na. Figure 5 and Table 1 show that the area of El-Tur City has pH values ranging between 7.5 and 8.4, which belong to a slightly alkaline water type (samples 1 to 16) and an alkaline type (samples 17 to 20).

Origin of the water in the studied area

Sulin's diagram (1946), is used for determining the origin of water in the studied area (Figure 6). It is found that water sample numbers 2, 8 to 16, 18 and 19 are of the Na_2SO_4 meteoric water type of deep percolation .The $MgCl_2$ water type of marine genesis is represented by samples 4, 6, 17 and 20. The $CaCl_2$ water type of old marine water genesis is represented by samples 1, 3, 5 and 7. This area contains a group of faults trending in the NNW-SSE direction, which allowed sea water to enter, causing the replacement of Mg by Ca.

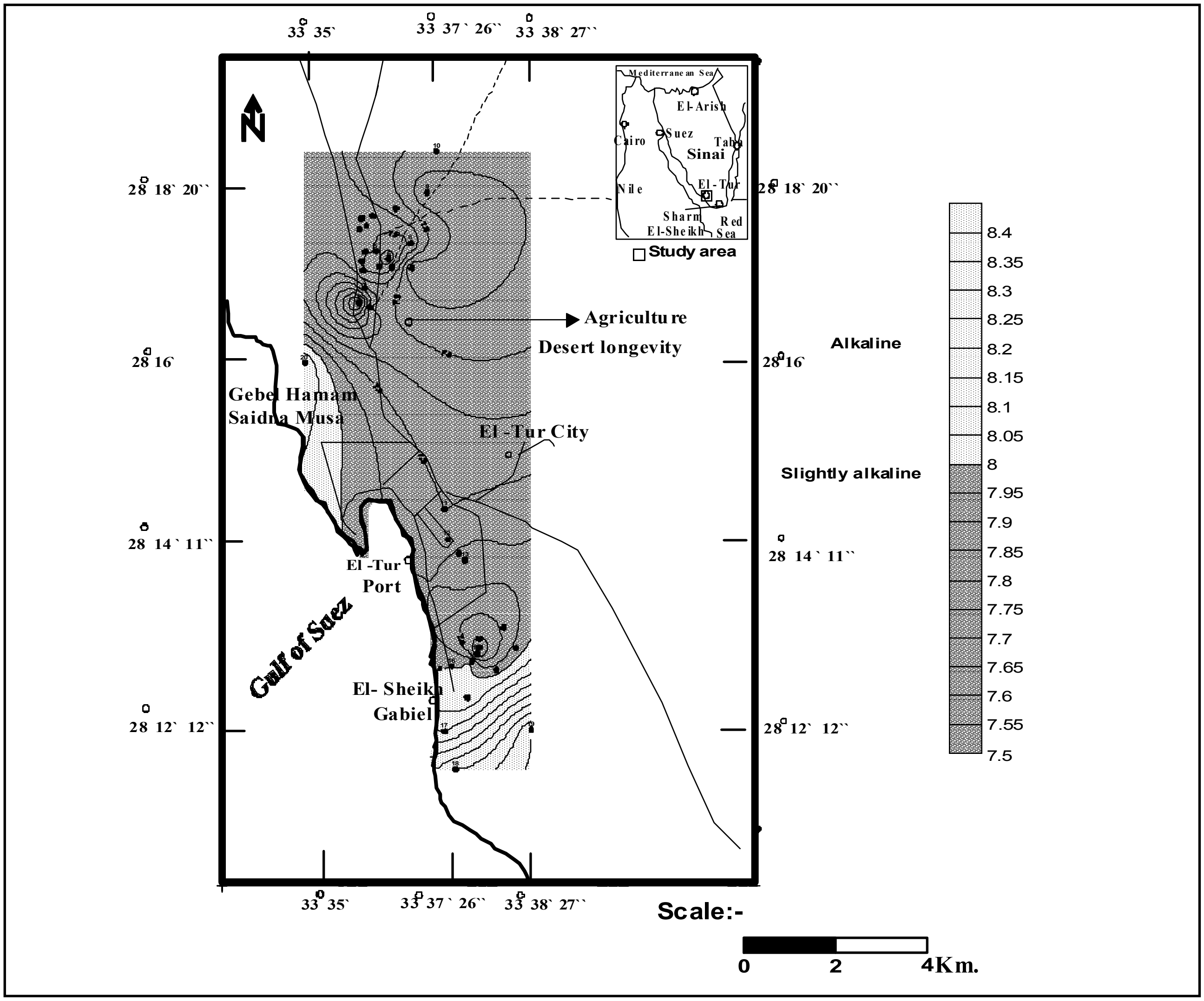

Figure 5. Iso-pH contour map.

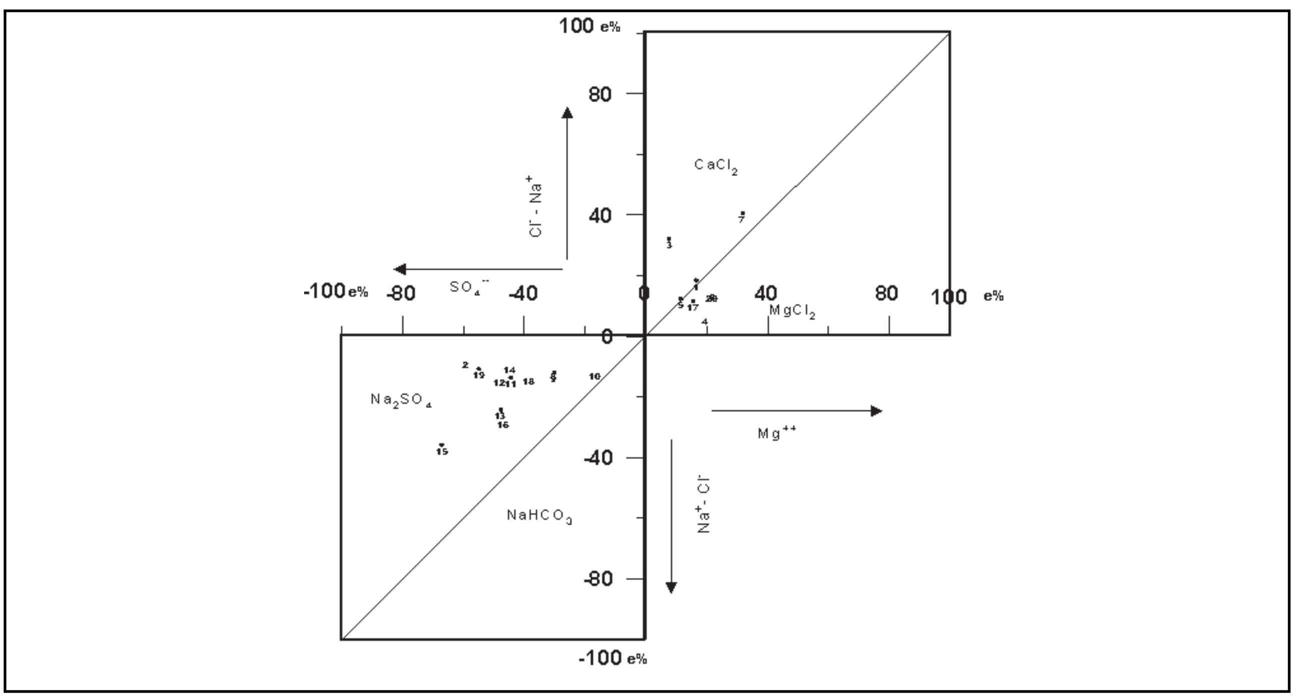

Figure 6. Sulin's graph for genetic classification of the groundwater in the study area.

Hypothetical salt combinations

Palmer (1911) proposed a bar graph representation of chemical data for groundwater. The bar graph is divided into three vertical columns. The left represents cations in epm % , while the right represents anions in epm %. The middle is the intersection between cations and anions at a hypothetical salt combination. In his study, Palmer (1911) used the graphs to determine the hypothetical salt combinations and to calculate them theoretically.

According to Palmer (1911), the hypothetical salt combinations of the studied groundwater samples are classified into four assemblages as follows (Table 2):

a - Assemblage (1): KCl, NaCl, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(HCO_3)_2$ in sample numbers 4, 5, 6, 17 and 20.

b - Assemblage (2): KCl, NaCl, Na_2SO_4, $MgSo_4$, $CaSO_4$ and $Ca(HCO_3)_2$ in sample numbers 2, 8, 9, 11 to 16, 18 and 19.

c - Assemblage (3): KCl, NaCl, $MgCl_2$, $CaCl_2$, $CaSO_4$, and $Ca(HCO_3)_2$ sample numbers 1, 3 and 7.

d - Assemblage (4): KCl, NaCl, Na_2SO_4, $MgSo_4$, $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ in sample number 10.

The variation in the salt assemblages among the studied water samples is due to the difference in the hydrochemical compositions.

Table 2. The Hypothetical Salt Combination of the Studied Water Samples

Sample No.	K Cl	Na Cl	Na_2SO_4	Mg Cl_2	Mg SO_4	$Mg(HCO_3)_2$	Ca Cl_2	Ca SO_4	$Ca(HCO_3)_2$
1	0.479	53.64		16.437			1.57	25.575	2.99
2	4.806	28.838	12.015		17.723			29.409	7.209
3	0.994	40.38		7.64			23.454	22.144	5.388
4	0.432	53.886		6.492	12.868			22.394	3.928
5	1.235	40.56		11.12	0.345			22.675	24.065
6	0.526	40.99		14.404	7.701			19.929	16.450
7	0.249	35.17		31.74			5.081	23.440	4.320
8	0.355	51.995	11.535		11.54			7.185	17.390
9	1	44.16	13.055		4.52			12.665	24.600
10	1.16	56.91	12.3		4.3	3.48			21.850
11	0.196	53.836	13.814		4.364			26.286	1.504
12	0.695	45.755	13.795		16.925			17.325	5.505
13	0.493	47.167	24.743		7.155			15.764	4.678
14	0.832	51.725	9.885		11.068			23.756	2.734
15	0.875	29.453	36.654		10.337			20.174	2.507
16	1.3	47.38	28.22		8.999			9.730	4.371
17	0.578	52.44		11.064	4.439			28.920	2.559
18	0.51	58.66	13.44		4.24			20.960	2.190
19	0.691	39.617	11.365		9.559			34.041	4.727
20	0.111	57.315		14.409	6.496			20.486	1.183

Hydrochemical coefficients

The hydrochemical coefficients are rK/rCl, rNa/rCl, rMg/rCl, rCa/rCl and rSO_4/rCl. Ovitchinikov (1955) took the water of the seas and oceans as standard values (0.2, 0.85, 0.20, 0.4 and 0.1). These values are compared with the calculated values of the hydrochemical parameters in the study water samples. The calculated values of rK/rCl (Table 3) are less than the standard value including sample numbers 1 to 4, 6, 7, 8, 11 to 14, and 17 to 20, while those with more than the standard value are represented by samples numbers 5, 9, 10, 15 and 16. The increase of K ionic concentration in the water samples over seawater may indicate that these groundwaters are of mixed genesis due to the recharge of meteoric water. The values of rNa/rCl show an increase in the concentration of Na ions over the standard value in sample numbers 2, 4, 8 to 16, 18 and 19. The hydrochemical parameters of rMg/rCl show that the increase of Mg ions is more than the standard value in sample numbers 1, 2, 5, 6, 7, 8, 11, 12, 14, 15, 17, 19 and 20 due to the highly flushing action of the percolating meteoric water, while the increase of Mg is due to the leaching process of meteoric water on rock constituents. The decrease of Mg ionic concentration is due to the cation exchanges between the Ca ions of the rock and Mg ions of water in sample numbers 3, 4, 9, 10, 11, 13, 16 and 18. The values of rCa/rCl are more than standard sea water in sample numbers 1 to 9, 11, 12 to 17 and 19. The increase of Ca ion concentration in the water is due to two main processes: the first is the cation exchange process between Ca in the surrounding rocks with Mg in water during the hydrochemical formation of the old marine water genesis, while the second is from the leaching process of the aquifer materials by deep meteoric water percolation. The calculated values of the parameter rSO_4/rCl of all samples are more than the standard seawater value. This may be confirmed by the increase of the concentration of sulfate ion in the aquifer, which is mainly due to the leaching process of meteoric water percolation.

Table 3. Calculated Values of Some Hydrochemical Coefficients for the Study Water Samples in the El-Tur Area

Well No.	Unit	r K/r Cl	r Na/r Cl	r Mg /r Cl	r Ca/r Cl	r SO4/r Cl
1	epm	0.007	0.743	0.228	0.408	1
2	epm	0.014	1.214	0.527	1.088	1.758
3	epm	0.014	0.557	0.105	0.704	0.305
4	epm	0.007	0.886	0.318	0.433	0.58
5	epm	0.023	0.767	0.217	0.883	0.435
6	epm	0.009	0.733	0.395	0.651	0.494
7	epm	0.004	0.487	0.439	0.455	0.324
8	epm	0.007	1.214	0.22	0.469	0.578
9	epm	0.022	1.267	0.1	0.825	0.67
10	epm	0.02	1.192	0.128	0.382	0.286
11	epm	0.004	1.252	0.081	0.51	0.826
12	epm	0.015	1.282	0.364	0.49	1.03
13	epm	0.01	1.509	0.15	0.429	1
14	epm	0.016	1.172	0.21	0.504	0.85
15	epm	0.029	2.18	0.341	0.748	2.21
16	epm	0.0267	1.553	0.185	0.29	0.96
17	epm	0.009	0.818	0.242	0.491	0.52
18	epm	0.009	1.216	0.072	0.391	0.65
19	epm	0.017	1.265	0.237	0.962	1.36
20	epm	0.0002	0.798	0.291	0.302	0.376

Hydrochemical facies

According to the distribution pattern of the Piper (1944) trilinear diagram (Figure 7) the study area showed three hydrochemical facies:

1 - The primary salinity hydrochemical facies, which is characterized by non-carbonate alkalinity exceeding 50%, is represented by sample numbers 1, 4, and 8 to 20.

2 - The secondary salinity hydrochemical facies, which is characterized by non-carbonate hardness exceeding 50%. This facies is represented by samples numbers 3 and 7.

3 - The non-dominant hydrochemical facies, which is characterized by the absence of any cation or anion pairs exceeding 50%, is represented by sample numbers 2, 5 and 6.

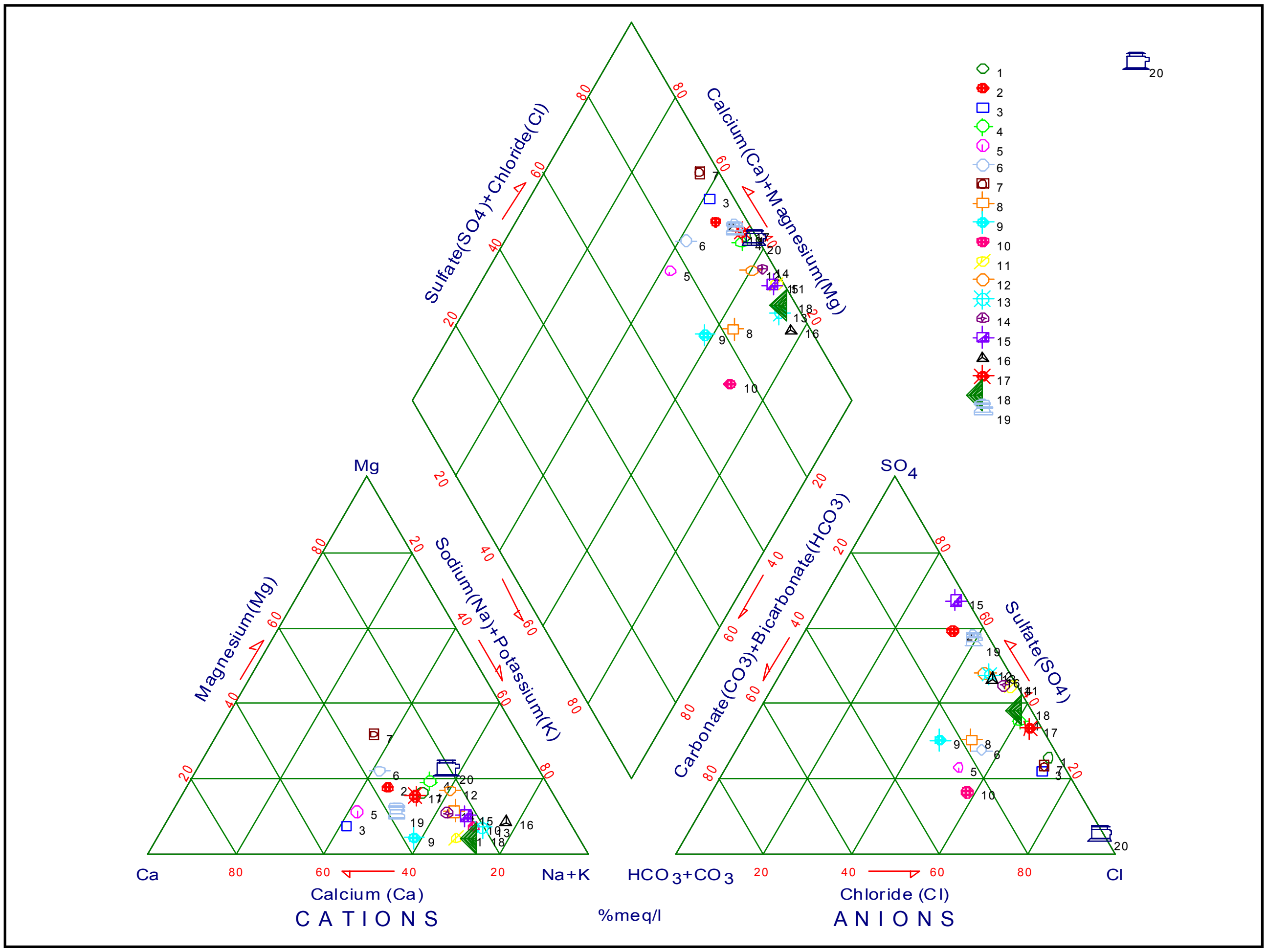

Figure 7. Presentation of the water samples in the study area on Piper's diagram.

MULTIVARIATE STATISTICAL ANALYSIS

Cluster and correlation analyses are used for classification of the hydrochemical variables in groundwater (Seyhan, et al., 1985; Erez and Gill, 1977; El-Refaei, 1992, 1999). Cluster and correlation analyses were carried out for wells tapping the Quaternary aquifer. The nontransformed input data matrix consisted of 20 cases (wells), representing a Quaternary aquifer, using the hydrochemical characteristics of TDS, pH, K, Na, Mg, Ca, Cl, SO_4, HCO_3, Zn, Pb, Fe and Mn. This 20 x 13 data matrix (Table 1) was processed by cluster analysis to classify the geochemical composition of the aquifer. The results are given as Q-mode and R-mode dendrograms (Figure 8), where the euclidean distance is 25. This value indicates that the processed cases are different in terms of their hydrochemical compositions. The Q-mode dendrogram is interpreted at one similarity level a-a' at euclidean distance 2. At similarity level a-a' the following case numbers are represented: 2 to 16, 18 and 19. The independent case includes sample numbers 1, 17 and 20, which are characterized by high water salinity and relatively high trace element concentration. Both cases tap the shallow Quaternary aquifer, but well No. 1 has a high concentration of salts due to clay content, and this well pumps many hours per day. Well number 17 is found in buried coral reefs, which might isolate this well from the aquifer, but well number 20 is located at a geomorphologically isolated hill.

The R-mode dendrogram of the hydrochemical variables (Figure 8) is processed using both the major and trace element concentrations, which show a distance coefficient of 25. The TDS shows independence and significance followed by Cl, HCO_3, Na, Ca, SO_4 and Mg, respectively. All trace elements with K are differentiated at a lower similarity level (i.e. short distance).

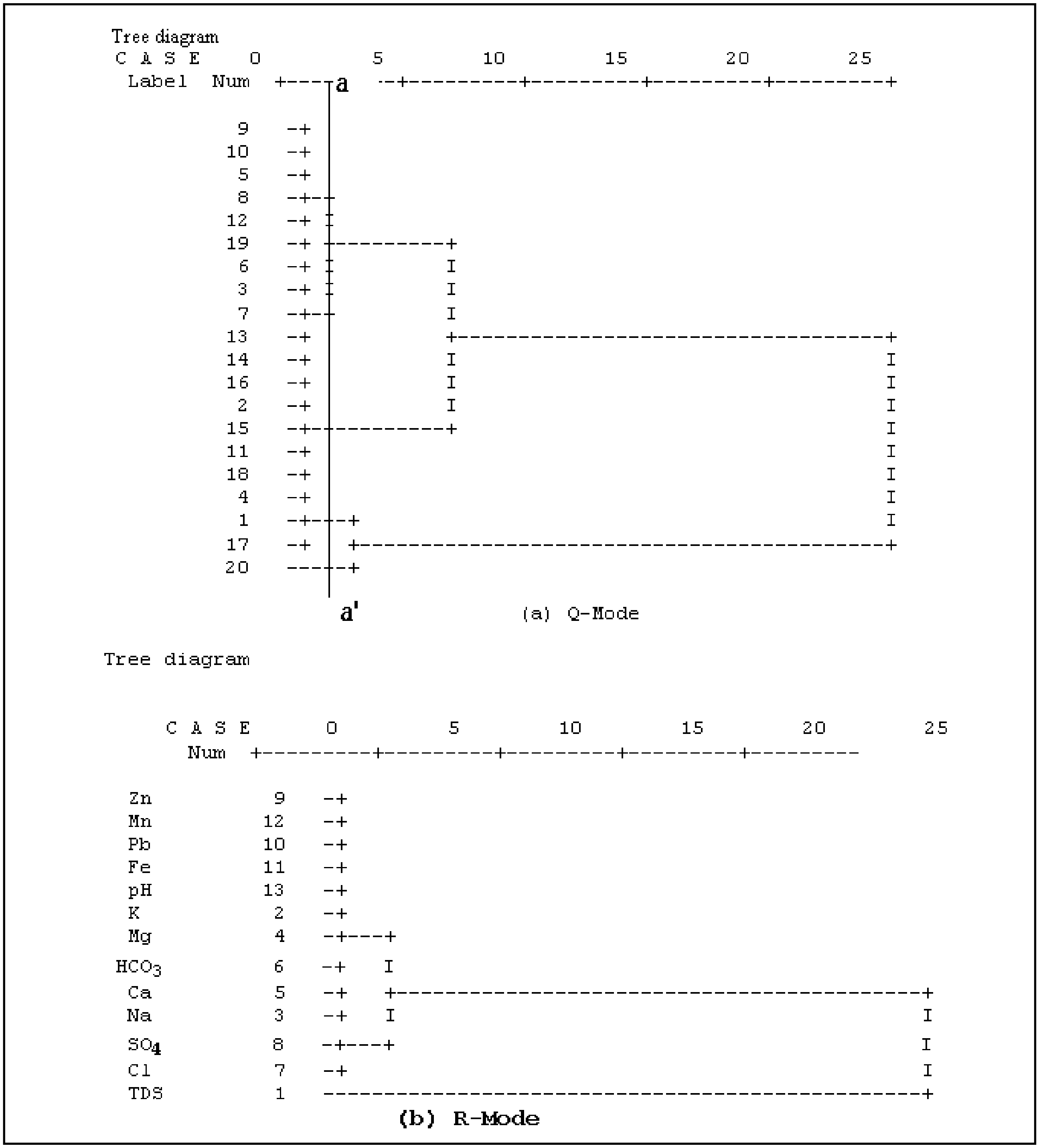

Figure 8. Q and R mode dendrograms.

Table 4. Correlation Matrix of Non-Transformed Data Input of the Major Elements in Groundwater

	PH	**TDS**	**K**	**Na**	**Mg**	**Ca**	**Cl**	**SO_4**	**HCO_3**	**Zn**	**Pb**	**Fe**	**Mn**
PH													
TDS	0.141												
K	0.365	0.448											
Na	0.104	0.689	0.613										
Mg	-0.286	0.358	0.446	0.4									
Ca	-0.174	0.72	0.566	0.84	0.729								
Cl	-0.007	0.665	0.56	0.891	0.625	0.919							
SO_4	-0.064	0.682	0.588	0.873	0.348	0.787	0.666						
HCO_3	-0.472	0.085	0.161	0.125	0.358	0.456	0.236	0.313					
Zn	0.518	-0.051	0.415	-0.201	-1.49	-0.211	-0.196	-0.18	-0.165				
Pb	-0.03	-0.132	0.066	0.287	0.199	0.17	0.262	0.163	0.122	-0.223			
Fe	-0.072	-0.316	-0.386	-0.282	-0.237	-0.293	-0.276	-0.283	0.051	-0.145	0.115		
Mn	0.201	0.556	-0.167	-0.171	-0.149	-0.107	-0.167	-0.099	-0.267	0.086	-0.462	-0.075	

The results of correlation analyses are given in Table 4 and are as follows:

1 - The TDS correlates well with the concentration of Na, Ca, Cl and SO_4, pointing to the role of the old marine water and deeply percolated meteoric water in the determination of the groundwater salinity.

2 - The good correlation between TDS and both Cl and SO_4 indicates mixing between waters of different genesis, old marine (rich in Ca and Cl ions), marine (rich in Mg and Cl ions) and deeply meteoric water (rich in Na and SO_4 ions).

3 - The weak correlation between TDS and HCO_3 reflects the distance of meteoric water recharge to the Quaternary aquifer, where HCO_3 ions decrease gradually due to precipitation as carbonates within rock pores.

4 - The concentration of Na correlates well with those of Mg, Ca, Cl and SO_4, which confirms the mixing process between waters of different genesis. The correlation between Mg and Cl and SO_4 is well matched, which represents a stage of dilution, where the $MgCl_2$ marine water is dominant within the aquifer.

5 - The weak positive correlation between HCO_3 and each of Na and Mg (0.125 and 0.358 respectively) reflects to the role of meteoric water recharge.

6 - The weak correlation value between the concentrations of SO_4 and HCO_3 points to the role of deeply percolated meteoric water in the hydrochemical composition of the aquifer.

7 - The weak correlation between concentrations of HCO_3 and those of Ca and Cl (0.456 and 0.236 respectively) indicates that they are derived from meteoric and sea water recharge.

8 - The K ions are correlated with Zn and Pb, which reflect the role of leaching processes that deliver those elements to groundwater.

9 - The pH value is inversely proportional to Ca and Cl ions, which means that old marine water increases in the mix with meteoric water.

Rock-water interaction model

The WATEQ program (Truesdell and Jones, 1974) computes the saturation indices in groundwater with minerals that are present in water samples. Eighteen minerals with different saturation indices were found. In this study, the chemical composition defines a saturation level with respect to a mineral. The minerals are differentiated with respect to the anion as carbonate, sulfate, or chloride minerals as follows:

1 - Carbonate minerals

Treated as four groups, the first consists of calcite, aragonite, magnesite and nesquehonite, the second group is represented by dolomite and huntite, the third group is the hydrated magnesium hydroxyl carbonates, which are represented here by artinite and hydromagnesite, and the fourth group is represented by nahcolite, natron, thermonatrite and trona.

2 - Sulfate minerals

Treated as two groups ,the first is the normal alkaline earth freshwater sulfate minerals, which include anhydrite and gypsum and the second group contains alkaline earth freshwater sulfate minerals , which include mirabilite and thenardite.

3 - Chloride minerals

These minerals are represented by halite.

4 - Hydroxide minerals

One of the hydroxide minerals identified by the model is brucite, a magnesium hydroxide.

The results are represented by saturation indices of minerals for each water sample. The chemistry of the rock-water interaction is determined in part by possible reactions with regard to the states of water (undersaturated or supersaturated with respect to solid phase or to a gas at certain pressure). The results of the WATEQ program are applied to the data of the area of El-Tur City (Table 5). The mineral saturation indices are plotted along one profile selected in the direction of water flow.

Table 5. Minerals Saturation Indices Through Wells in the Cross-Section A-A'

Mineral	**Well No.**									
	10	9	8	7	11	12	13	16	17	18
ANHYDRITE	-2.175	-1.724	-0.96	-0.96	-0.485	-1.228	-1.228	-1.101	0.684	-0.676
ARAGONITE	-0.07	0.085	0.37	0.37	0.278	-0.059	-0.059	0.107	0.877	0.652
ARTINITE	-5.316	-4.847	-4.187	-4.187	-4.096	-4.868	-4.868	-4.611	-3.489	-3.195
BRUCITE	-4.366	-3.904	-3.209	-3.209	-3.808	-3.578	-3.578	-3.546	1.946	-3.21
CALCITE	0.07	0.225	0.508	0.508	0.419	0.081	0.081	0.247	0.917	0.794
DOLOMITE	-0.143	0.317	1.233	1.233	0.239	0.23	0.23	0.493	-6.771	1.029
GYPSUM	-2.007	-1.556	-0.829	-0.829	-0.318	-1.06	-1.06	-0.924	1.686	-0.48
HALITE	-6.211	-6.074	-5.169	-5.169	-4.601	-5.682	-5.682	-5.097	-3.241	-4.597
HUNTITE	-4.34	-3.272	-1.06	-1.06	-3.891	-3.244	-3.244	-2.793	-14.934	-2.29
HYDROMAGNESITE	-13.266	-11.588	-8.361	-8.361	-12.578	-11.033	-11.033	-10.611	-17.111	-10.313
MAGNESITE	-0.593	-0.289	0.341	0.341	-0.559	-0.231	-0.231	-0.132	-3.263	-0.139
MIRABILITE	-7.037	-6.556	-6.039	-6.039	-4.398	-5.77	-5.77	-4.877	-9.844	-4.346
NAHCOLLITE	-4.487	-4.472	-4.365	-4.365	-4.097	-4.533	-4.533	-4.064	-8.569	-3.97
NATRON	-8.629	-8.443	-8.363	-8.363	-7.332	-8.297	-8.297	-7.377	-16.778	-6.748
NESQUEHONITE	-3.627	-3.323	-2.698	-2.698	-3.595	-3.265	-3.265	-3.166	-6.471	-3.173
THENARARDITE	-7.734	-7.252	-6.548	-6.548	-5.088	-6.465	-6.465	-5.617	-3.65	-5.177
THERMONATRITE	-9.84	-9.653	-9.397	-9.397	-8.537	-9.507	-9.507	-8.629	-11.46	-8.087
TRONA	-13.726	-13.525	-12.984	-12.984	-12.034	-13.439	-13.439	-12.138	-12.919	-11.594

The A-A* profile (hydrogeochemical cross-section profile), (Figure 9 and Table 5) passes through wells 7 to 13 and 16 to 18. This profile shows that the saturation indices increase in the direction of water flow for all minerals. Anhydrite and gypsum run nearly parallel to each other in the direction of water flow. This is also true for mirabilite and thenardite, although they are lower in saturation than anhydrite and gypsum due to alkaline and normal alkaline earth fresh water. Moreover, all minerals decrease in well 17 except calcite, brucite, gypsum, aragonite, anhydrite, artinite, hydromagnesite, halite and thenardite because this well is found in buried old coral reefs.

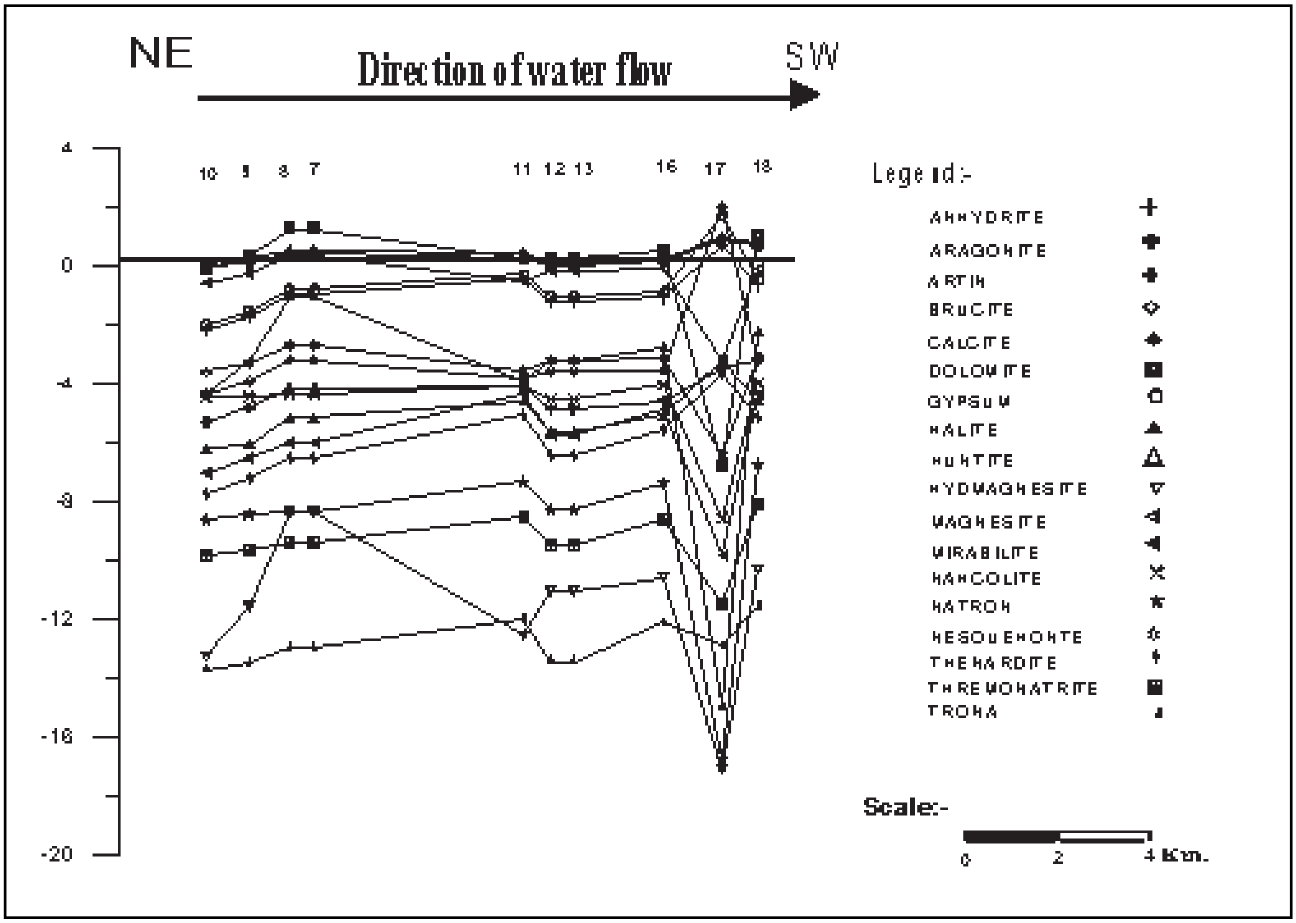

Figure 9. Hydrogeochemical cross-section A-A' in El-Tur City.

Classification of water according to salinity content and sodium adsorption ratio

The increase of total salinity in the irrigation water causes an increase of salt in the soil which damages plants. The quality of salts which can be withdrawn by plants, the type of soil and poor drainage permits salt concentrations in the root zone to build up to toxic levels.

According to a U.S. Salinity Laboratory (1954) classification, with a slight modification in the high salinity level (El-Ghandour et al., 1983), the water is divided into five types according to its salinity and electrical conductivity (Figure 10). Wells 5, 6, 8 to 10, 12 and 19 are good water quality and can be used for irrigation. Wells 3 and 7 have excess salts for irrigation. Wells 13, 14 and 16 are very poor for irrigation. Wells 1, 2, 4, 11, 15, 17, 18 and 20 are excessively saline, and cannot be used for irrigation without desalination.

CONCLUSION

From the chemical analysis of the twenty groundwater samples it is found that the groundwater

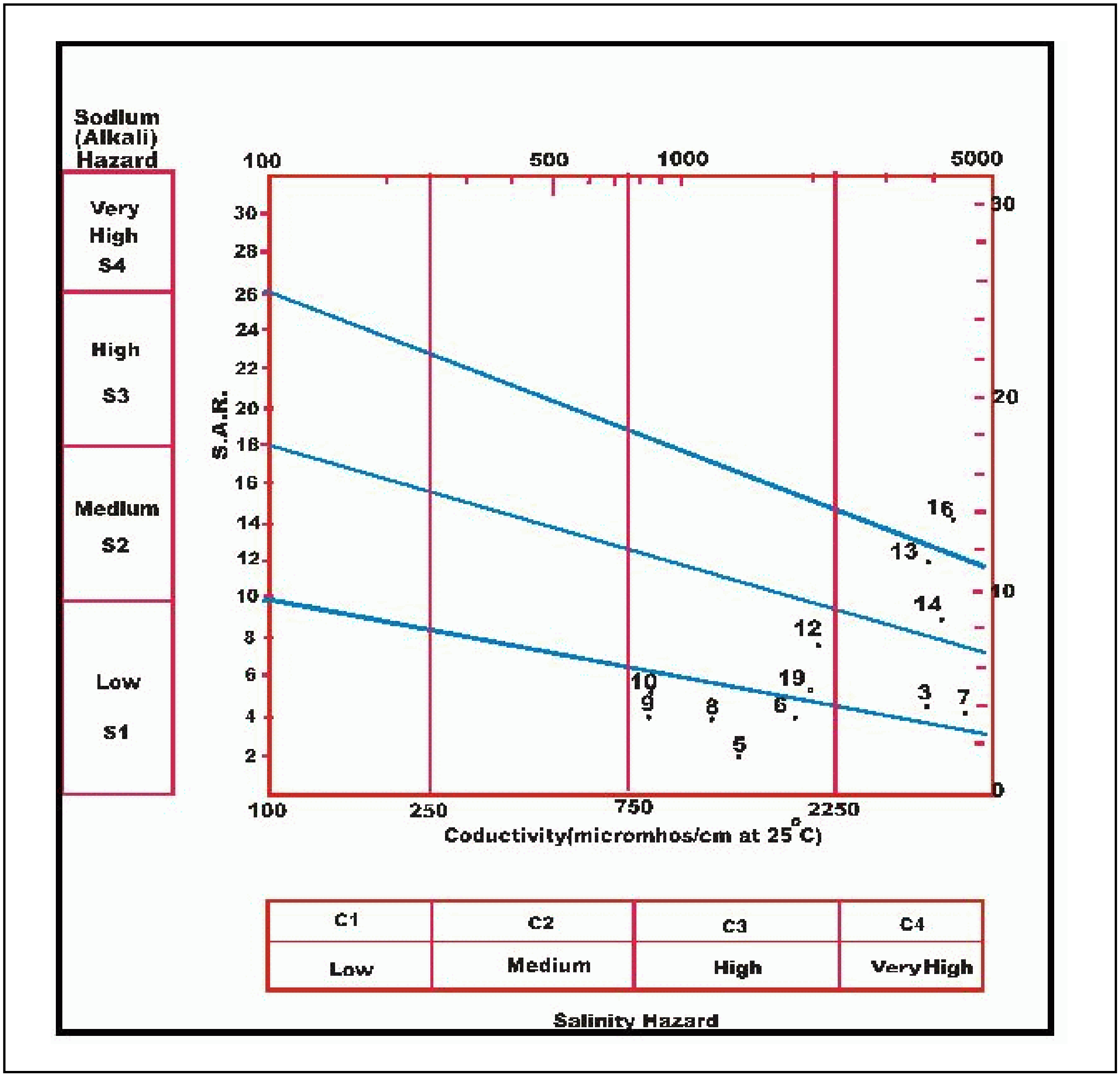

Figure 10. Diagram for classification of irrigation water (U.S. Salinity Laboratory Staff, 1954) for the groundwater of El-Tur City.

of the Quaternary aquifer in El-Tur area has a salinity content ranging from 534.91 to 8173 ppm. The salinity content is affected by the following:

1 - Saltwater intrusion of old marine water.

2 - The permeability and water flow within the aquifer.

3 - The annual floods and runoff, along the interconnected wadis.

4 - The discharge ratio of groundwater from the aquifer.

The hydrochemical parameters show that all samples in the aquifer of El-Tur City are of the Na_2SO_4 water type of meteoric genesis as in samples 1, 2, 8 to 16, 18, 19 and 20, while samples 4, 6 and 17 are of the marine water type ($MgCl_2$) showing intrusion of sea water in the study area . The $CaCl_2$ type of old marine water genesis is represented by samples 3, 5 and 7.

The hypothetical salt combinations of groundwater are classified into four groups as follows:

(1): KCl, $NaCl$, $MgCl_2$, $MgSO_4$, $CaSO_4$ and $Ca(CHO_3)_2$ (sample numbers 4, 5, 6, 17 and 20).

(2): KCl, $NaCl$, Na_2SO_4, MgSO4, CaSO4 and $Ca(CHO_3)_2$ (sample numbers 2, 8, 9, 11 to 16, 18 and 19).

(3): KCl, $NaCl$, $MgCl_2$, $CaCl_2$, $CaSO_4$ and $Ca(CHO_3)_2$ (sample numbers 1, 3 and 7).

(3): KCl, $NaCl$, Na_2SO_4, $MgSO_4$, $Mg(CHO_3)_2$ and $Ca(CHO_3)_2$ (sample number 10).

The El-Wadi village area shows that samples 2, 5 and 6 in subarea 9 are characterized by non cation-anion pair that exceeds 50 %, but sample numbers 3 and 7 in subarea 6, are characterized by non-carbonate hardness "secondary salinity" that exceeds 50 %. Sample numbers 1, 4, 8, 9 and 10 in subarea 7, where non-carbonate hardness "primary salinity" exceeds 50 %, is characterized by alkalis and strong acids.

In the El-Sheihk Gabel area, sample numbers 11 to 20 are found in subarea 7.

The WATEQ program is used to calculate the saturation indices for all minerals in the water samples. Using the chemical analyses and physicochemical parameters, 18 minerals were found with different saturation indices. These minerals are classified into four mineral groups according to the anion part of the mineral. They have the same behavior in the direction of water flow. Also each group is classified into different subgroups according to the cation part of the minerals. The saturation indices of all minerals increase due to rock-water interactions.

Multivariate statistical analyses were carried out for elements in groundwater from wells tapping the shallow Quaternary aquifer at the El-Tur area .The cluster analyses show good agreement with the iso-salinity map and the water level map, reflecting recharge direction and flushing system.

Wells 2 to 10, 12 to 14, 16, 18, and 19 are good quality water and can be used for irrigation. Wells 1, 11, 15, 17 and 20 need the removal of excess salts before using their water for irrigation.

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