Evaluation of Quaternary aquifer for agricultural purposes in northwest Sinai, Egypt

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Abstract: Northwest Sinai is characterized by a semiarid climate and due to insufficient surface water resources; Quaternary aquifer is the main water supply. The Quaternary groundwater exists under free water table conditions with water level ranges between -3.7 m and 10 m. The groundwater flow is concentric around El-Salam Canal as a result of its closure and over-pumping of groundwater. In order to evaluate the suitability of Quaternary aquifer for irrigation purposes, the chemical characteristics have been investigated in fifty samples collected from tube wells and dug wells. The total dissolved solids (TDS) range from 692 mg/l to 9384 mg/l; indicating fresh to saline water classes. Sodium, chloride and sulphate ions display a nearly linear increase with increasing salinity. The main groundwater genetic types are $CaCl_2$ and $MgCl_2$, reflecting the marine water affinity. Such waters are mostly unsuitable for irrigation under a normal condition and further action for salinity control is required in remediating such a problem. Also, the poor irrigation water can be managed by improving irrigation management technologies and using salt tolerance plants.

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Keywords: Quaternary; aquifer; Sinai; Egypt; evaluation**;** agriculture**.**

Introduction:

The Sinai Peninsula covers an area of about 61,000 km^2 in the northeastern side of Egypt. The study area is located in the northwest corner of Sinai Peninsula, bordered from the north by the Mediterranean Sea and from the west by the Suez Canal (Fig. 1). The northern Sinai coast is located within the rainy belt of Egypt; while the aridity increases generally to the south (El-Ghazawi, 1989). Rainfall is scarce and varies from place to place and increases in the northeastern direction, ranging from about 30 mm/year in the southwest at Isamilia to about 300 mm/year in the northeast at Rafah. The annual rainfall in northwest Sinai varies between 36 to 54.8 mm and the total quantity of rainfall generally increases northward (El-Sheikh, 2008). The rainfall has a direct contribution to groundwater recharge in the sand dune aquifer north Sinai, particularly El-Arish−Rafah area (El-Ghazawi, 1989). The northern Sinai is occupied by sand dunes that mostly acting as water bearing formation, where the groundwater exists as a thin layer above the main saline water (El-Shazly *et al.,* 1974). The salinity values of Quaternary aquifer between Rommana and Bir El-Abd region range from 1876 to 7937 mg/l. This variation is due to the variation of the annual rainfall (Eweida *et al.,* 1992). The sources of high salinity in the area between Baloza and Rommana can be attributed to evaporation, the dissolution of evaporites, salt water intrusion and the influence of brines (Groschke, 2010). The total dissolved solids (TDS) of groundwater in El-Tineh plain and its vicinities increase in the direction of groundwater flow and range from 2450 mg/l to 16940 mg/l (Deiab, 1998). The salinity of surface and subsoil water in northwest Sinai is a mixture of meteoric and marine water due to salt water intrusion from the Mediterranean Sea and leaching processes of the lagoonal deposits (Deiab, 1998). Mohamed (2007) found that the danger of sea water intrusion on the Quaternary aquifer may not permit exploiting north Sinai as an industrial district for Bir El-Abd and its surroundings as was planned before.

Much of the arable land in the area would eventually be irrigated with Nile River water through the El-Salam Canal after blending with agricultural drainage water in a ratio of about 1:1 to reach TDS not more than 1000-1200 mg/l to be suitable for cultivated crops (Hafez, 2005). The estimated reclamation area in East Suez Canal is about 400,000 feddans (feddan= 4200 m^2) divided to 50,000 feddans for El-Tina plain area, 75,000 feddans south El-Qantara Shark area, 70,000 feddans for Rabaa area, 86,000 feddans for Bir El-Abd area, 33,000 feddans for El-Mazar and Midan areas, and 85,000 feddans for Alsir and Qwareer areas (Hafez, 2005).

The objective of the present study is to assess the chemical groundwater composition and its suitability for agricultural uses in northwest Sinai. To achieve this goal the collected samples were analyzed for the major constituents, nitrogen (nitrate and nitrite) and phosphate and different chemical indices are calculated.

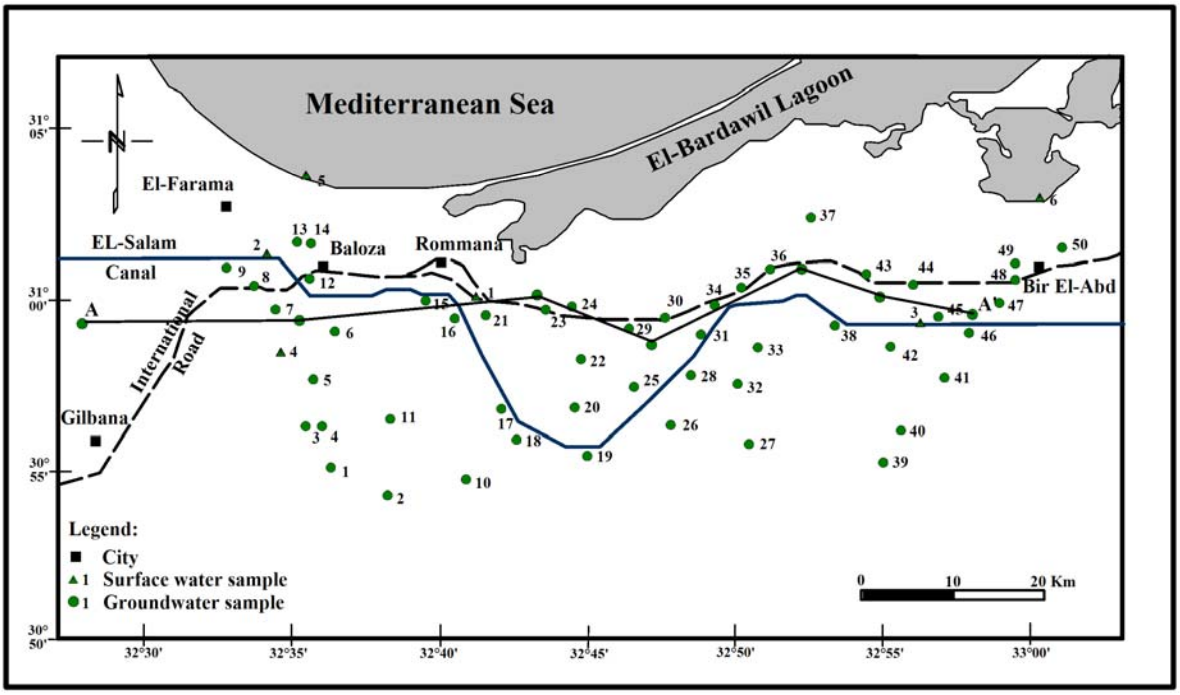

Fig. (1): Location map of the collected surface- and ground-water samples, northwest Sinai, Egypt (April, 2010).

Methodology:

Fifty groundwater samples from wells tapping the Quaternary sandy aquifer were collected in addition to five surface water samples in April 2010 (Fig. 1). Unstable parameters such as pH and electrical conductivity (EC) were measured in the field using pH meter (CONSORT P903, after Richards, 1954) and EC meter (Cyberscan Conductivity Meter CON 100). Major ions were analyzed in the laboratory. Calcium and magnesium contents were determined by EDTA titration using Eriochromeblack-T as indicator (Jackson, 1958). Sodium and potassium contents were determined using Flame Photometer (Rhoades, 1982). Carbonate and bicarbonate contents were measured by acid-base titration (Nelson, 1982). Sulphate was measured using a turbidity method (Adams, 1990). Chloride concentration was measured by silver nitrate titration using Volhard's method. Nitrate and nitrite ions were determined colorimetrically by using UV/visible Spectrophotometer (Harrison and Perry, 1986). Phosphate was determined colorimetrically based on hydroquinone method described by Snel and Snel (1967).

Geomorphologic and geologic setting:

Northwest Sinai is located within the semi-arid belt of Egypt. This aridity is manifested by the occurrence of sand dunes and sand sheets, salt marshes and ponds as well as lack of vegetation. Geomorphologically, northwestern Sinai embodies five distinctive units; 1) coastal area, which includes old shore, coastal sand dunes, the strand plain of successive beach ridges with intervening runnels recording shoreline progradation during Late Holocene, and deltaic plain covered by mouth bar and distributary channel fill sands (El-Asmar, 1999); 2) El-Bardawil Lagoon; 3) aeolian sand which covers the majority of north Sinai and consists of wind-laid sediments including aeolian siliclastic sabkhas (Assal, 1999); 4) mobile sand dunes; and 5) salt marshes and sabkhas (inland sabkhas and coastal sabkhas).

Geologically, northwestern Sinai is covered by Quaternary deposits. The Pleistocene deposits include: Sahl El-Tineh Formation which consists of a mixture of black and white sands with silt, Al-Qantara Formation which consists of sand and grits with minor clay interbeds, coquina deposits, fanglomerates, and alluvial hamadah deposits (Geological Survey of Egypt, 1992). According to GSE (1992), the Holocene deposits are classified into: coastal sand dunes which extend parallel to the Mediterranean Sea coast, inland sand dunes and sheets that cover large areas of northwestern Sinai (the main water bearing formation for groundwater), coastal and inland sabkhas, and interdunal playa deposits; consist of fine sand and silt associated with evaporates (Deiab, 1998).

Hydrological setting:

The Quaternary deposits constitute the important water-bearing formations in the northwestern Sinai area. These deposits consist mainly of loose sand with few clay intercalations (Fig. 2). The thickness of such deposits increases towards the west. The Quaternary groundwater exists under free water table condition (Fig. 2). The depth to water varies from 0.5 m in the northwest to 9.1 m in the southeast. It is principally controlled by the surface topography, lithology and recharge. The water table ranges between -3.7 m to 10 m in the northeast corner where steep gradient is observed (Fig. 3). A remarkable local groundwater flow is detected in two locations; the first is concentric around El-Salam Canal to the east of Baloza and south El Farama sector, while the second is recorded to the south of Rommana where extensive parts of land are waterlogged forming salt marshes and salty ponds, e.g. Rommana pond. The amount of rainfall recharging the Quaternary groundwater aquifer within the period 2005-2006 is about 8.67 million m^3 (El-Sheihk, 2008).

Geochemical properties of Quaternary aquifer:

The source of recharge, type of sediment, and groundwater flow are mainly affecting the geochemical characteristics of the Quaternary aquifer in northwest Sinai. From the chemical analyses given in Tables (1 & 2), the following properties could be deduced:

The pH values of groundwater mostly reflect slightly alkaline condition. The total dissolved solids (TDS) range from 692 mg/l to 9384 mg/l (Table 3). The salinity decreases at some patches located along El-Qantara Shark/El-Arish Road. The Quaternary groundwater along this road is affected by seepage from municipal water. Most of the Quaternary groundwater samples belong to brackish and saline classes; only 8% of the samples are fresh water (less than 1500 mg/l) according to Chebotarev's classification (1955).

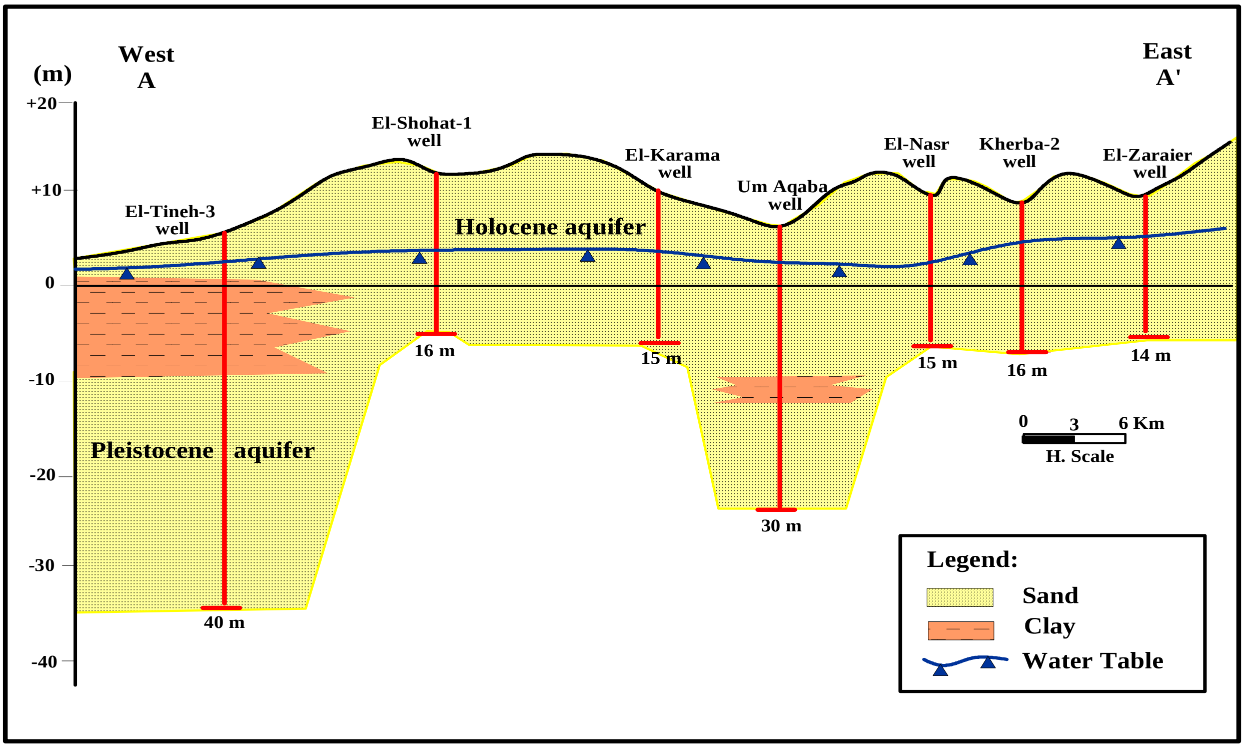

Fig. (2): West-East hydrogeological cross section (modified after El-Osta, 2000), the locations of these wells are shown in Fig. (1).

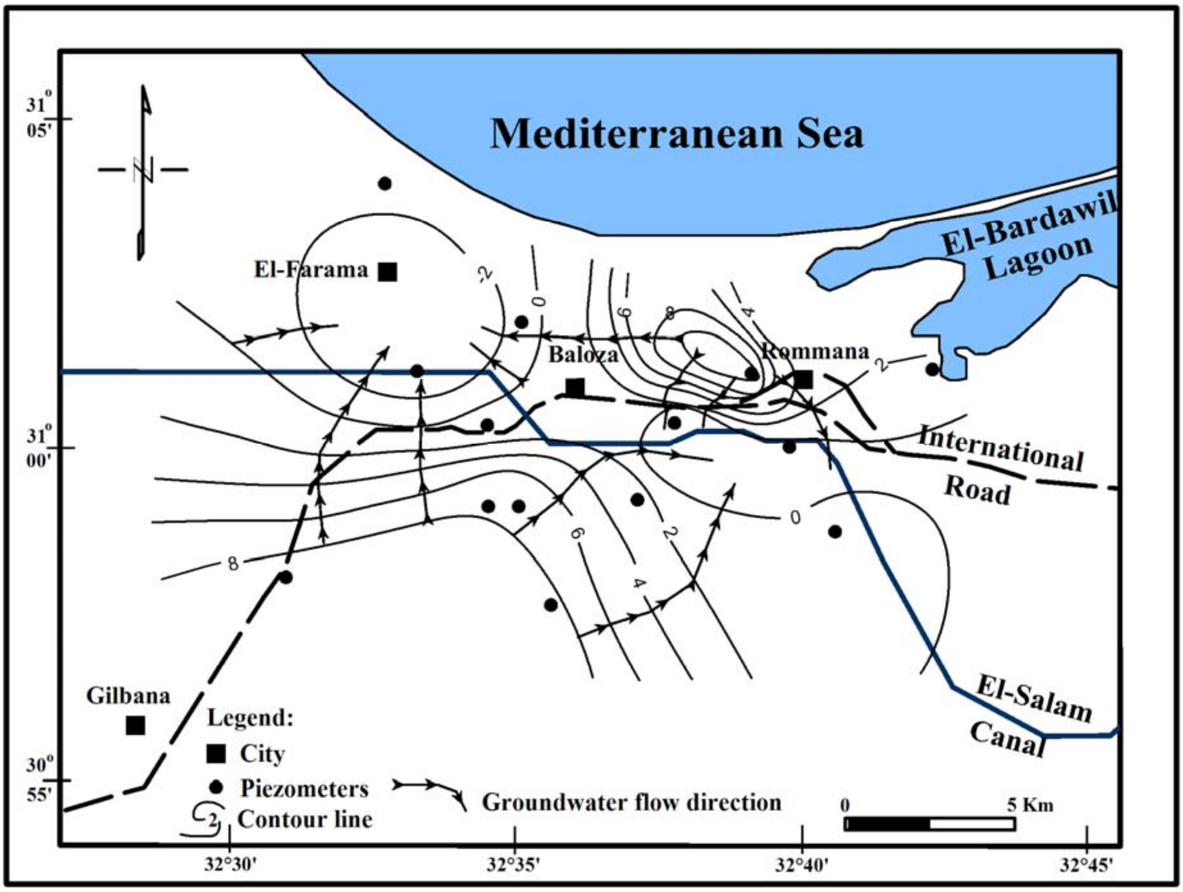

Fig. (3): Water table contour map of Baloza-Rommana area (April, 2009) with groundwater flow direction.

Potassium represents the least dominant cation; ranges from about 3 to 80 mg/l with an average of about 21 mg/l (Fig. 4 & Table 3). Sodium represents the dominant cation in the majority of the analyzed groundwater samples; varies between 86 and 2902 mg/l with an average of 1121 mg/l (Fig. 4 & Table 3). The highest Na^+ concentrations are recorded near the Mediterranean Sea. Sodium, chloride and sulphate ions display a nearly linear increase with increasing salinity of Quaternary groundwater (Fig. 5).

Magnesium ranges between 4 and 571 mg/l. The high values of magnesium reflect the abundance of magnesium salts that formed by marine water intrusion (mainly $MgCl_2$ & $MgSO_4$ salts). Calcium ranges between 20 and 1002 mg/l. Calcium concentrations increase generally towards northeast direction due to leaching and solubility processes of calcium carbonate rich deposits (Kurkar) due east. Similar conclusions have been suggested by El-Osta (2000).

Chloride ranges between 68 and 4756 mg/l. The highest concentrations are recorded near the Mediterranean Sea due to sea water encroachment. Sulphate content ranges between 108 and 1340 mg/l. In addition to salt water encroachment, the high values of sulphate may be due to dissolution of sulphate-bearing sediments and input from sulphate fertilizers applied in new reclaimed lands. Bicarbonate content ranges between 121 and 416 mg/l with an average of 201 mg/l (Table 3).

Table (1): Results of chemical analyses for the surface water samples in the area Northwest Sinai, Egypt (April, 2010).

Ser. No.	Locality	EC	TDS	pH	Cations				Anions				NO_2^- &NO_3^-	PO_4^{-3}	Water parameters				
					K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	CO_3^{--}	HCO_3^-			SAR	Na^+ %	MH	RSC	TH
1	Municipal water (mosque in 6th October village)	1.02	952	8.24	12.9	174	55	40	238	197	0.0	235	1.22	1.40	4.2	52.6	69.2	-2.7	325
2	El-Salam Canal at pumping station No. (5)	2.90	2518	9.29	46.0	656	68	148	1208	257	66.0	134	0.08	0.35	11.2	66.8	43.0	-8.6	650
3	El-Salam Canal at pumping station No. (6)	2.20	1549	8.97	26.5	532	8	40	500	302	19.8	141	0.44	1.40	20.0	87.4	25.1	0.3	134
4	Water logged area at Baloza El-Shohat road	38.20	23160	7.32	114.9	6999	717	521	11572	2968	0.0	269	0.05	1.75	46.7	77.6	69.4	-80.6	4251
5	Mediterranean Sea.	48.20	34252	8.07	938.5	9749	1434	440	18631	2857	0.0	201	0.17	0.35	50.7	72.1	84.3	-137.0	7000
6	El-Bardawil Lagoon.	57.20	37416	7.95	24.6	12948	371.9	721	19740	3368	0.0	242	0.29	1.05	97.5	89.3	45.9	-62.7	3332

Table (2): Results of chemical analyses for the groundwater samples of the Quaternary aquifer in the area Northwest Sinai, Egypt (April, 2010).

Ser. No.	Locality	EC	TDS	pH	Cations				Anions				NO_2^- &NO_3^-	PO_4^{-3}	Water parameters				
					K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	CO_3^{--}	HCO_3^-			SAR	Na^+ %	MH	RSC	TH
1	Mohamed Abd Al-Rahman	5.92	4296	7.92	17.2	1091	95	341	1906	686	0.0	161	0.39	1.05	13.5	65.2	31.4	-22.2	1241
2	Farm south El-Shohat road	5.78	3808	7.34	15.3	894	109	293	1702	660	0.0	134	0.07	0.70	11.3	61.8	38.1	-21.4	1181
3	El-Akharsa (1)	9.02	5783	7.26	20.0	1534	340	100	3063	584	0.0	141	0.86	1.05	16.4	66.6	84.8	-30.7	1650
4	El-Akharsa (2)	6.08	4505	7.14	18.6	1210	103	301	2042	629	0.0	201	0.90	0.70	15.3	68.7	36.1	-20.2	1176
5	El-Shohat	8.81	6697	7.08	18.6	1961	255	80	3403	784	0.0	195	0.00	0.70	24.1	77.0	84.0	-21.8	1250
6	Amr Tawfik	7.27	3799	7.50	15.3	614	316	301	1702	718	0.0	134	0.15	1.05	5.9	39.2	63.4	-38.8	2051
7	Ali Selim	6.32	4385	7.54	41.5	1190	67	220	2042	556	0.0	268	1.05	0.70	18.0	74.6	33.3	-12.1	825
8	Masoud Abo El-Sood (1)	1.97	1574	7.74	21.5	451	34	60	400	225	0.0	383	1.76	1.05	11.5	75.5	48.2	0.5	290
9	Masoud Abo El-Sood (2)	0.81	820	7.47	19.3	86	12	116	68	143	0.0	376	2.16	1.40	2.0	33.8	14.7	-0.6	340
10	Salama Nasaar	4.93	4443	7.60	20.1	931	272	252	2246	600	0.0	121	0.35	1.05	9.7	53.3	64.0	-33.0	1751
11	Fathy	7.22	3895	7.42	14.4	759	122	441	1634	724	0.0	201	0.25	1.05	8.2	50.5	31.2	-28.7	1601
12	Hanan Kamal	19.75	9384	7.44	80.4	2902	58	481	4756	905	0.0	201	0.81	2.10	33.2	80.3	16.6	-25.6	1441
13	Yasser El-Sayd (1)	5.25	3549	7.87	38.3	631	168	333	1787	324	0.0	268	10.03	0.70	7.0	46.6	45.3	-26.0	1521
14	Yasser El-Sayd (2)	10.56	6566	8.19	56.5	2179	56	200	3403	470	0.0	201	2.85	1.05	35.0	85.5	31.5	-11.3	730
15	Ebrahem Salem	16.57	8697	7.00	27.2	2591	407	20	4254	1270	0.0	128	3.34	1.75	27.1	76.2	97.1	-32.4	1725
16	Mohamed El-Atar	6.32	4242	6.90	15.7	635	365	361	2042	622	0.0	201	0.95	0.70	5.6	36.3	62.4	-44.7	2401
17	Mahmoud Hussein	6.22	3760	7.34	20.0	635	304	200	1872	581	0.0	148	0.27	0.70	6.6	43.7	71.4	-32.6	1751
18	Abu Elgolod	4.75	3329	7.67	12.5	865	80	212	1566	473	0.0	121	1.06	0.70	12.8	68.2	38.3	-15.2	860
19	Farm beside lifting station 46,750 km	4.92	3614	7.27	17.9	802	134	301	1702	457	0.0	201	0.14	0.70	9.7	56.8	42.2	-22.7	1301
20	Mohamed Abdallah	9.20	3152	7.26	31.6	319	105	557	1361	644	0.0	134	1.30	0.70	3.2	27.1	23.6	-34.2	1821

Table (2): Cont.

Ser.					Cations				Anions						Water parameters				
No.	Locality	EC	TDS	pH	K^+	Na^+	Mg^{++}	Ca^{++}	Cl^-	SO_4^{--}	CO_3^{--}	HCO_3^-	NO_2^- &NO_3^-	PO_4^{-3}	SAR	Na^+ %	MH	RSC	TH
21	Sabry Ali	1.95	1437	7.59	11.4	160	182	100	681	168	0.0	134	0.29	0.70	2.2	25.5	75.0	-17.8	1000
22	Mohamed Salah	15.10	6495	6.84	61.3	1613	95	541	3063	987	0.0	134	0.71	2.80	16.8	65.8	22.4	-32.7	1741
23	Abdalla Khalifa	2.05	2072	7.40	15.4	432	80	160	817	159	52.8	356	0.93	4.20	6.9	55.6	45.1	-7.0	730
24	Salama Abdel -Allah	7.17	5280	7.45	12.3	1451	85	381	2723	454	0.0	175	0.93	1.05	17.5	70.5	26.9	-23.2	1301
25	Seliman Maqbol	5.46	4467	7.10	20.7	511	571	261	2424	444	0.0	235	16.22	1.75	4.1	26.9	78.3	-56.2	3001
26	Farm in Taia village	5.00	5692	7.50	15.3	1795	90	224	3063	343	0.0	161	0.15	0.35	25.6	80.4	39.7	-16.0	930
27	Farm to the south of Taia village	11.04	7165	7.12	13.4	1915	97	581	3744	613	0.0	201	1.03	1.05	19.3	69.0	21.6	-33.8	1851
28	Abdel-Baset Elsaid	10.06	7707	7.18	23.6	1923	523	40	4084	771	0.0	342	0.29	1.75	17.6	64.7	95.6	-39.4	2250
29	Um Oqba	5.66	6862	7.40	28.7	2165	122	257	3725	444	0.0	121	0.61	1.05	27.9	80.0	43.8	-20.8	1141
30	Seliman Hassan	0.67	692	7.59	13.1	95	29	100	78	108	66.0	268	0.57	1.05	2.1	34.8	32.4	-0.8	370
31	El-Shahat Ebrahem	11.63	7752	7.05	19.3	1279	365	1002	4186	733	0.0	168	0.88	1.05	8.8	40.8	37.4	-77.3	4002
32	Farm to the north of Taia village	11.45	4777	7.14	26.8	513	231	761	2174	883	0.0	188	1.01	1.40	4.2	27.9	33.3	-54.0	2852
33	Abu Kharab	12.73	7759	6.67	24.3	2131	450	100	4131	735	0.0	188	0.78	1.75	20.2	68.5	88.1	-38.9	2100
34	Mashrqy	11.24	5315	7.07	13.8	749	352	661	2772	619	0.0	148	0.64	5.60	5.8	34.3	46.7	-59.6	3101
35	Abd Alkarim	6.03	4200	7.36	22.9	535	219	641	2178	416	0.0	188	0.59	1.40	4.6	31.5	35.9	-47.0	2501
36	El-Masoody	4.28	2531	7.41	12.3	463	109	252	1021	378	0.0	295	1.08	5.95	6.1	47.9	41.6	-16.8	1081
37	El-Naga	16.90	8600	6.91	40.8	1620	462	782	4171	1337	0.0	188	0.52	5.25	11.3	47.4	49.3	-74.0	3852
38	Hassan Hammad	6.18	4609	7.20	15.0	695	182	701	2314	533	0.0	168	1.13	0.70	6.0	37.5	29.9	-47.3	2501
39	El-Tophaha	5.51	2337	7.39	8.5	297	149	313	956	479	0.0	134	0.32	3.85	3.5	31.5	43.9	-25.7	1393
40	El-Zarawita	6.99	5477	7.46	15.4	1094	238	489	2723	784	0.0	134	0.34	4.55	10.1	51.7	44.4	-41.8	2199
41	Salem Ali	6.63	5697	7.43	8.5	1400	171	393	2927	664	0.0	134	0.24	4.55	14.8	64.2	41.7	-31.5	1683
42	El-Fater	6.78	6144	7.33	11.5	1609	236	329	3403	394	0.0	161	0.27	3.50	16.5	65.9	54.2	-33.2	1793
43	Abu Mahmoud	1.86	1800	7.78	8.6	281	135	140	608	298	0.0	329	3.07	3.15	4.1	40.0	61.2	-12.7	904
44	Salem Soliman	2.03	2837	7.76	3.1	869	46	76	1361	213	6.0	268	0.68	0.70	19.4	83.1	49.9	-3.0	380
45	Ahmed Ebrahem	9.12	6408	7.29	19.3	1745	122	501	3335	559	0.0	128	0.86	0.70	18.1	68.1	28.5	-33.0	1751
46	El-Himida	9.79	7703	6.89	16.2	2064	277	473	4084	654	105.6	134	0.52	3.50	18.6	65.7	49.1	-40.7	2321
47	Wael Ebrahem	10.97	7948	7.15	13.1	1959	331	493	4325	625	0.0	201	0.29	4.90	16.7	62.0	52.5	-48.6	2593
48	Ragy El-Magfra (2)	1.20	954	7.82	7.9	264	4	20	102	140	0.0	416	0.96	0.70	14.0	88.2	25.4	5.5	67
49	Farm in Bir El-Abd city	2.08	1569	7.44	15.7	301	49	140	613	162	0.0	289	21.62	1.05	5.6	53.4	36.3	-6.3	550
50	Aisha El-Heed	15.93	8257	7.28	17.7	1821	397	573	3948	1340	0.0	161	1.42	5.25	14.3	56.2	53.2	-58.6	3063

Units in mg/l except pH, Electrical Conductivity (EC) in mmhos/cm at 25^oC, Sodium Absorption Ratio (SAR) and Residual sodium carbonate (RSC) in epm, Total Hardness (TH) in mg/l, 1 mg/l of nitrate-N is equivalent to 4.5 mg/l of nitrate-NO_3 (Bauder *et al.*, 2004). Magnesium hazard (MH) % = (Mg^{2+}×100)/ (Ca^{2+}+Mg^{2+}), where all ionic concentration expressed in equivalent per million (epm), according to Szabolcs and Darab (1964). Na % = (Na^+) x 100/ (Ca^{2+} + Mg^{2+} + Na^+ + K^+), where the concentrations of ions are expressed in epm (Wilcox, 1955). TDS are the summation of anions and cations.

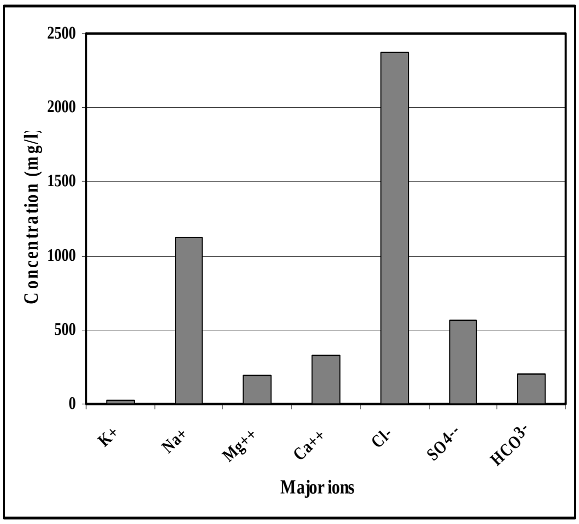

Fig. (4): Average values of major ions (mg/l) for the groundwater samples of the Quaternary aquifer, northwest Sinai, Egypt.

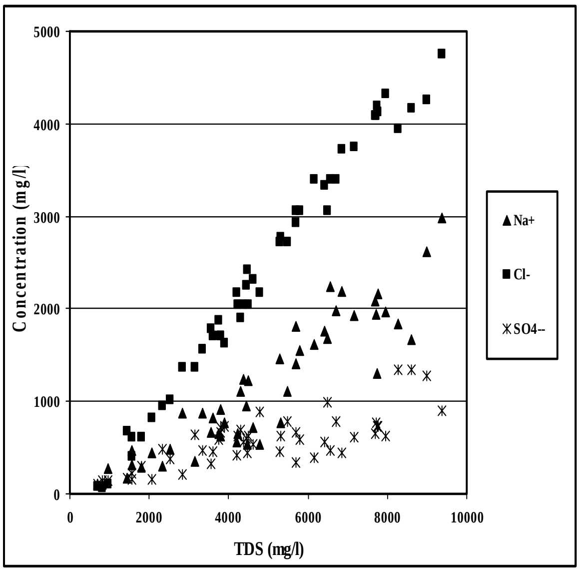

Fig. (5): Relationship between TDS and chloride, sodium, and sulfate concentrations (mg/l) for the groundwater samples of the Quaternary aquifer in the area northwest Sinai, Egypt.

Table (3): Concentration ranges for the measured constituents, water parameters and hydrochemical ratios in the groundwater samples of the Quaternary aquifer in the area northwest Sinai, Egypt.

		Minimum	Maximum	Average
pH values		6.67	8.19	7.36
E.C. (mmohs/cm at 25°C)		0.67	19.75	7.42
TDS (mg/l)		692	9384	4817
Ions (mg/l)	**K^+**	3.1	80.4	21.2
	Na^+	86	2902	1121
	Mg^{+2}	4	571	196
	Ca^{+2}	20	1002	333
	Cl^-	68	4756	2374
	SO_4^{-2}	108	1340	570
	HCO_3^-	121	416	201
	PO_4^{-3}	0.35	5.95	1.90
	NO_2^-&NO_3^-	0.0	21.6	1.75
Water parameters	**SAR**	2	35	12.8
	Na^+ %	25.5	88.2	56.5
	MH%	14.7	97.1	46.8
	RSC	-77.3	5.5	-29.3
	TH	67	4002	1638
Hydrochemical coefficients (ratios)	**rNa/rCl**	0.33	3.99	0.83
	rMg/rCl	0.04	1.09	0.29
	rCa/rCl	0.01	3.03	0.38
	rCa/rMg	0.03	5.81	1.57
	rSO_4/rCl	0.08	1.55	0.26
	r(Cl-Na)/rCl	-2.99	0.67	0.17
	$rCl/r(HCO_3+CO_3)$	0.3	57.3	23.5

SAR: Sodium absorption ratio in epm, RSC: Residual sodium carbonate in epm, MH: Magnesium hazard in %, TH: Total hardness in mg/l.

The comparison of the average values of the calculated hydrochemical ratios of the Quaternary groundwater with those of sea water indicates that all ratios are higher than sea water except r(Cl-Na)/rCl ratio (Fig. 6 and Table 3).

Ion exchange between intruding sea water and fresh water aquifer matrix results in an increase in the rCa/rMg ratio when compared to the sea water ratio (Daniele *et al*., 2010). Thus, the values of rCa/rMg ratio in 32% of the groundwater samples approach the value of the Mediterranean Sea sample (0.19) reflecting the effect of sea water intrusion. The calculated values of rSO_4/rCl of the groundwater samples 14, 26, 29, 42 and 47 are around the sea water value (0.11). This may also reflect the effect of sea water encroachment. Meanwhile, ninety percent of the samples are more than the sea water value, which may be due to the effect of evaporation and agricultural activities (Fig. 6).

In addition, the majority of Quaternary groundwater samples (70%) has values of $rCl/r(HCO_3+CO_3)$ ratio more than 15.5, which indicates highly contaminated groundwater. The rest of samples (30%) vary between moderately contaminated and injuriously contaminated groundwater (according to Simpson, 1946). Thus, the Quaternary groundwater aquifer is highly contaminated with salt water intrusion.

The analyzed Quaternary groundwater samples comprise two main water types; $CaCl_2$, $MgCl_2$, reflecting the marine affinity (Fig. 7). The $CaCl_2$ type (48% of the groundwater samples) represents the hydrochemical composition of old marine water genesis. The $MgCl_2$ type (represents 42% of groundwater samples) reflects normal sea water composition. El-Salam Canal sample (2) belongs to this type. The $NaHCO_3$ water type (samples 8 & 48) suggests a meteoric origin and corresponds to surface running water or shallow water conditions. The Na_2SO_4 water type (samples 9, 30 & 44) corresponds to the deep meteoric water percolation (Fig. 7).

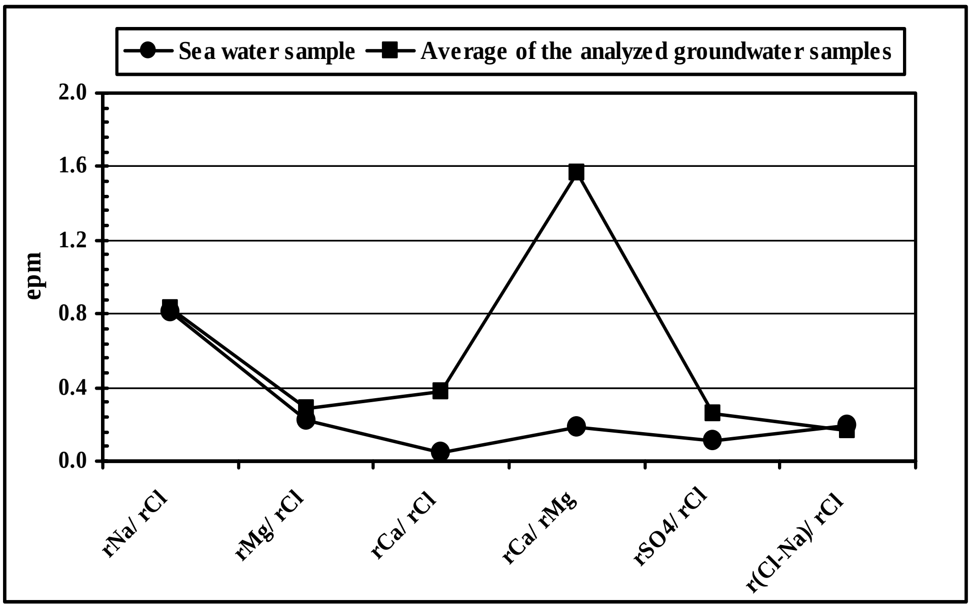

Fig. (6): The hydrochemical ratios in the Quaternary groundwater in the study area compared with sea water.

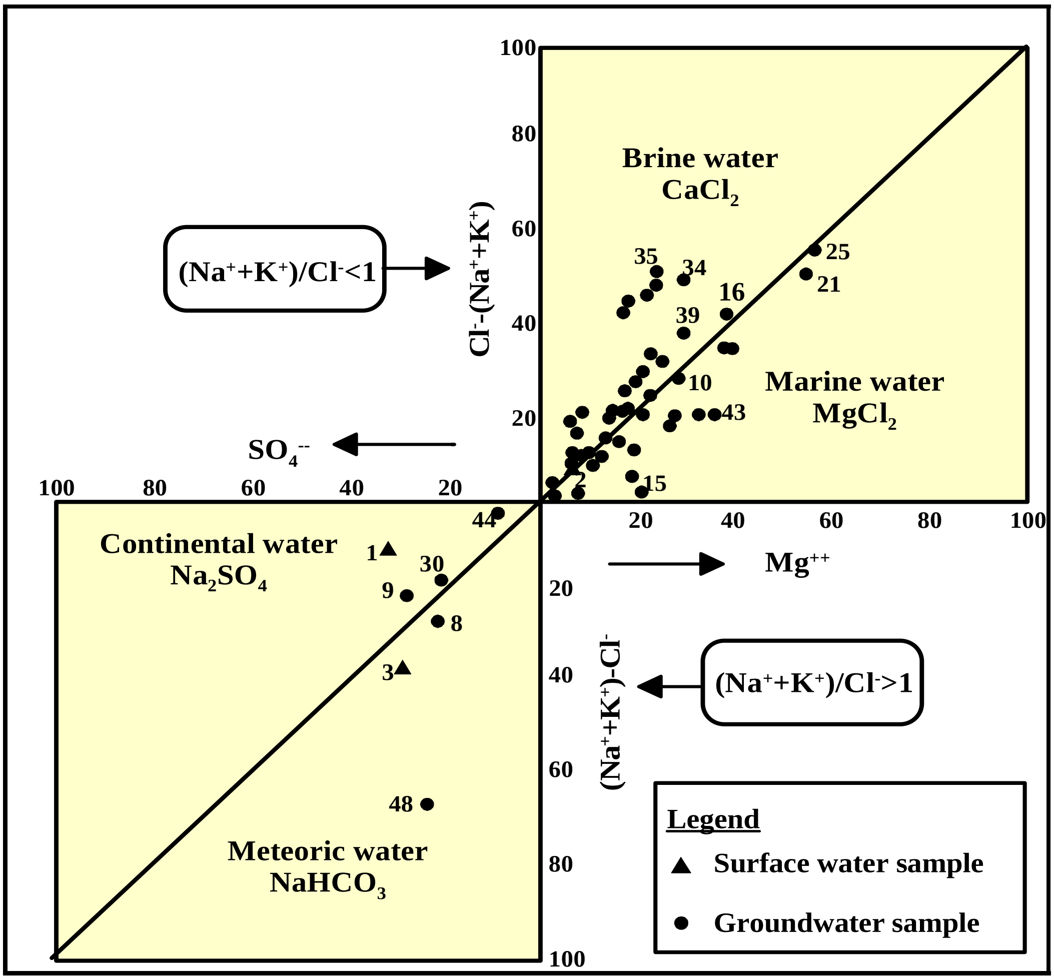

Fig. (7): Hydrochemical classification of water samples using Sulin's (1946) diagram in the area northwest Sinai, Egypt.

Evaluation of Groundwater Quality for Irrigation Purposes:

Several parameters, which affect both the plant and the soil, are used to assess the suitability of groundwater of the Quaternary aquifer of northwest Sinai for irrigation purposes.

Salinity Hazard:

Water with high salinity can limit growth of plants physically, by restricting the taking up of water through modification of osmotic processes. Most of groundwater samples (84%) have very high salinity water (Table 4). They are unsuitable and require high leaching before usage.

Regarding the relative tolerance of crop plants to groundwater salinity (Table 5), only 20% of the examined groundwater samples are suitable for irrigation of sensitive and moderately salt tolerant crops. Forty four percent of the samples can be used to irrigate salt tolerant crops such as sunflower, oats, soy bean, zucchini, broccoli, olive and peach. Twenty four percent of the samples can be used to irrigate very salt tolerant crops such as cotton, sugar beet, sorghum and wheat. Only 12% of the water samples are recommended to irrigate saline tolerant crops such as barley (grains) and tall wheat grass (Table 5 and Fig. 8).

Table (4): Classification of collected samples based on salinity hazard (Fipps, 1996).

Classes of water	Samples	%
Class 1, Excellent (TDS < 175 mg/l)	-	-
Class 2, Good (TDS= 175-525 mg/l)	-	-
Class 3, Permissible (TDS= 525-1400 mg/l)	9, 30 & 48	6
Class 4, Doubtful (TDS= 1400-2100 mg/l)	8, 21, 23, 43 & 49	10
Class 5, Unsuitable (TDS > 2100 mg/l)	1, 2, 3, 4, 5, 6, 7, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 44, 45, 46, 47 & 50	84

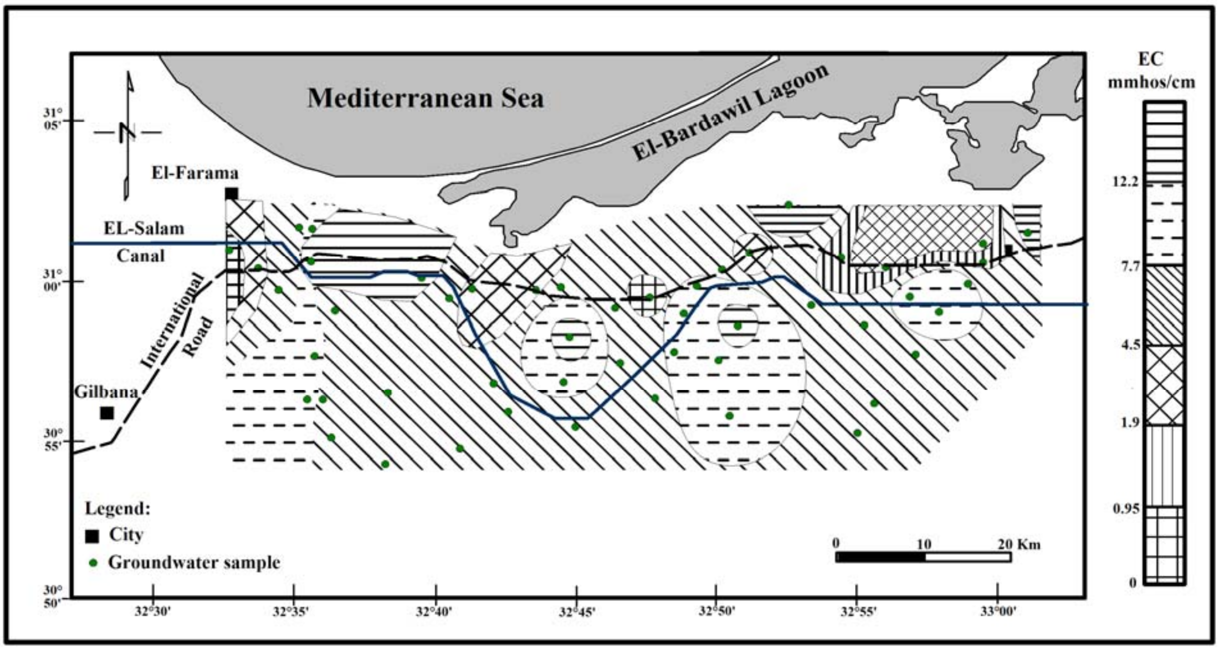

Fig. (8): Salinity zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Ayers and Westcot, 1976; and NWQMS, 2000).

Sodium hazard:

While a high salt content (high EC) in water leads to formation of saline soil, high sodium content (SAR) leads to development of an alkaline soil. Irrigation with Na-rich water results in ion exchange reactions: uptake of Na^+ and release of Ca^{++} and Mg^{++} (Khodapanah *et al*., 2009). This causes soil aggregates to disperse, reducing its permeability (Tijani, 1994). SAR of the groundwater samples ranges from 2 to 35 (Table 3). Moderate to high SAR values; causing alkali hazard, are recorded in 48% of the analyzed samples (Table 6 and Fig. 9). The relation between SAR and salinity (Fig. 10) reveals the following:

1- Water of very high salinity and very high SAR (C4S4); this class includes the majority of groundwater samples (50%). These water samples are unsuitable for irrigation in most soils; special soil management and high leaching are required.

2- Water of very high salinity and medium SAR (C4S2); this class contains 18% of the total groundwater samples (samples 6, 16, 20, 25, 32, 33, 35, 36 & 39). This water category is satisfactory for salt tolerant crops and soils of good permeability with special leaching.

3- Water of very high salinity and high SAR (C4S3); this class represents 14 % of the total groundwater samples (samples 10, 11, 17, 18, 19, 34 & 40) and El-Salam Canal water sample (2). These groundwater samples are generally unsuitable for continuous use in irrigation of most soils and require special soil management and high leaching.

Table (5): Relative tolerance of crop plants to groundwater salinity, northwest Sinai, Egypt (adapted from Ayers and Westcot, 1976; and NWQMS, 2000).

Classes of crops	Samples	%	Remarks
Class 1, Sensitive crops (EC> 0.95 mmhos/cm)	9 & 30.	4	**Field crops**: Bean (field), cowpea **Vegetables**: Beans, lettuce, onion, radish. **Fruits**: Avocado, strawberry.
Class 2, Moderately sensitive crops (EC= 0.95-1.9 mmhos/cm)	43 & 48.	4	**Field crops**: Broad bean, corn, flax **Vegetables**: Cabbage, pepper, potato, spinach, sweet corn, tomato. **Forages:** Alfalfa, clover, corn (forage), orchard grass. **Fruits**: Almond, apple, apricot, fig, grape, grapefruit, lemon, orange.
Class 3, Moderately salt tolerant crops (EC= 1.9-4.5 mmhos/cm)	8, 21, 23, 36, 44 & 49.	12	**Field crops**: Groundnut, rice, safflower. **Vegetables**: Beet. **Forages:** Tall fescue, barley hay, trefoil (small), harding grass. **Fruits**: Date palm.
Class 4, Salt tolerant crops (EC= 4.5-7.7 mmhos/cm)	1, 2, 4, 6, 7, 10, 11, 13, 16, 17, 18, 19, 24, 25, 26, 29, 35, 38, 39, 40, 41 & 42.	44	**Field crops**: Sunflower, oats, soy bean. **Vegetables**: Zucchini, broccoli. **Forages:** Bermuda grass, wheat grass. **Fruits:** Olive, peach.
Class 5, Very salt tolerant crops (EC= 7.7-12.2 mmhos/cm)	3, 5, 14, 20, 27, 28, 31, 32, 34, 45, 46 & 47.	24	**Field crops**: Cotton, sugar beet, sorghum, wheat.
Class 6, Generally too saline crops (EC> 12.2 mmhos/cm)	12, 15, 22, 33, 37 & 50.	12	**Field crops**: Barley (grains). **Forages:** Tall wheat grass.

Table (6): The sodium hazard of groundwater based on SAR Values (Fipps, 1996).

Water class	SAR	Remarks	Groundwater samples	%
Low	1-10	Use on sodium sensitive crops such as avocados must be cautioned.	6, 9, 10, 11, 13, 16, 17, 19, 20, 21, 23, 25, 30, 31, 32, 34, 35, 36, 38, 39, 43 & 49	44
Medium	10-18	Amendments and leaching needed.	1, 2, 3, 4, 7, 8, 18, 22, 24, 28, 37, 40, 41, 42, 47, 48 & 50	34
High	18-26	Generally unsuitable for continuous use.	5, 26, 27, 33, 44, 45 & 46	14
Very high	>26	Generally unsuitable for use.	12, 14, 15 & 29	8

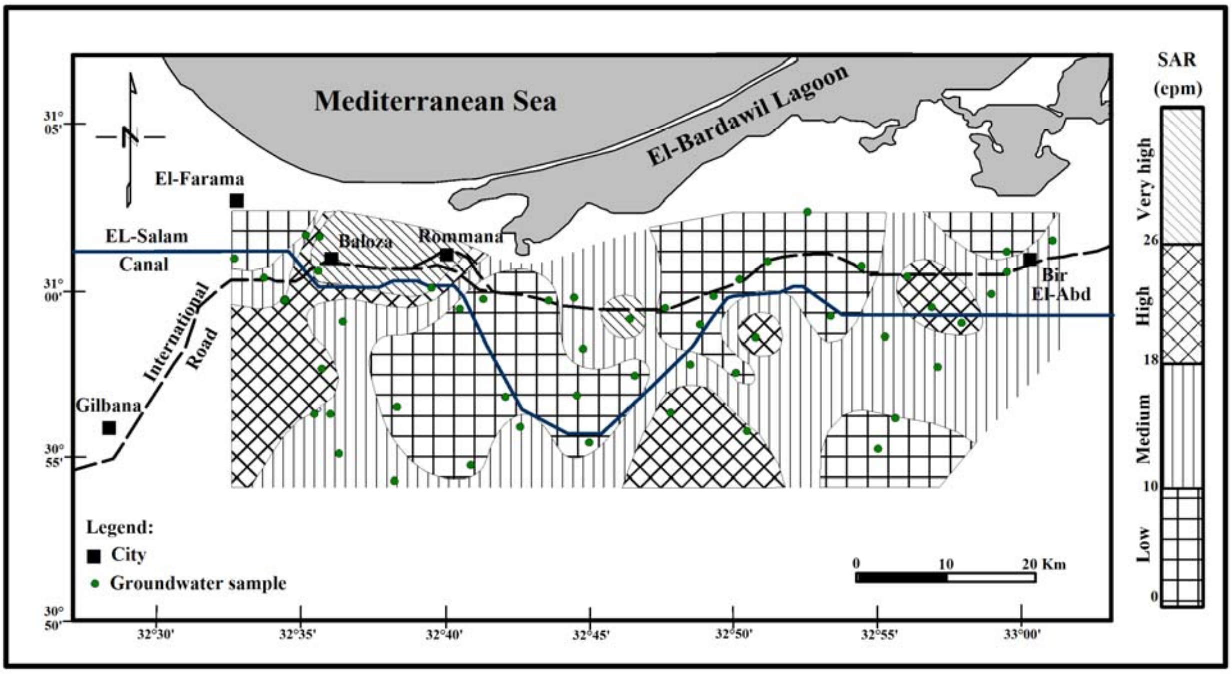

Fig. (9): Sodium adsorption ratio (SAR) zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Fipps, 1996)

Groundwater may be classified according to Na% (Wilcox, 1955). Regarding the examined Quaternary groundwater samples, Na% ranges from about 26% to 88% (Table 7); good to doubtful for irrigation uses. Ten percent of the Quaternary groundwater samples are unsuitable for irrigation due to high Na% (greater than 80%). Forty percent of the samples belong to the doubtful class of water. Fifty percent of the samples fall within the permissible and good water classes. The Na% zonation of the Quaternary groundwater samples is illustrated in Fig. (11).

Magnesium hazard (MH):

Although calcium and magnesium ions are essential for plant growth but they may associated with soil aggregation and friability (Khodapanah *et al.,* 2009). Magnesium hazard (MH) must be less than 50 to ensure safe and suitable water for irrigation (Khodapanah *et al.,* 2009). In the study area, the MH values range between about 15% and 97% (Table 3). Seventy percentage of the Quaternary groundwater samples have MH< 50% and are considered suitable for irrigation use. The remaining 30% of the samples are unsuitable for irrigation (Table 8 and Fig. 12).

Table (7): Water classes for irrigation purposes according to sodium percent (Wilcox, 1955).

Water class	Na%	Samples	%
Excellent	<20	-	-
Good	20-40	6, 9, 16, 20, 21, 25, 30, 32, 34, 35, 38 & 39	24
Permissible	40-60	10, 11, 13, 17, 19, 23, 31, 36, 37, 40, 43, 49 & 50	26
Doubtful	60-80	1, 2, 3, 4, 5, 7, 8, 15, 18, 22, 24, 27, 28, 29, 33, 41, 42, 45, 46 & 47	40
Unsuitable	>80	12, 14, 26, 44 & 48	10

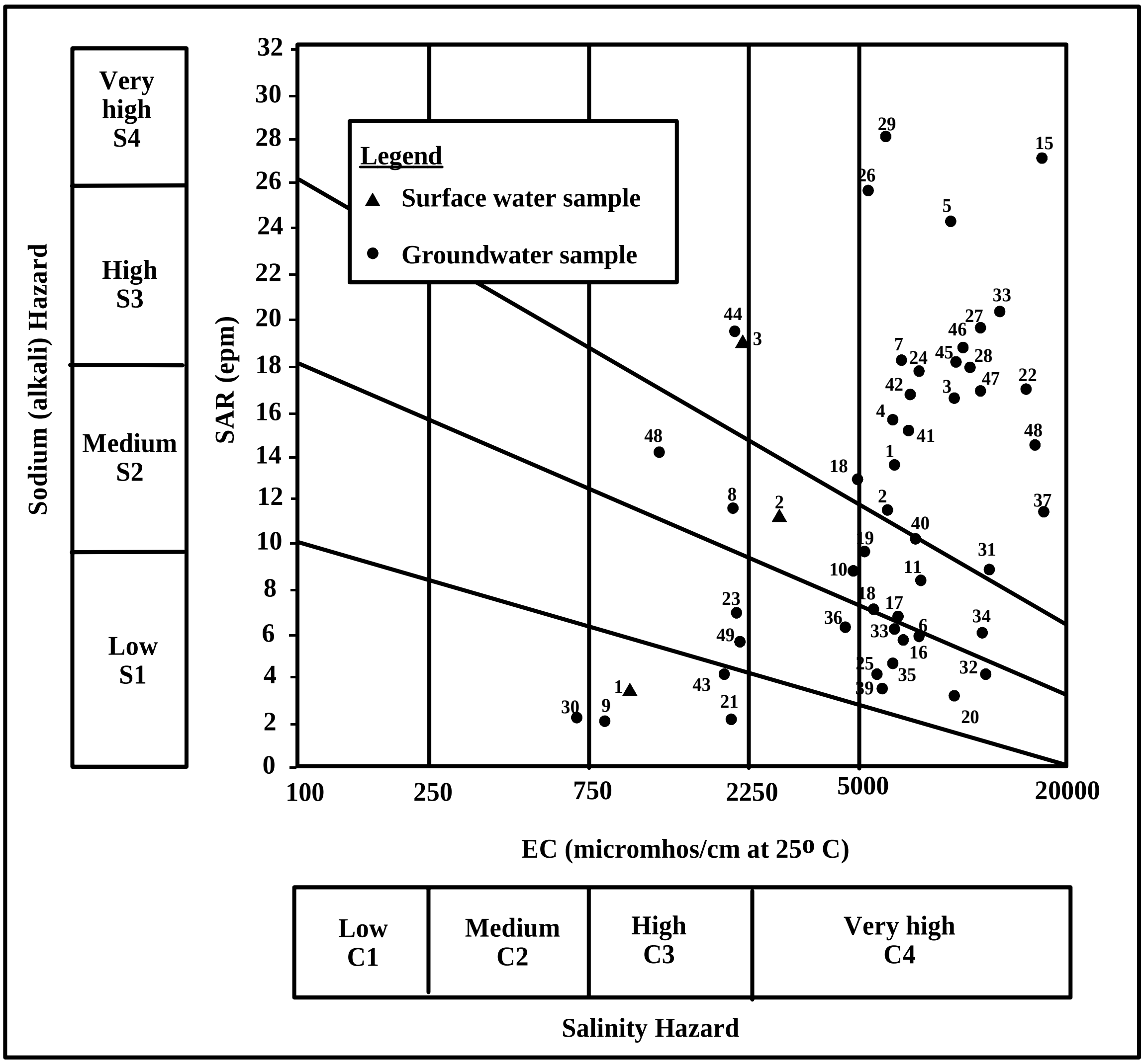

Fig. (10): Classification of irrigation waters (U.S. Salinity Laboratory Staff, 1954) for the analyzed groundwater samples.

Table (8): Classification of the Quaternary groundwater samples, northwest Sinai, according to magnesium hazard (MH), according to Khodapanah *et al.* (2009).

Classes of water	MH range (%)	Samples	%
Excellent	<50	1, 2, 4, 7, 8, 9, 11, 12, 13, 14, 18, 19, 20, 22, 23, 24, 26, 27, 29, 30, 31, 32, 34, 35, 36, 37, 38, 39, 40, 41, 44, 45, 46, 48 & 49	70
Unsuitable	>50	3, 5, 6, 10, 15, 16, 17, 21, 25, 28, 33, 42, 43, 47 & 50	30

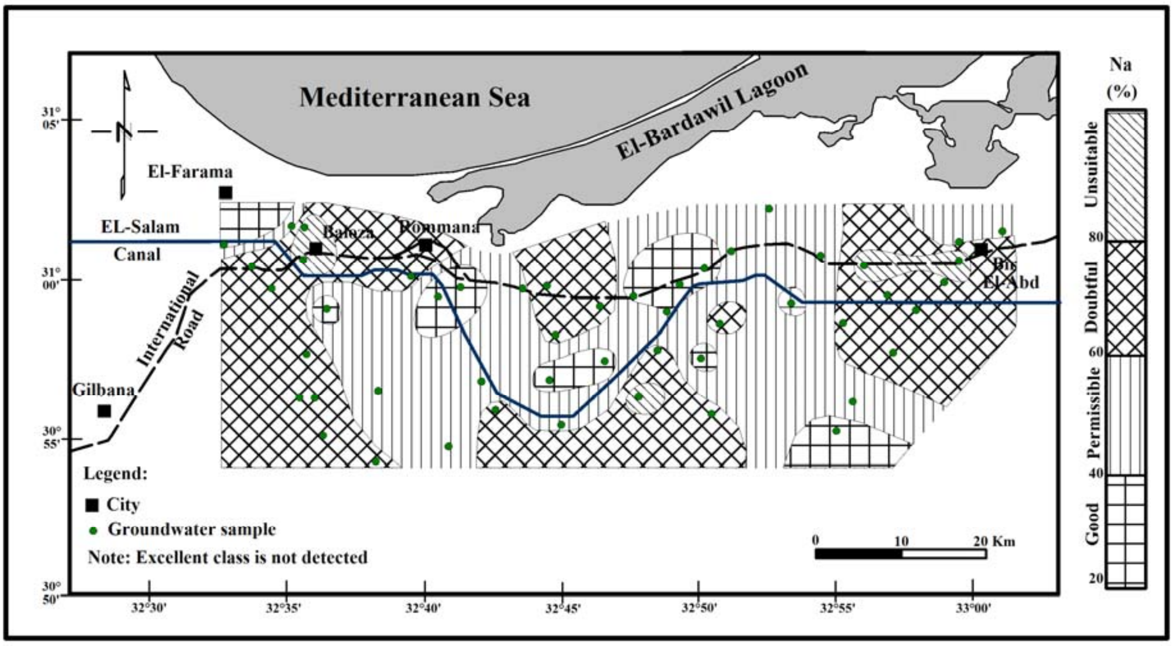

Fig. (11): Sodium percent (Na %) zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Wilcox, 1955)

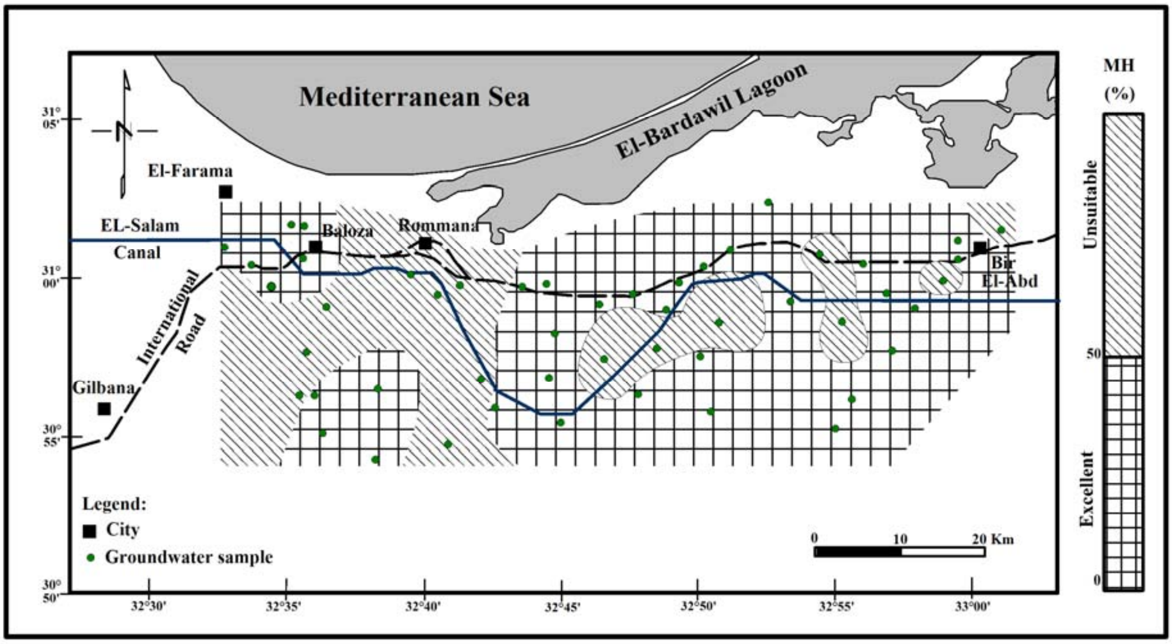

Fig. (12): Magnesium hazard (MH %) zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Khodapanah *et al.*, 2009)

Residual sodium carbonate (RSC):

Residual sodium carbonate (RSC) has been calculated to determine the hazardous effect of carbonate and bicarbonate on the quality of water for agricultural purposes. RSC<1.25 is suitable for irrigation purposes (Eaton, 1950). In waters having high concentration of bicarbonates, there is a tendency for calcium and magnesium to precipitate as the water in the soil becomes more concentrated. As a result, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate (Sadashivaiah *et al*., 2008). All the analyzed water samples (surface- and ground-water) fall in the suitable class (RSC< 1.25), except groundwater sample 48 (RSC= 5.48 epm) belongs to the unsuitable class and poses bicarbonate hazard (Tables 1 & 2 and Fig. 13).

Total hardness (TH):

Hardness is an indication of the amount of calcium and magnesium in the water; expressed as mg $CaCO_3$/l. Water with hardness less than 150 mg/l (considered moderately hard based on Todd's classification, 1980), is considered desirable for plant growth. All the analyzed surface- and ground-water samples exceed the permissible limit (150 mg/l) and range from hard (150-300 mg/l) to very hard (> 300 mg/l) waters, except surface water sample (3) and groundwater sample (48), (Tables 1 & 2 and Fig. 14).

Nitrogen (NO_3^- & NO_2^-):

Nitrate ion (NO_3^-) is the common form of combined nitrogen in natural water. Nitrogen in irrigation water especially nitrate-nitrogen (NO_3-N), which often occurs at higher concentrations than ammonia in irrigation water and causes quality problems in crops such as barley and sugar beets and excessive vegetative growth in some vegetables (Bauder *et al*., 2004). However, these problems can usually be overcome by good fertilizer and irrigation management. Regardless of the crop, nitrate should be credited toward the fertilizer rate especially when the concentration exceeds 10 mg/l NO_3-N (Bauder *et al.,* 2004). In the study area, all the analyzed surface and groundwater samples are within the safe limit, less than 45 mg/l, (Tables 1 & 2).

Phosphate (PO_4^{---}):

Phosphate (and nitrate) in surface and groundwater are generally associated with usage of nitrogen and phosphorus fertilizers. The acceptable limit for phosphate concentrations in irrigation water is between 0-2 mg/l (Shahinasi and Kashuta, 2008). All surface water samples and the majority of the analyzed groundwater samples (72%) fall in the permissible class and the rest of samples exceed 2 mg/l, indicating pollution in 28% of the total samples (Tables 1 & 2 and Fig. 15).

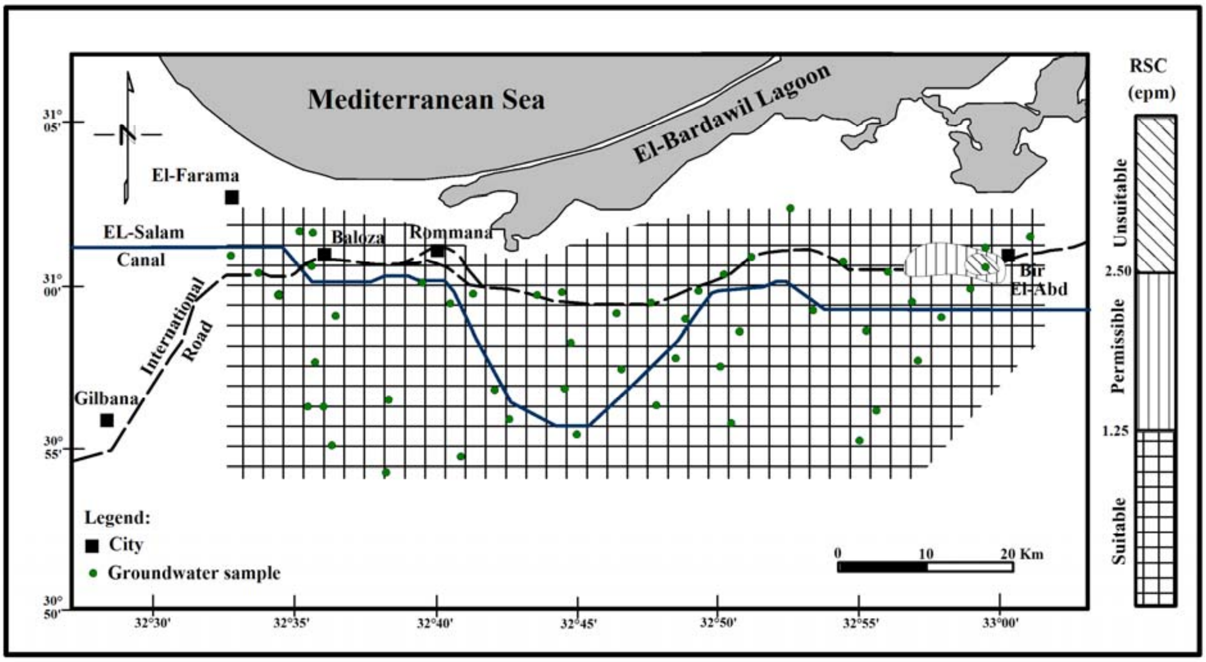

Fig. (13) Residual sodium carbonate (RSC) zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Eaton, 1950)

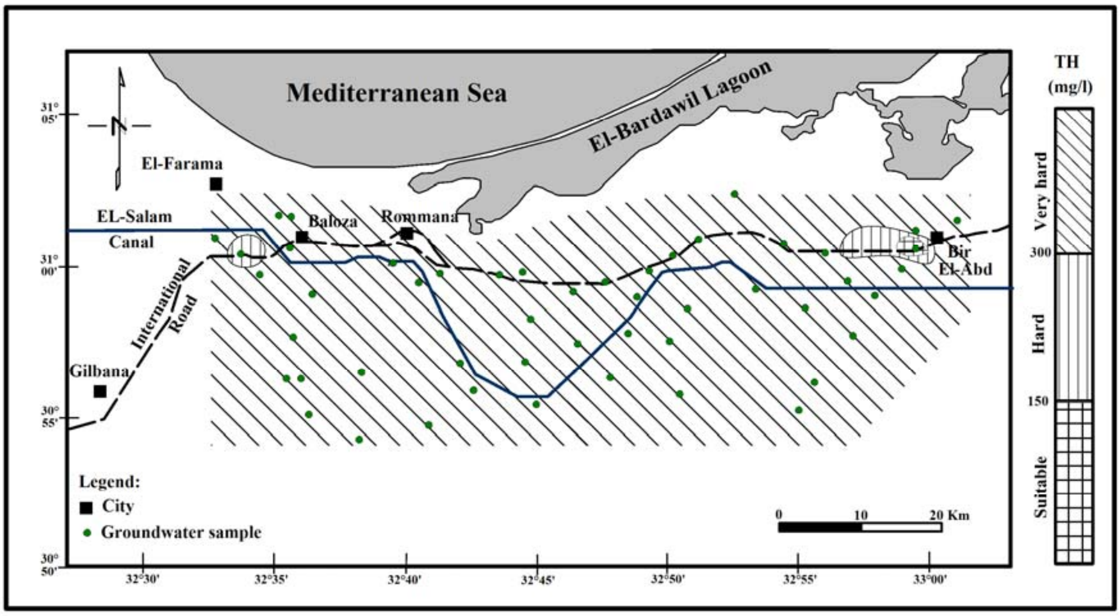

Fig. (14): Total hardness (TH) zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Todd, 1980).

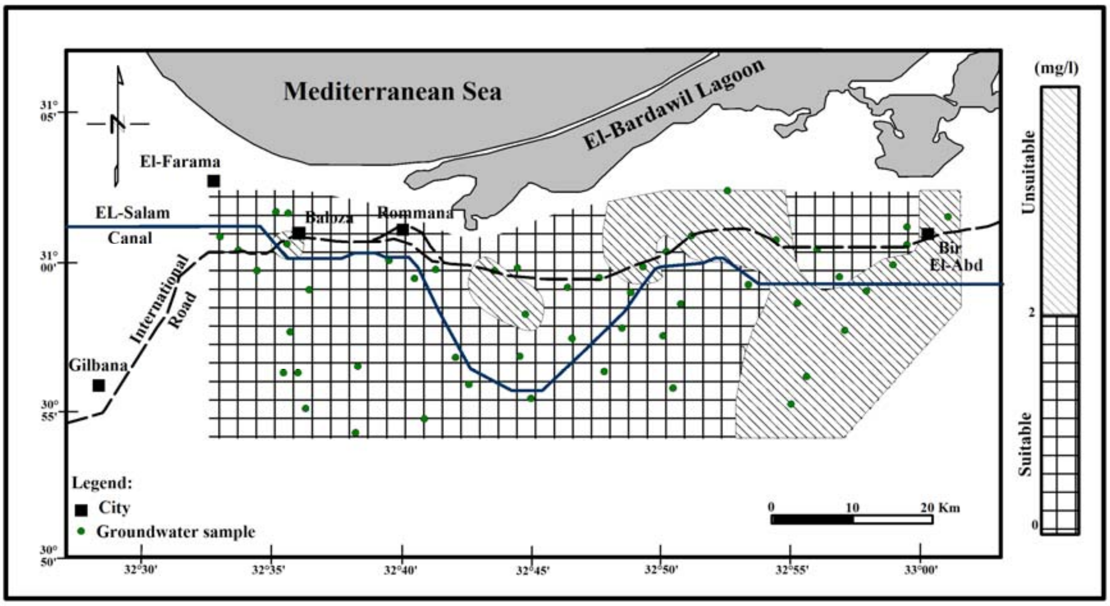

Fig. (15): Phosphate zonation map of the Quaternary groundwater samples, northwest Sinai, for irrigation uses (categories classified according to Shahinasi and Kashuta, 2008)

Excess chloride:

Excess chloride deposited on leaves cause foliar burn (Hopkins *et al.*, 2007). Based on Ayers (1975), chloride concentrations less than 142 mg/l show no chloride toxicity problems which increase if chloride concentration ranges between 142-335 mg/l. Irrigation water with chloride concentration exceeds 335 mg/l causes severe problem of chloride toxicity in most plants. All the analyzed samples of El-Salam Canal and the groundwater of the Quaternary aquifer, northwest Sinai suffer from chloride toxicity as chloride concentrations exceed 355 mg/l, except groundwater samples 9, 30 and 48 ($Cl^- < 142$ mg/l) which show no chloride toxicity problem (Tables 1 & 2).

Damage caused by high-chloride irrigation water can be minimized by planting less sensitive crops; avoiding foliar injury by using furrow, flood, or drip irrigation; and rinsing the plants at the end of each irrigation event if a source of high-quality water is available (Hopkins *et al.,* 2007).

Summary and conclusions:

The Quaternary aquifer is the most important source of water in northwest Sinai for agricultural purposes. It exists under unconfined conditions. The depth to water varies from 0.5 m in the north to 9.1 m below the ground surface and water level ranges between -3.7 m to 10 m in the northeast corner. The Quaternary groundwater is mainly brackish to saline in character with TDS range from 692 to 9384 mg/l. Chloride, sodium and sulphate increase with salinity increasing. The groundwater belongs to two main genetic water types; $CaCl_2$ (48%) and $MgCl_2$ (42%) of the samples, reflecting the marine origin.

Irrigation water quality was determined based on salinity, sodium, magnesium, and bicarbonate hazards, in addition to total hardness, nitrate, phosphate and excess chloride. Accordingly, more than fifty percent of the analyzed samples are unsuitable for irrigation under normal condition and requires special soil management and high leaching. Thus, for agricultural development special management of salinity control and certain kind of plants with good salt tolerance should be considered.

Only twenty percent of the examined groundwater samples are suitable for irrigation of sensitive and moderately salt tolerant crops. Forty four percent of the water samples can be used to irrigate salt tolerant crops such as sunflower, oats, soy bean, zucchini, broccoli, olive and peach**.** Twenty four percent of the samples can be used to irrigate very salt tolerant crops such as cotton, sugar beet, sorghum and wheat. The rest of groundwater samples percent (12%) are only recommended to irrigate too saline tolerant crops such as barley (grains) and tall wheat grass

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