

Assessment of Human Impact on Quaternary Aquifers of Rafah Area, NE Sinai, Egypt

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Abstract. Groundwater is endangered by agricultural activities, wastes disposal, aquifer over exploitation and seawater intrusion. The pollution risk is high, as the depth to the water table is shallow and the aquifers are highly permeable and have poor buffering capacity. Intensive farming activities have also put stress on groundwater quality due to intensive use of fertilizers and pesticides. As a result, concentrations of NO_3^- , SO_4^{2-} and PO_4^{2-} are very high. Most of the house owners do not have access to public sewers, which poses another risk for the aquifers. More than 71.2% of the aerial distribution of nitrate concentration is greater than 44.29 mg/L, thus causing a serious problem. Static water level maps from 1983 to 2000 show the declining of the water level with time. The discharge from Quaternary aquifers exceeds the recharge rates after 1988 resulting in both upward leakage of the deeper high saline water and seawater intrusion. Factor analyses were used to define the factors that affect the groundwater quality. Dissolution and deposition of several minerals, evaporation from the groundwater, human impact on the aquifers, cation exchange, mixing between different waters and rainfall recharge were identified as the main factors impacting the ground waters.

Introduction

The study area is located in the north eastern part of Sinai Peninsula and covers about 152 km². The area extends between latitudes 31°11'08"-31°18'17"N and longitudes 34°04'08"-34°16'38"E (Fig. 1). It is bordered in the north by the Mediterranean Sea, to the east by the international border between Egypt and Palestine and in the south by central Sinai Peninsula. The annual rainfall varies between 266 mm/y at El Sheikh Zeweid and 303.8 mm/y at Rafah.

Environmental impact assessment studies are aimed at identifying and predicting the effect on the environment and man's health. These studies will also leave impact on legislative proposals, policies, projects, operational procedures, interpretation and dissemination of information about the impacts (Munn, 1979). The study area is characterized by its shallow Quaternary aquifers, which are most vulnerable to pollution. These coastal aquifers recharged by rainfall are in direct contact with pollution sources and marine (saline) impact.

The purpose of this study was to evaluate the pollution of the groundwater. In this regard, a total of 26 groundwater samples were collected during two different periods (October, 1999 and April, 2000) and investigated for major, minor and trace elements (Table 1). Different methods for determining individual elements were used such as titration (HCO_3^- and CO_3^{2-}), IC (Na, K, Ca, Mg, Cl, SO_4^{2-} and NO_3^-), ICP-MS (metals and rare earth elements) and Spectrophotometric (PO_4^{3-}). A Geographic Information System tool (GIS) was used to construct maps. In particular TNT-MIPS form Microimages inc, USA was used, which is a complex GIS software, which can display layers (Raster, Vector, CAD, TIN, and

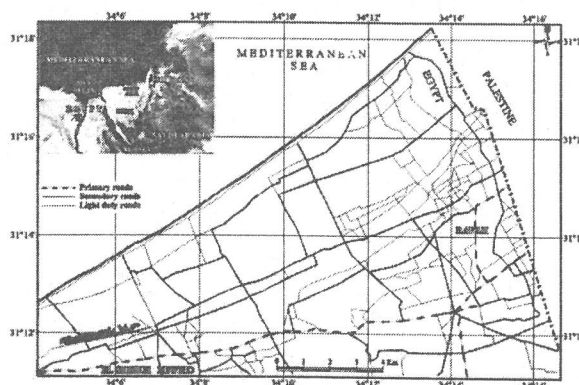


Fig.1. Location map of the study area

Database) in different coordinates and projections in one window without previous recalculation (Microimages, 2004).

Hydrogeology

According to the stratigraphic position, the permeability and storage capacity, three major aquifers can be distinguished: Sand dunes (Holocene), old beach (Upper Pleistocene) and calcareous sandstone (Lower Pleistocene). The Quaternary aquifers are extended to the east and west outside the study area. In the north, they are bounded by the Mediterranean Sea, and in the south, Tertiary rocks are cropping out or coming close to the surface. The shallow aquifer is formed by sand dunes overlying clayey sand. The second aquifer is built up by sand and gravel (old beach) and the third one by calcareous sandstone (Kurkar aquifer) separated by a silty clay unit (Fig. 2).

Table 1. Chemical analyses of the groundwater of Sand dune and Old beach aquifers and Kurkar aquifer, Rafiah area.

Well	pH	Eh mv	EC µS/cm	TDS mg/L	K mg/L	Na mg/L	Mg mg/L	Ca mg/L	Cl mg/L	NO ₃ mg/L	SO ₄ mg/L	HCO ₃ mg/L	PO ₄ mg/L	Be µg/L	Al µg/L	V µg/L	Cr µg/L	Mn µg/L	Co µg/L	Ni µg/L	Cu µg/L	Zn µg/L	As µg/L	Se µg/L	Sr µg/L	Cd µg/L	Ba µg/L	Hg µg/L	Tl µg/L	Pb µg/L	Th µg/L	U µg/L
Sand dune and Old beach aquifers																																
11-10	7.83	184	847	806	53.00	79	29	103	179	122	48	193	0.07	<5	<50	21	39	<25	<5	7.9	9.9	<5	5.8	41	1525	<5	166	<1	<0.4	<0.5	<0.5	1.8
12-1	8.10	193	1940	1491	19.70	266	63	146	459	202	144	191	2.75	<5	<50	12	<25	<25	<5	15	5.3	<5	6.4	19	2740	<5	70	1.2	<0.4	<0.5	1.41	3.3
12-12	8.02	193	2780	2034	10.30	355	95	240	800	161	217	156	0.06	<5	<50	9.9	<25	<25	<5	11	52	<5	25	50	7114	<5	63	1.0	<0.4	7.27	0.80	4.5
12-21	8.17	174	2320	1440	2.60	290	27	130	440	174	230	147	0.05	<5	<50	21	74	<25	<5	6.7	16	6.8	16	52	3685	<5	137	<1	<0.4	1.51	<0.5	2.1
Pz1	7.96	212	1483	1244	20.00	128	57	155	176	402	104	202	0.07	<5	<50	17	29	<25	<5	8.7	7.7	20	<5	21	2280	<5	94	<1	<0.4	<0.5	<0.5	2.1
16-6	8.16	175	1560	1156	3.60	203	38	110	280	150	160	211	0.06	<5	<50	21	95	<25	<5	<5	13	8.9	17	43	1798	<5	88	<1	<0.4	<0.5	<0.5	3.6
16-14	8.06	175	1151	797	1.60	159	26	69	187	68	86	201	0.07	<5	<50	41	90	<25	<5	5.9	8.9	<5	16	55	1306	<5	94	<1	<0.4	<0.5	<0.5	4.1
16-31	8.33	170	2280	1428	1.00	389	40	63	445	65	148	277	0.04	<5	<50	24	139	<25	<5	<5	14	13	16	67	1615	<5	77	<1	<0.4	1.17	<0.5	4.9
16-34	8.07	217	1680	1196	1.00	280	32	70	320	42	240	211	0.06	<5	<50	43	112	<25	<5	8.4	26	9.1	29	33	1204	<5	125	1.1	<0.4	0.56	0.55	5.7
16-41	8.09	172	1033	657	3.20	103	30	67	159	101	35	159	0.04	<5	<50	26	47	<25	<5	<5	9.4	15	17	60	1372	<5	162	<1	<0.4	0.52	<0.5	2.6
16-52	8.09	174	1225	772	1.60	161	28	60	197	58	77	189	0.04	<5	<50	33	62	<25	<5	<5	7.5	24	25	39	1150	<5	150	<1	<0.4	<0.5	<0.5	3.8
16-67	7.93	218	1006	809	25.10	123	38	70	180	108	58	207	0.07	<5	<50	21	40	<25	<5	5.8	8.7	<5	11	57	1820	<5	184	<1	<0.4	<0.5	<0.5	2.3
16-73	8.18	169	2320	1459	2.80	401	37	71	459	31	225	232	0.05	<5	<50	44	102	<25	<5	<5	20	7.4	24	56	1121	<5	42	<1	<0.4	1.60	<0.5	6.0
16-80	7.01	194	801	655	3.30	56	29	97	86	172	35	177	0.05	<5	<50	15	<25	<25	<5	11	<5	29	8.4	30	1365	<5	228	<1	<0.4	0.54	<0.5	2.3
16-143	7.27	205	1251	842	8.60	148	40	58	285	114	59	130	0.06	<5	<50	21	29	<25	<5	15	<5	35	13	17	2885	<5	180	2.9	<0.4	0.94	1.79	3.1
Kurkar aquifer																																
12-26	7.96	177	3400	2224	2.00	470	105	170	830	18	530	99	0.08	<5	<50	34	51	<25	<5	5.5	37	73	39	90	5760	<5	183	<1	<0.4	5.59	<0.5	3.7
12-32	7.81	164	3730	2448	9.40	264	139	289	1040	463	136	107	0.07	<5	<50	16	<25	<25	<5	12	10	41	15	34	7274	<5	114	1.5	<0.4	0.50	1.04	3.3
12-52	7.90	228	4860	3678	13.40	811	152	288	1134	235	849	195	0.06	<5	<50	23	33	<25	<5	6.0	46	30	41	148	11639	<5	79	<1	<0.4	0.79	<0.5	9.0
12-69	7.82	208	5570	4323	25.00	870	185	370	1970	450	280	173	0.07	<5	<50	19	<25	<25	<5	19	32	51	31	67	7438	<5	82	1.5	<0.4	<0.5	0.69	4.7
16-98	8.44	173	3400	2297	20.30	698	51	49	678	73	398	329	0.03	<5	<50	27	111	<25	<5	<5	19	24	25	50	1512	<5	77	<1	<0.4	1.51	<0.5	9.8
16-114	8.22	182	4690	3219	22.00	950	89	86	992	73	675	332	0.05	<5	<50	31	157	<25	<5	<5	30	17	23	88	2714	<5	39	<1	<0.4	<0.5	<0.5	13
16-124	8.49	184	4760	3709	5.80	1150	90	90	1200	37	910	226	0.06	<5	<50	24	123	<25	<5	<5	35	8.7	36	103	2287	<5	16	<1	<0.4	<0.5	<0.5	9.4
16-125	8.44	182	3300	2601	4.60	757	46	100	736	162	356	439	0.08	<5	<50	31	200	<25	<5	<5	6.3	9.1	22	55	1017	<5	44	<1	<0.4	<0.5	0.83	13
16-138	8.23	172	5200	3537	2.10	1080	98	90	1160	46	785	275	0.10	<5	<50	23	128	<25	<5	<5	26	11	23	133	2498	<5	49	<1	<0.4	<0.5	<0.5	11
16-150	8.09	170	3770	2474	2.90	650	92	120	910	94	380	225	0.03	<5	<50	20	87	<25	<5	<5	17	15	17	88	3573	<5	40	<1	<0.4	0.90	<0.5	6.0
16-153	8.45	160	3830	2943	9.70	901	56	73	839	81	569	401	0.06	<5	<50	34	231	<25	<5	<5	12	6.7	29	70	1127	<5	20	<1	<0.4	<0.5	<0.5	13

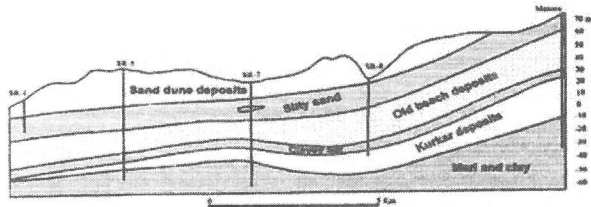


Fig.2. Hydrogeologic cross section from southeast to northwest in Rafah area.

Groundwater fluctuations of the Quaternary aquifers are affected by rainfall, excessive pumping and evapotranspiration especially in the north (JICA, 1992), where the water table is very close to the ground surface. Except the lower clay layer of the Tertiary (base of the aquifers) most of the clay and shale layers form lenses with different thicknesses and extensions. Measurements of groundwater level indicate that there are no differences in the water levels of the three aquifers, reflecting that these aquifers are hydraulically connected. Depth to groundwater encountered in these aquifers ranges between <1 m in the north (along the sea coast) and 70 m in the southeastern part. Downward leakage is expected to take place depending upon the thickness and the vertical hydraulic conductivity of the clayey beds or lenses separating these three aquifers. According to JICA (1992) groundwater level indicates that these aquifers are unconfined (sand dune) to leaky and confined (old beach and Kurkar).

Two regional contour line maps (referenced to sea level) were prepared for the aquifers for the year 1983 and 2000 by means of Kriging based on a variogram analysis (Fig. 3). Assuming low abstraction rates before 1983, the static water level is considered to represent the steady state conditions of the aquifers (Fig. 4).

The piezometric level slopes to the north and northwest directions from about 6.0 m (southeastern part) to <1 m (northern part) above sea level, along a uniform gradient between 0.06% and 0.13%. The constructed water level contour map in the year 2000 shows the general water flow from south to north. But there are local flow directions towards the pumped areas (Fig. 5). The water level varies between +4.4 m asl in the southern part, while the minimum values are 0.0 m asl in Rafah area. The hydraulic gradient varies between 0.04% and

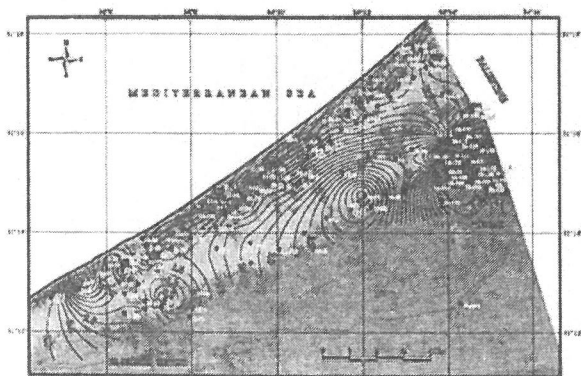


Fig.3. The variogram model fitted to the static water level data at 1983.

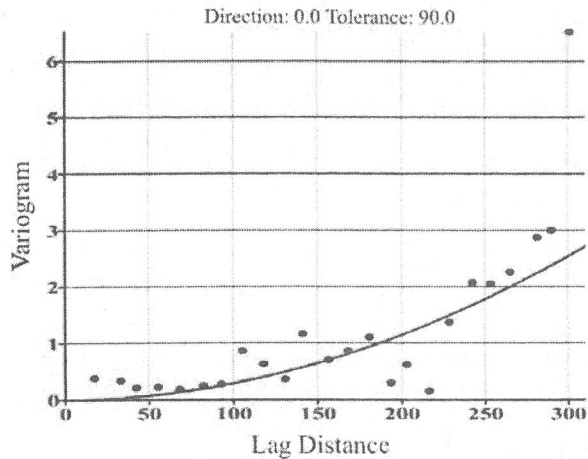


Fig. 4. Iso-potentiometric contour map of Quaternary aquifer in the year 1983.

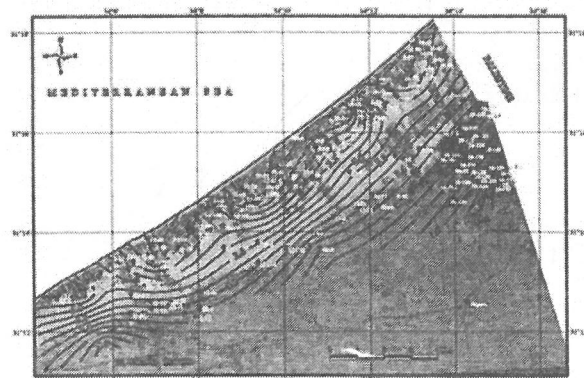


Fig.5. Contour map of Quaternary aquifers in the year 2000.

0.14%. Several local cones of depression in water level in Rafah and El Sheikh Zeweid represent the pumped areas.

Abstraction Rate

Groundwater of the Quaternary aquifers in North Sinai has been used for thousands of years by means of springs and dug wells (Fig. 6). Drilled wells were rarely found only in the vicinity of settlements to meet the need for drinking water in villages (Fig. 7). Abstraction rate was relatively low until 1982 and after 1982, it has grown dramatically, with the increasing population of the Rafah and El Sheikh Zeweid and the expansion of farmland and artificial irrigation (Fig. 8).

Disturbance of the Water Balance

Due to over-pumping of the Quaternary aquifers in the study area, mixing between the deeply saline groundwater of Pre-quaternary aquifers and the Sand dune and Kurkar groundwaters, which are relatively shallow and fresh (El Alfy, 2003), occurred. Over-pumping has a direct impact on the hydrodynamic interface between the seawater and fresh groundwater by lowering the natural head of the shallow aquifer below the seawater head. Fig. (9) shows the declining static water level between 1983 and 2000.

The water level declines with time, where the hydraulic gradients become non-uniform, especially near Rafah and El Sheikh Zeweid cities. More than 84.23 % of the whole study area (75.70 km²) is affected by more than 1 m of the static water decline (Table 2), while the rest (15.77 %) of the area is affected by less than 1 m of water level decline (14.17 km²).

The over pumping from the Quaternary aquifers (1983-2000) is calculated to be 6.59 x 10⁶ m³. Also the calibrated numerical modeling method was used, where pumping rate was calculated as 18032 m³/d (1983). The calibrated total leakage on top of the main model layer is estimated to be 12040 m³/d (El Alfy, 2003). Boundary inflow and outflow were obtained through Dirichlet nodes to be 35382 m³/d. In the year 2000, pumping rate was calculated to be 74000 m³/d (Fig. 9). This reflects that the discharge rates exceed the recharge rates of these aquifers resulting in some critical problems such as upward leakage from the high saline water of the pre-Quaternary aquifers as well as seawater intrusion.

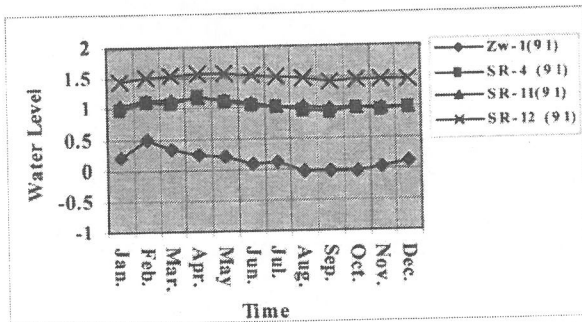


Fig.6. Groundwater hydrographs of monitored boreholes in 1991 (modified after Mekhemer, 1994).

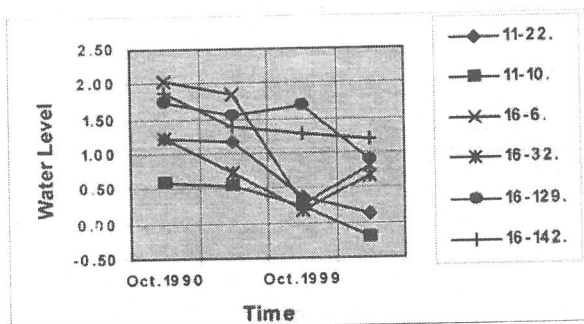


Fig.7. Groundwater hydrographs of monitored boreholes between 1990 and 2000.

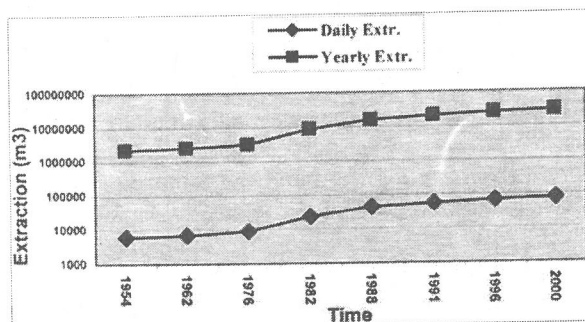


Fig.8. Groundwater abstraction rate in the study area (modified after RIWR, 1993).

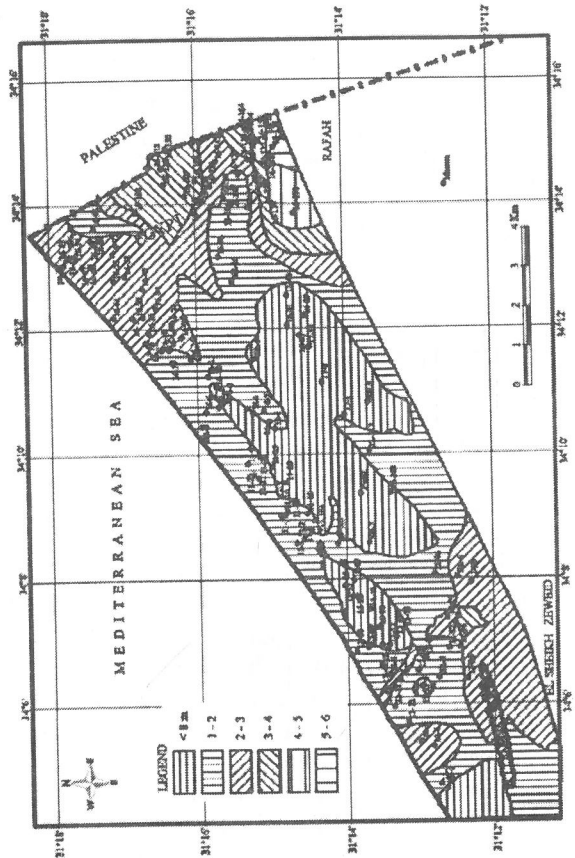


Fig.9. Water level declines zonation map of Quaternary aquifer between 1983 and 2000.

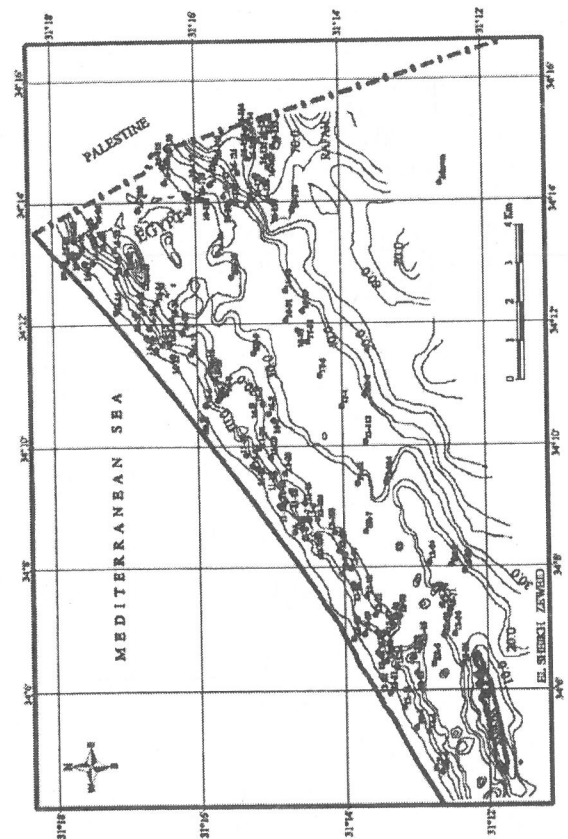


Fig. 10. Depth to water contour map of the Quaternary aquifer.

Table 2. Water level declines of Quaternary aquifer between 1983 and 2000.

Static water level declines	Area (km ²)	Area %	Cumulative area %	Volume (km ³)
< 1 m	14.17	15.77	15.77	7,085,000
1-2 m	43.80	48.74	64.51	65,700,000
2-3 m	22.80	25.37	89.88	57,000,000
3-4 m	6.51	7.24	97.12	22,785,000
4-5 m	2.15	2.39	99.51	9,675,000
5-6 m	0.44	0.49	100.00	2,420,000
Total	89.87	100	100	164,665,000

Pollution Processes and Sources

Human and agricultural activities have affected the hydro-ecology of the study area in particular, where the depth to the water table is very shallow especially in the northern parts of the area and where the soil cover is represented by permeable sands resulting in high infiltration rates (Fig. 10). On the other hand, the aquifers are highly permeable and show poor geochemical buffering capacity. Due to relatively high rates of groundwater flow, the mean residence time of groundwater in the aquifer to attenuate pollutants is very limited. Soils and ground waters in the study area are endangered by agricultural activities, wastes disposal, over pumping of groundwater and seawater intrusion (Table 3).

Septic system and latrines are widely used to dispose the wastewater into the ground and open area defecation happens as well. Both are causing pollution of groundwater by means of organic (humic acids and pathogen microorganisms) and inorganic compounds (NH₄, nitrate and urea). This pollution is clearly observed in the area where depth to groundwater is less than 3 m. Most of the house owners in the study area do not have access to public sewers, but they have simple on-site waste treatment system. This system is poorly constructed and exposes the groundwater to a high risk. Since, the

Quaternary aquifers are composed of sand and gravel plumes of contaminated groundwater develop as the effluent of wastewater discharge into the groundwater. Plumes are characterized by high concentrations of K⁺, Cl⁻, PO₄⁻² and NO₃⁻, which are mainly derived from the waste effluent (Table 4). There are some ions such as Cl⁻ which are not degraded or attenuated as they reach the water table. On the other hand, there are ions such as PO₄⁻² -slowed or degraded because they are absorbed by soil.

Nitrate in Groundwater of the Quaternary Aquifers

Quality of water is the most important parameter affecting the exploration and exploitation of the groundwater in the study area. Groundwater chemistry depends on the interaction of many hydrochemical, geochemical and biochemical processes, where the role of human activities impacts on groundwater quality due to intensive use of fertilizers and pesticides, can be indicated by increased concentrations of NO₃⁻, SO₄²⁻ and PO₄⁻². The deterioration of the quality of ground water becomes obvious. Nitrate occurs naturally from precipitation due to NO_x(g) in the atmosphere mainly produced by lightning, and through burning of fossil organics (oil, gas, coal), as a byproduct of farming activities and from human wastes. Nitrogen occurs in water as NO₃⁻, NO₂⁻, NH₃(g), N₂O(g), NH₄⁺, and in a variety of organic compounds (Hem, 1989). The input of nitrate by means of rainfall can be considerably high (18.5 mg/L) due to enrichment of rainwater concentrations by evaporation effects during groundwater recharge. It is calculated according to rainwater chemistry, where nitrate has average mean value of 3.14 mg/L, the average rainfall within the area is 275 mm/y and the mean recharge is 47 mm/y (Herut et al., 2000). Nitrate is the oxidized form of nitrogen in the nitrogen cycle and mobile nitrate and organic species are metastable compounds in aerated water, while ammonium as reduced species is strongly sorbed on clay mineral surfaces. The Quaternary aquifers

Table 3. Potential sources of pollutants, affected zones and the types of impacts

Pollution potential	Emitted pollutants	Affected ecological resources	Affected zones	Type of impact and pollution	Remarks
Agricultural activities	Organic and chemical fertilizers and irrigation with treated waste water	Soil and groundwater	Northern and southern parts of the study area	Chemical and organic pollution of groundwater, increasing soil salinity	NO ₃ ⁻ in groundwater has very high values
Dug holes waste water disposal	Organic matter, NO ₃ ⁻ , K ⁺ , Cl ⁻ and SO ₄ ²⁻ .	Groundwater	Rafah and El Sheikh Zeweid cities	Chemical and organic pollution of groundwater	Waste water infiltrated to aquifers
Over pumping of the aquifer	High saline water	Groundwater	El Sheikh Zeweid and Rafah area	Upward leakage of high saline water into aquifers	Upward leakage from Pre-Quaternary aquifers
Seawater intrusion	Sea water	Groundwater	Northern part of the study area	Encroachment of seawater into the aquifers	Balance disturbance between recharge and discharge

Table 4. Concentrations of NO₃⁻ and PO₄⁻² in the groundwater of Quaternary aquifers.

Pollution	Natural level	Minimum	Maximum	Average	Source
NO ₃ ⁻	<15.00 mg/l	31.00	463.00	142.37	Human and animals wastes
PO ₄ ⁻²	0.005-0.1 mg/l	0.03	2.75	0.16	Sewage, animal manure and fertilizers

are the main source of groundwater, which is used for domestic and agricultural purposes. Geologically these aquifers are composed of sand, gravel and calcareous sandstone characterized by high permeabilities. They are underlain by Tertiary marls and limestones. The vulnerability of the aquifers is apparent due to high permeability and hydraulic conductivity of the aquifers and absence of impermeable layers on top of them, as well as unwise use of nitrate fertilizers and pesticides (Fig. 11). Nitrate represents one of the main serious water pollution problems in the study area, where the major anthropogenic sources of nitrate are fertilizers, latrines and high risk septic tank drainage, dairy and poultry farming and the leaching of soil as a result of the application of irrigation water.

According to the classification of nitrate concentration of Madison and Brunett (1985), the interpretations of nitrate range concentrations are estimated in the study area (Table 5). More than 71.16% of the area has nitrate concentration values (> 44.29 mg/L) representing a serious problem (Fig. 12).

In the southern and eastern parts, nitrate concentration is recorded to be less than 10 mg/L. This low level of concentration refers to minor agricultural activities and relatively deep occurrence of the water table. In the northwest part of the area there is a huge increase of nitrate concentrations exceeding 450 mg/L. This refers to the very shallow water table (< 10 m) and intensive agricultural activities. Nitrogen fertilizers are very frequently applied to crops as well as pesticides. The high porosity and permeability of Quaternary aquifers and the absence of thick impermeable rocks is responsible for the presence of high nitrate levels in groundwater, where a viable pathway exists from the surface (nitrate sources) to the groundwater. Concentrations exceeding 70 mg/l nitrate in drinking water may likely cause deadly Methemoglobinemia (blue baby syndrome) for children at an age less than 2 years (Hem, 1989). In the east and northeast of the area, the nitrate concentrations are higher than 250mg/L. Compared with the western part of the area, there are relatively few agricultural activities and the water table is relatively deeper in particular in the southeast (> 70 m). This high concentration may be

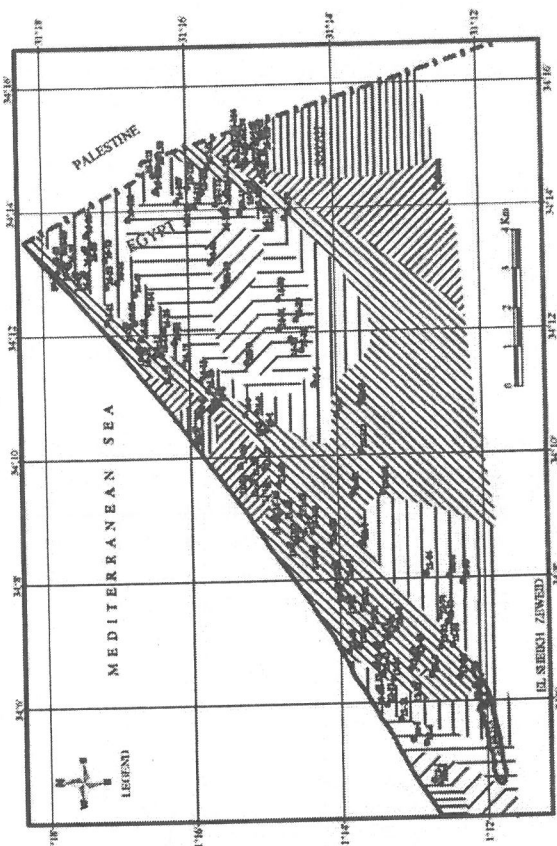


Fig.11. Hydraulic conductivity zonation map of the Quaternary aquifers

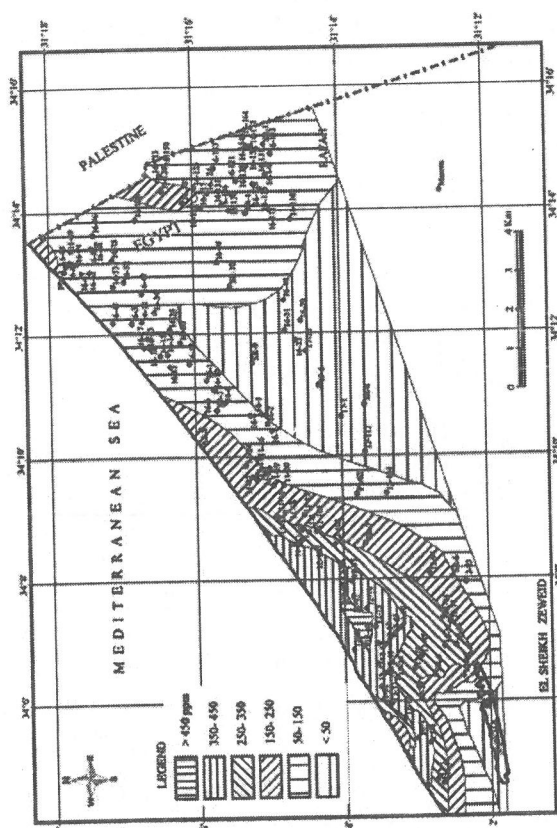


Fig.12. Areal distribution of nitrate concentrations of Quaternary aquifer during April 2000.

Table 5. Nitrate concentration in groundwater of the Quaternary aquifers.

Zone	Nitrate Concentration	Area (Km)	Area %	Remarks
I	< 0.89 mg/l	0	0	Assumed to represent natural background concentrations.
II	0.89- 13.29 mg/l	16.19	18.15	Transitional; concentrations that may or may not represent human influence.
III	13.29- 44.29 mg/l	9.54	10.69	May indicate elevated concentrations resulting from human activities
IV	> 44.29 mg/l	63.49	71.16	Exceeds maximum concentration for National Interim Primary Drinking-Water Regulations.

referred to the pollution of groundwater in Gaza strip in Palestine, where nitrate concentrations are as high as 150 mg/L in north Gaza and up to 350 mg/L in the Khan Younis area, and peaking with 600 mg/L in Khan Younis Refugee Camp.

Factor Analysis

Factor analyses were used to define the factors that have impact on the groundwater quality. R-mode factor analysis (Dalton and Upchurch, 1978; Al Yamany, et al, 1994) was carried out with the software STATISTICA for the entire set of data, including major, minor and trace chemical constituents. Factors were rotated using Varimax method.

Sand Dune and Old Beach Aquifers

Factor analysis for data from sand dune and old beach aquifers used 15 cases and 15 variables. There are four main factors affecting the hydrochemical formation of the groundwater of sand dune and old beach aquifers representing a cumulative total variance 83.47 %, with

Table 6. Factor analysis loadings and Eigenvalues of sand dune-old beach aquifers.

	Factor 1	Factor 2	Factor 3	Factor 4
pH	0.12	0.20	0.84	-0.05
TDS	0.80	0.35	0.40	0.22
K ⁺	0.11	-0.85	0.14	0.09
Na ⁺	0.42	0.67	0.56	0.08
Mg ⁺²	0.87	-0.02	0.04	0.26
Ca ⁺²	0.93	-0.19	0.00	0.17
Cl ⁻	0.81	0.42	0.33	0.02
NO ₃ ⁻	0.39	-0.47	-0.26	0.49
SO ₄ ⁺²	0.49	0.62	0.44	0.09
HCO ₃ ⁻	-0.37	0.14	0.73	0.18
PO ₄ ⁺²	0.16	-0.11	0.20	0.77
Zn ⁺²	-0.37	0.21	-0.81	0.13
As ⁺³	0.09	0.78	0.16	-0.45
Se ⁺²	-0.06	0.11	0.60	-0.69
Sr ⁺²	0.97	0.03	-0.13	-0.10
Expl.Var	4.75	2.85	3.19	1.74
Prp.Totl	0.32	0.19	0.21	0.12
Eigenval	5.74	3.72	1.88	1.19
Cumul. Eigenval %	5.74	9.46	11.33	12.52
Total Variance %	38.26	24.79	12.50	7.93
Cumul. %	38.26	63.04	75.54	83.47

the smallest Eigenvalue being 1.19 and cumulative Eigenvalues of 12.52 (Table 6).

The first factor accounts 38.26 % of the total variance and 5.74 of the Eigenvalues. This factor shows high loadings with Sr²⁺, Ca²⁺, Mg²⁺, Cl⁻, and TDS (0.97, 0.93, 0.97, 0.81 and 0.80 respectively) and moderate loadings with SO₄²⁻ and Na⁺ (0.49 and 0.42 respectively). This factor reflects two main processes affecting the water chemistry. The first one is the role of dissolution of several minerals, in particular gypsum (CaSO₄.2H₂O), anhydrite (CaSO₄), strontianite (SrCO₃), halite (NaCl) and in some localities calcite (CaCO₃), aragonite (CaCO₃) and dolomite (CaMg(CO₃)₂), where they show a negative saturation index calculated with PHREEQC software (Parkurst and Appelo, 2001), (Table 7).

The second process is the evaporation of the groundwater, where the water table is very shallow (Fig. 10). These two processes (dissolution and evaporation) cause the increasing of the total dissolved salts (TDS) of the groundwater. The second factor accounts for 24.79 % of the total variance and 3.72 of the Eigenvalue. This factor has high loadings with K⁺, As⁺⁵, Na⁺, SO₄⁻² (-0.85, 0.78, 0.67 and 0.62) and moderate loadings with NO₃⁻ and Cl⁻ (-0.47 and 0.42). This factor reflects human impact on the aquifer, where it shows the role of uncontrolled pesticides, which are used in agriculture. The third factor accounts 12.50 % of the total variance and 1.88 of the Eigenvalue, this factor has high loadings with pH, Zn⁺², HCO₃⁻, Se⁺² (0.84, -0.81, 0.73, 0.60) and moderate loadings with Na⁺ and SO₄⁻² (0.56 and 0.44). This factor corresponds to two processes, the first one is the role of rainfall recharge and this can be evidenced by the high loading of HCO₃⁻, which occurred under alkaline conditions. The second one is the use of sulfate fertilizers, where it has remarkable high loading with Zn⁺², Se⁺² and Na⁺. The fourth factor accounts 7.93 % of the total variance and 1.19 of the Eigenvalue, having high loadings with PO₄⁻² and Se⁺² (0.77, -0.69), and moderately loading with NO₃⁻ and As⁺⁵ (0.49 and -0.45). This factor reflects the role of phosphate and nitrate fertilizers, where these fertilizers are used as the soil is relatively poor in these elements.

Kurkar Aquifer

Factor analysis of data from Kurkar aquifer was performed using 11 cases and 11 variables. Four main factors control

Table 7. Saturation indices (SI) of different mineral phases of Sand dune and Old beach aquifer.

Mineral	Chemical Composition	11-10	12-1	12-12	12-21	Pz-1	16-6	16-14	16-31	16-34	16-41	16-52	16-67	16-73	16-80	16-143	Mean
Calcite	CaCO ₃	0.58	0.89	0.88	0.80	0.84	0.90	0.64	0.92	0.61	0.59	0.59	0.54	0.74	-0.27	-0.39	0.55
Aragonite	CaCO ₃	0.44	0.74	0.74	0.65	0.70	0.76	0.50	0.78	0.46	0.44	0.45	0.40	0.60	-0.41	-0.54	0.42
Dolomite	CaMg(CO ₃) ₂	0.96	17.60	17.10	12.56	15.97	16.94	12.13	19.96	12.24	11.77	12.03	11.68	15.46	-0.71	-0.60	10.87
Strontianite	SrCO ₃	-0.79	-0.38	-0.19	-0.30	-0.54	-0.43	-0.63	-0.21	-0.70	-0.65	-0.67	-0.59	-0.61	-16.68	-12.44	-2.34
Witherite	BaCO ₃	-26.79	-25.45	-27.77	-26.11	-26.11	-24.15	-24.57	-21.48	-25.36	-24.83	-24.45	-25.56	-24.01	-35.00	-34.11	-24.75
Gypsum	CaSO ₄ .2H ₂ O	-18.69	-14.03	-11.26	-12.12	-14.75	-14.02	-17.74	-16.97	-14.17	-21.45	-18.74	-19.49	-14.78	-19.97	-20.21	-15.31
Anhydrite	CaSO ₄	-20.89	-16.23	-13.45	-14.31	-16.95	-16.22	-19.94	-19.16	-16.37	-23.65	-20.94	-21.69	-16.97	-22.17	-22.41	-17.36
Celestite	SrSO ₄	-19.85	-14.13	-0.94	-10.43	-15.93	-14.72	-17.81	-15.68	-14.66	-21.19	-18.76	-18.20	-15.62	-21.37	-16.12	-14.44
Hydroxyapatite	Ca ₅ (PO ₄) ₃ OH	0.59	64.59	17.29	15.10	14.21	14.59	0.74	0.37	0.25	0.16	-0.13	0.18	0.32	-35.74	-32.55	4.01

the hydrochemistry of the groundwater of the Kurkar aquifer (Table 8).

Table 8. Factor analysis loadings and Eigenvalues of Kurkar aquifer.

	Factor 1	Factor 2	Factor 3	Factor 4
Ph	-0,79	0,15	-0,48	0,06
K ⁺	-0,16	-0,04	0,62	0,67
Na ⁺	-0,70	0,62	0,23	-0,09
Mg ⁺²	0,59	0,11	0,76	-0,06
Ca ⁺²	0,62	-0,10	0,72	-0,05
Cl ⁻	0,11	0,18	0,91	-0,10
NO ₃ ⁻	0,35	-0,49	0,72	0,00
SO ₄ ⁻²	-0,23	0,89	-0,12	-0,13
HCO ₃ ⁻	-0,89	-0,12	-0,22	0,09
PO ₄ ⁻²	0,01	0,07	0,22	-0,92
AS ⁺⁵	0,23	0,84	0,08	0,02
Expl.Var	2,92	2,21	3,24	1,34
Prp.Totl	0,27	0,20	0,29	0,12
Eigenval	4,81	2,31	1,55	1,04
Cumul. Eigenval %	4,81	7,12	8,67	9,71
Total Variance %	43,74	20,98	14,10	9,44
Cumul. %	43,74	64,72	78,82	88,26

These four factors have a cumulative total variance of 88.26%, while the smallest Eigenvalue is 1.04 and the cumulative Eigenvalue being 9.71. The first factor accounts 43.74% of the total variance and 4.81 of the Eigenvalue. It has high loading with HCO₃⁻, pH, Na⁺, Ca⁺² and Mg⁺² (-0.89, -0.79, -0.70, 0.62 and 0.59). This factor reflects two main processes, the first one is the deposition of calcite, aragonite and dolomite with the increase of flow distance and depth from recharge area, as these minerals have positive saturation indices (Table 9).

The second process is cation exchange between Ca⁺² and Mg⁺² with Na⁺ on the intercalated clays of the aquifer. The second factor accounts for 20.98 % of the total variance and 2.31 of the Eigenvalue. It has high loadings with SO₄⁻², As⁺⁵ and Na⁺ (0.89, 0.84 and 0.62) and moderate loading with NO₃⁻. This factor reflects the human impact on groundwater, where it shows the pollution with pesticides and nitrate fertilizers as well as wastewater (personal communication with farmers). The third factor accounts for 14.10% of the total variance and 1.55 % of the Eigenvalue, it has high loadings with Cl⁻, Mg⁺², Ca⁺², NO₃⁻ and K⁺ (0.91, 0.76, 0.72, 0.72 and 0.62) and moderate loading with pH (-0.48). This factor shows the mixing between different waters (sand dune water, Kurkar water, seawater and Pre-quaternary water). This mixing process will increase the salinity and decrease pH of the mixed water resulting in the increase of the mobility of heavy metals.

On the other hand, NO₃⁻ increases because of the increase of dissolved O₂, where nitrification reactions are enhanced to produce NO₃⁻ (the stable form of nitrates). The fourth factor accounts 9.44 % of the total variance and 1.04 of the Eigenvalue. It has high loadings with PO₄⁻² and K⁺ (-0.92, 0.67). This factor reflects the human impact on groundwater. The role of phosphate and potassium fertilizers can be noticed clearly, where fertilizers are used, as the soil is relatively poor with respect to these elements.

Summary and Conclusions

The area of study is located at the northern part of Sinai Peninsula (Egypt). It is thought to be a promising area for agricultural, industrial and tourism projects, but the present water supplies are insufficient to meet the expected huge increase in water demands. The sustainable development is retarded by many environmental problems such as over pumping, pollution of the limited water resources and seawater intrusion.

The potential pollution sources of groundwater in the study area are represented by agricultural activities, wastes disposal, over pumping of groundwater and seawater intrusion. The depth to the water table is very shallow and the aquifers are very permeable and offer only poor chemical buffering capacity. Intensive farming activities put stress on groundwater quality due to intensive use of fertilizers and pesticides resulting in high NO₃⁻, SO₄⁻², and PO₄⁻² concentrations. Most of the house owners do not have access to public sewers. Static water level maps from 1983 and 2000 show that the water level is declining with time. The groundwater extracted from the Quaternary aquifers (1983- 2000) is calculated by means of water table decline and the average storage coefficient to be 6.59 x10⁶ m³. More than 71.2% of the areal distribution of nitrate concentration greater than 44.29 mg/L represents a serious problem. This refers to the very shallow water table and high agricultural activities.

Factor analyses were used to define the factors that have impact on the groundwater quality.

Dissolution of several minerals, evaporation of the groundwater, human impact on the aquifers (nitrate, sulfate fertilizers and pesticides) and rainfall recharge are the main factors affecting sand dune and old beach aquifers. While Kurkar aquifer is affected by different factors deposition of calcite and aragonite, cation

Table 9. Saturation indices (SI) of different mineral phases of Kurkar aquifers.

Mineral	Chem. Comp	12-26	12-32	12-52	12-69	16-98	16-114	16-124	16-125	16-138	16-150	16-153	Mean
Anhydrite	CaSO ₄	-11.29	-15.21	-0.84	-12.44	-17.24	-13.70	-12.71	-14.95	-13.17	-14.08	-14.74	-11.56
Aragonite	CaCO ₃	0.03	0.44	0.67	0.66	0.75	0.72	0.78	11.64	0.65	0.63	0.96	1.63
Calcite	CaCO ₃	0.18	0.58	0.81	0.81	0.89	0.86	0.92	13.08	0.79	0.78	11.04	2.80
Dolomite	CaMg(CO ₃) ₂	0.49	11.97	16.98	16.75	21.54	20.89	21.92	26.35	19.64	17.91	24.45	18.08
Gypsum	CaSO ₄ .2H ₂ O	-0.91	-13.02	-0.63	-10.26	-15.05	-11.52	-10.52	-12.76	-10.99	-11.88	-12.55	-9.01
Rhodochrosite	MnCO ₃	-14.60	-13.16	-11.13	-12.24	-0.59	-0.72	-0.69	-0.56	-0.77	-0.86	-0.58	-5.08
Strontianite	SrCO ₃	-0.84	-0.57	-0.12	-0.43	-0.16	-0.18	-0.21	-0.22	-0.31	-0.29	-0.24	-0.30
Celestite	SrSO ₄	-0.66	-11.86	-0.30	-10.06	-12.92	-0.93	-0.93	-15.43	-0.94	-1.00	-13.42	-6.14
Hydroxyapatite	Ca ₅ (PO ₄) ₃ OH	0.01	12.76	0.99	13.23	-0.60	-0.09	10.22	20.43	0.82	-0.33	0.87	5.23
Gibbsite	Al(OH) ₃	0.80	0.67	0.57	0.65	0.05	0.26	-0.01	0.05	0.25	0.40	0.04	0.32
Al(OH) ₃	Al(OH) ₃	-18.94	-20.17	-21.15	-20.42	-26.37	-24.28	-27.02	-26.40	-24.41	-22.92	-26.54	-21.29

exchange, pollution with pesticides, potassium phosphate and nitrate fertilizers as well as wastewater and mixing between different waters.

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