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# 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 $km^2$. 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 $CO_3$), IC (Na, K, Ca, Mg, Cl, $SO_4$ and $NO_3$), ICP-MS (metals and rare earth elements) and Spectrophotometric ($PO_4$). 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 Database) in different coordinates and projections in one window without previous recalculation (Microimages, 2004).

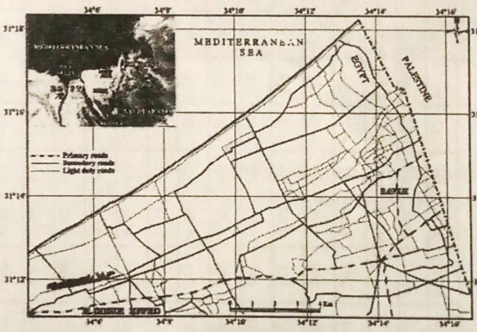


Fig.1. Location map of the study area

## 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).



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

| Well | pH | Eh | EC | TDS | K | Na | Mg | Ca | Cl | NO3 | SO4 | HCO3 | PO4 | Be | Al | V | Cr | Mn | Co | Ni | Cu | Zn | As | Se | Sr | Cd | Ba | Hg | Tl | Pb | Th | U |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mv | µS / cm | mg/L | mg/L | mg/L | mg/L | mg/L | Mg/L | mg/L | mg/L | mg/L | mg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | µg/L | 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 |
| Pzl | 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 |

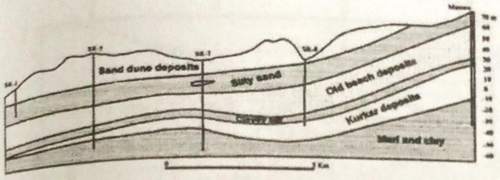


Fig.2. Hydrogeologic cross section from southeast to northwest in Rafah area.

Groundwater fluctuations of the Quaternary aquifers are affected by rainfall, excessive pumping and evapo-transpiration 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 avariogram 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 0.14%. Several local cones of depression in water level in Rafah and El Sheikh Zeweid represent the pumped areas.

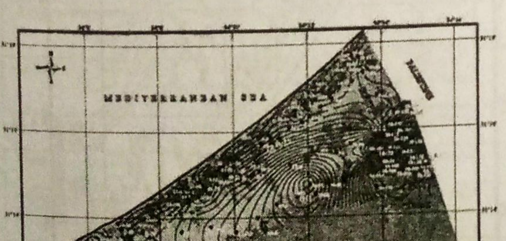


Fig.3. The variogram model fitted to the static water level data at 1983.

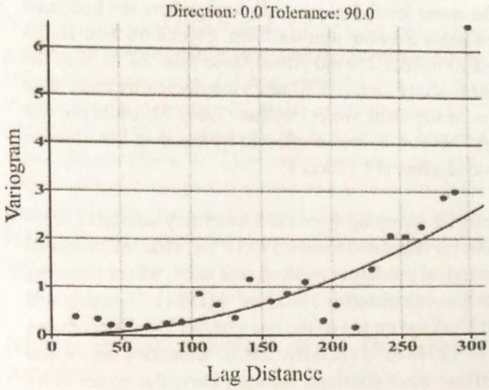


Fig. 4. Iso-potentiometric contour map of Quaternary aquifer in the year 1983.

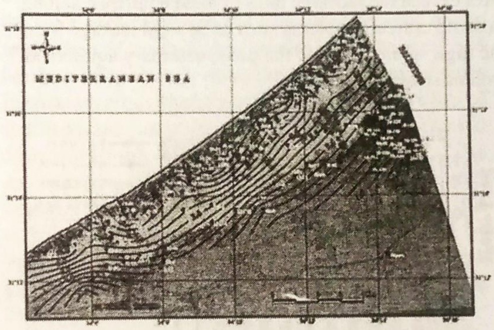


Fig.5. Contour map of Quaternary aquifers in the year 2000.

## 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 $km^2$) 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 $km^2$).

The over pumping from the Quaternary aquifers (1983-2000) is calculated to be $6.59 \times 10^6$ $m^3$. Also the calibrated numerical modeling method was used, where pumping rate was calculated as 18032 $m^3/d$ (1983). The calibrated total leakage on top of the main model layer is estimated to be 12040 $m^3/d$ (El Alfy, 2003). Boundary inflow and outflow were obtained through Dirichlet nodes to be 35382 $m^3/d$. In the year 2000, pumping rate was calculated to be 74000 $m^3/d$ (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.

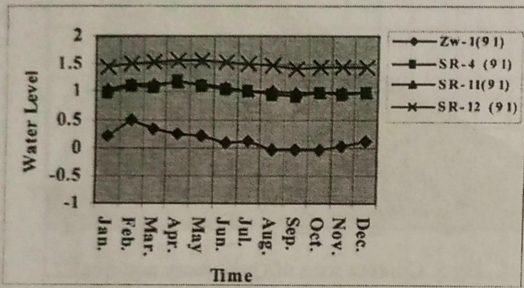


Fig.6. Groundwater hydrographs of monitored boreholes in 1991 (modified after Mekhemer, 1994).

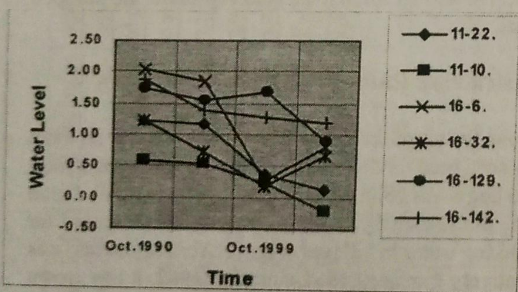


Fig.7.Groundwater hydrographs of monitored boreholes between 1990 and 2000.

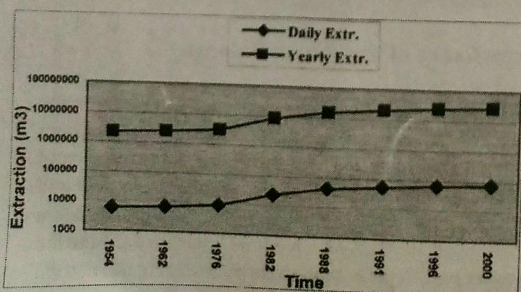


Fig.8. Groundwater abstraction rate in the study area (modified after RIWR, 1993).

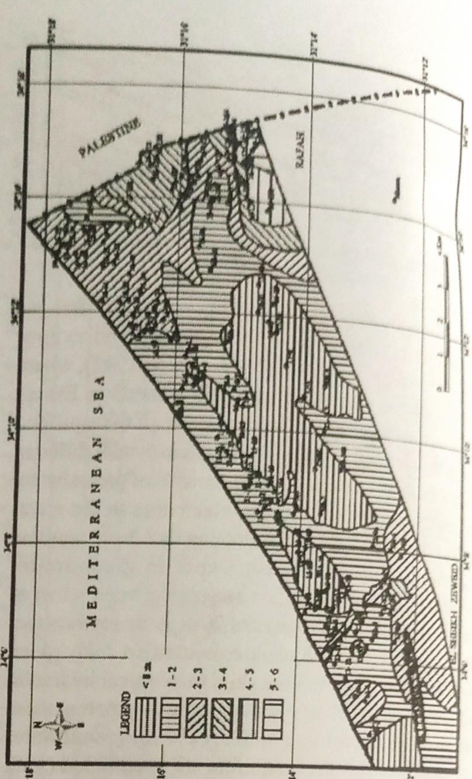


Fig.9. Water level declines zonation map of Quaternary aquifer between 1983 and 2000.

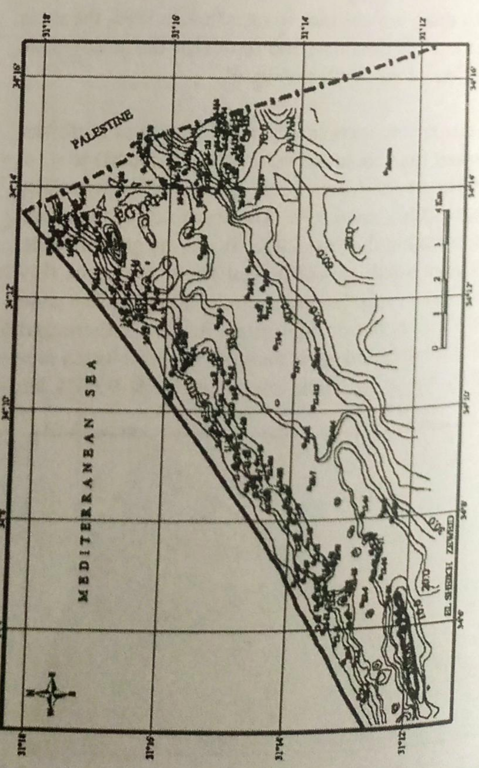


Fig. 10. Depth to water contour map of the Quaternary aquifer.

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 ($NH_4$, 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 $K^+$, $Cl^-$, $PO_4^{-2}$ and $NO_3^-$, 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 $PO_4^{-2}$ -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 $NO_3^-$, $SO_4^{2-}$ and $PO_4^{-2}$. The deterioration of the quality of ground water becomes obvious. Nitrate occurs naturally from precipitation due to NOx(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 $NO_3^-$, $NO_2^-$ $NH_{3(g)}$, $N_2O_{(g)}$ $NH_4^+$, 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 nitrite 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 $NO^{-3}$ and $PO_4^{-2}$ 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 permeabuity 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

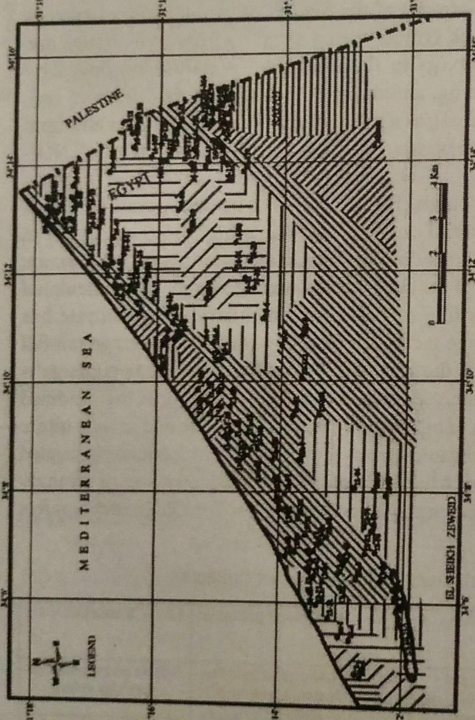


Fig.11. Hydraulic conductivity zonation map of the Quaternary aquifers

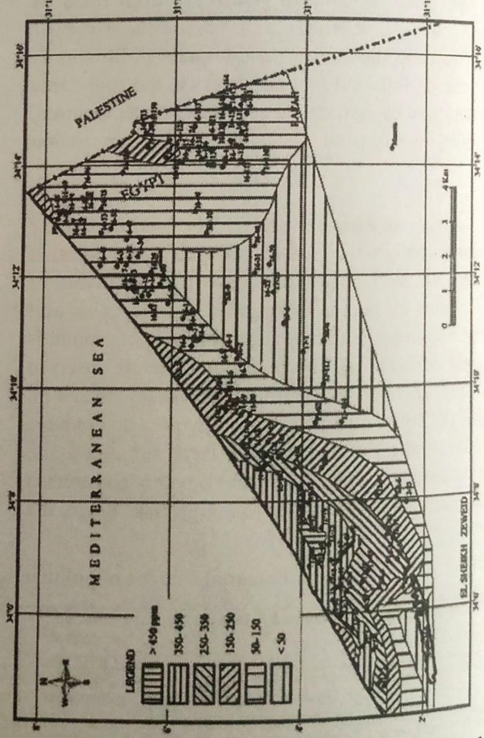


Fig.12. Areal distribution of nitrate concentrations of Quaternary aquifer during April 2000.

Table 5. Nitrate concentration in groundwater of the Quaternay 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 the smallest Eigenvalue being 1.19 and cumulative Eigenvalues of 12.52 (Table 6).

Table 6. Factor analysis loadings and Eignevalues 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 first factor accounts 38.26 % of the total variance and 5.74 of the Eigenvalues. This factor shows high loadings with $Sr^{2+}$, $Ca^{2+}$, $Mg^{2+}$, $Cl^-$, and TDS (0.97, 0.93, 0.97, 0.81 and 0.80 respectively) and moderate loadings with $SO_4^{2-}$ 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 ($CaSO_4.2H_2O$), anhydrite ($CaSO_4$), strontianite ($SrCO_3$), halite ($NaCl$) and in some localities calcite ($CaCO_3$), aragonite ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$), 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 $K^+$, $As^{+5}$, $Na^+$, $SO_4^{-2}$ (-0.85, 0.78, 0.67 and 0.62) and moderate loadings with $NO_3$ 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, $Zn^{+2}$, $HCO_3^-$, $Se^{+2}$ (0.84, -0.81, 0.73, 0.60) and moderate loadings with $Na^+$ and $SO_4^{-2}$ (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 $HCO_3^-$, 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 $PO_4^{-2}$ and $Se^{+2}$ (0.77, -0.69), and moderately loading with $NO_3^-$ 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 | $CaSO_4.2H_2O$ | -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 | $Ca_5(PO_4)_3OH$ | 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 Eignevalues 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 $HCO_3^-$, 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 $SO_4^{-2}$, $As^{+5}$ and $Na^-$ (0.89, 0.84 and 0.62) and moderate loading with $NO_3^-$. 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 $Cl^-$, $Mg^{+2}$, $Ca^{+2}$, $NO_3^-$ 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, $NO_3^-$ increases because of the increase of dissolved $O_2$, where nitrification reactions are enhanced to produce $NO_3^-$ (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 $PO_4^{-2}$ 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 $NO_3^-$, $SO_4^{2-}$, and $PO_4^{-2}$ 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 $x10^6$ $m^3$. 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 | $CaSO_4.2H_2O$ | -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 | MnCO3 | -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 | $Ca_5(PO_4)_3OH$ | 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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