The environmental impact on the hydrogeochemical characterization of the Kurkar aquifer system, Gaza strip, Palestine.

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Abstract: The Gaza strip is suffering groundwater deterioration as a result of high population density where the outflow exceeds inflow by about 20 Mm^3/y. This quantity of water is believed to be replaced by deep seawater intrusion and/or upconing of deep brines in the southern areas or by anthropogenic wastewater. Large cones of depression have been formed over the last 40 years within the Gaza, Khan Younis, and Rafah governorates. The salinity increases in the northwestern and the southeastern parts of Gaza Strip. Nitrate and chloride exceed the WHO maximum permissible limits and are considered as the major pollutants of the aquifer, their high concentration values are attributed to agricultural activity and leaked wastewaters as well as the scarcity of the resource. The cluster analysis (Q-mode) classified the data into 5 clusters and 3 independent cases depending upon salinity and nitrate concentrations. The rotated factor analysis identified 3 factors. The AquaChem program clarified that the study area was supersaturated with calcite and dolomite and undersaturated with gypsum and anhydrite minerals. In general, the groundwater was unsuitable for drinking according to their TDS and NO_3 contents. The groundwater can be used in permeable soils for irrigation purposes.

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1. Introduction.

The scarcity of water and the increasing of population density during the last few decades led to a very high water consumption rates reflected in depletion and decline in groundwater levels as well as serious salinity problems. Agricultural activity and lack of infrastructure (sewer system) were additional sources of pollution to the groundwater. In Gaza strip**,** about 100,000 cesspools, with depth 8-12 m and 2 m diameter, spray 30-40 Mm^3/y wastewaters into groundwater system. It is gray and black wastewaters contributed to groundwater pollution specially NO_3 content (Abu Mailah 1991). About 1500 chemical septic tanks constructed into the groundwater system. The Gaza Strip is situated in the southern part of the Mediterranean Sea of the Palestinian coastal plain, bordered by Egypt to south. It has an area of 365 km^2. Agricultural land occupies about 50% of the land surface and **a**bout 3500 Israeli settlers live in about 40 % of the total Gaza area (Al Agha and El Nakhal, 2004). These settlers were lived in 18 settlements, most of them along the coast and they have their own wells. Twenty four groundwater samples were analyzed for subsequent analyses of cations and anions in the labs of Ministry of Agriculture **(Fig. 1a)**. Chemical analyses data of the groundwater were processed by different programs to clarify the hydrogeochemical characteristics of the groundwater samples, genesis and the water quality distribution.

The surface exposures composed of a series of alternating elongated ridges and depressions which run parallel to the coast. Most of the exposures are covered by Quaternary soil and wadi alluvium (El Nakhal, 1968). The coastal belt covered with calcareous sand dunes (Holocene), which susceptible to natural recharge from the intense rainfall. The coastal aquifer of the Gaza Strip belongs to Kurkar Group (Pleistocene age). It is composed of marine sands, sandstone, calcareous siltstone, and red loamy soils (Al Agha, 1995). The thickness of the aquifer is about 80 m at most near the sea and its thickness decreases considerably down to 10 m in the east. The aquifer subdivided into several subaquifers (A, B, C, & D) along the coast by impermeable clay and silt lenses **(Fig. 1b)**. The latter lenses wedged out and disappeared gradually due southeast. These subaquifers were interconnected hydrogeologically and considered as a one aquifer. The marine Kurkar is underlained by Saqiya Formation of marine clay, shale, and marl **(Fig. 1b).** Due the southeastern part of Gaza strip, the aquifer is underlained by chalk and limestone of Eocene, Senonian, and Cretaceous aquifers **(Fig. 1b).** More than 2500 wells were in the sand dunes of unconfined part of the aquifer (continental Kurkar). While the remaining wells lies in the confined to semiconfined part of the marine Kurkar aquifer. The total thickness of clay and silt lenses increased seaward in the southern part of the

Gaza strip than those in the northern part **(Fig. 1c).** Rainfall intensity is increased due the northeastern part to reach about 400 mm/y (Gaza Environmental Profile 1994)**.** This intense rainfall recharges the coastal aquifer through the sand dunes in unconfined part of the aquifer. A negative water balance exists whereby, on average, more water is pumped from the aquifer than naturally replenishes it. Outflows exceed inflows by about 20 Mm^3/y (Melloul and Collin, 1994). This quantity of water is believed to be replaced by deep seawater intrusion and/or upconing of deep brines in the southern areas or by anthropogenic wastewater. The amount of natural fresh water in Gaza is not enough to dilute the saline groundwater and the saline water under Israeli territory also flows into the aquifer under the Gaza Strip (Anderson 2004)**.**

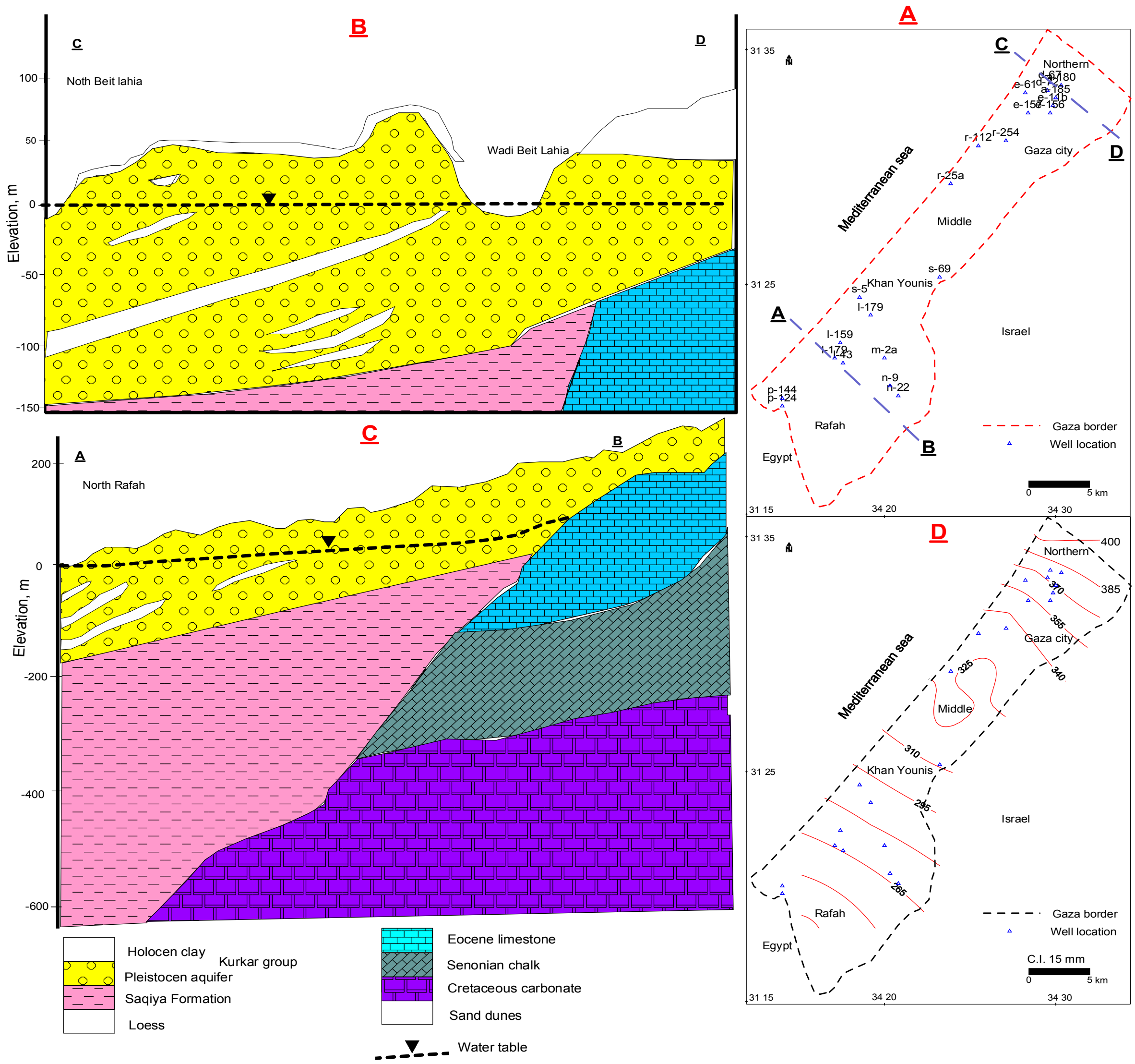

Fig. 1 Location map and pumping wells (A), hydrogeological cross sections through C-D (B) and A-B (C) directions of Fig. 1, and yearly rainfall in Gaza strip (D

According to George (1979), the Kurkar aquifer is extremely highly potential. The effective porosity is 25 % and water depth ranges from 90 m along southeastern part to < 8 m near shore (Khalid and AbdelKader, 2003). Both transmissivity (T) **(Fig. 2a)** and hydraulic conductivity (K) **(Fig. 2b)** values increase in the northern part of Gaza Strip as a result of the high rate of rainfall. Regional groundwater flow is toward the Mediterranean Sea **(Fig. 2c)** with some disturbance by pumping and artificial recharge.

Large cones of depression have been formed over the last 40 years within the Gaza, Khan Younis, and Rafah governorates.

There is an increase in water table in the southeastern part **(Fig. 2d)**, caused by infiltration of wastewaters into the aquifer system and may inflow from the Israeli surrounding aquifers. The Kurkar aquifer recharged from rainfall, wastewaters, and Israeli aquifers amounts to 4.5 Mcm/y, 30 Mcm/y, and < 10 Mcm/y, respectively.

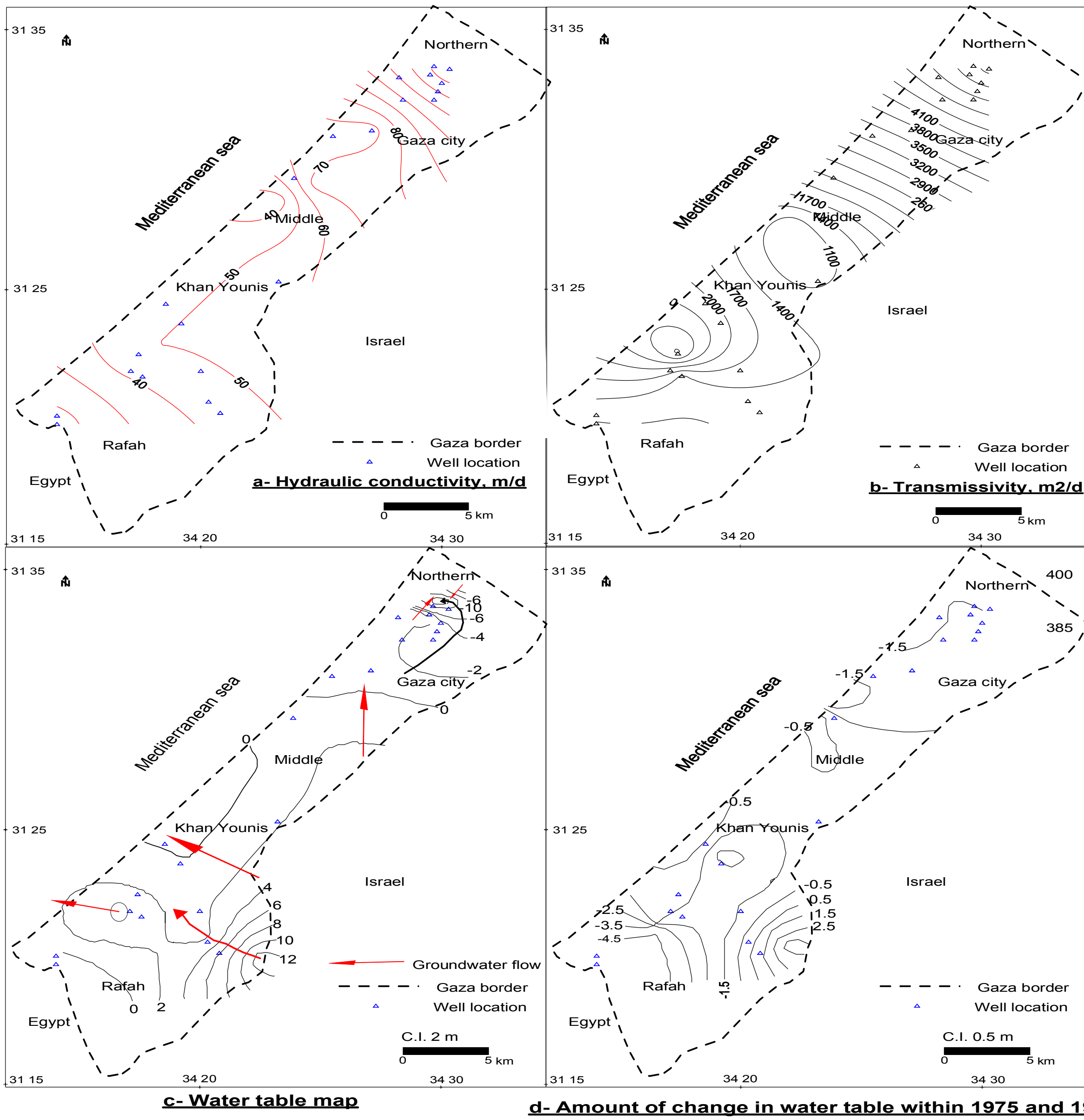

Fig. 2 The hydraulic conductivity (a), the transmissivity (b), the water table map (c) and its change (d) within different periods in Gaza aquifer

2. Materials and Methods.

Groundwater chemistry data (major ions and NO_3) were obtained from the Palestinian Water Authority. Primarily the wells are used for public supply, domestic and irrigation purposes. Samples were taken directly from each well, filtered, preserved, and delivered to an analytical laboratory within prescribed maximum holding times. The hydrogeological data for the wells was given by the same authority.

3. Results and discussion.

3.1. Hydrochemistry

3.1.1. Electrical conductivity (EC) and Total dissolved solids (TDS).

The most significant hydrochemical characteristics of Gaza Strip arise from the influence of interacting factors including; seawater intrusion, salt water intrusion, overpumping, evaporation, and anthropogenic activities. The pH has a considerable influence on the water chemistry, because it affects ionic strength, organic carbon content, mobility of metallic ions and the oxidation/ reduction potential. The pH values of the studied groundwater varied from neutral to slightly alkaline. The increasing of rainfall rate due west lead to decreasing in pH value, where this area covered with sand dunes that permit rainfall water to infiltrate to the aquifer. According to Langenegger (1990), EC is greatly affecting the water quality for drinking purpose. In the northern area, EC ranges from 506 to 2683 µS/cm, whereas in the southern area it ranges from 1064 to 5660 µS/cm. The total dissolved solids (TDS) in the northern part of Gaza Strip ranges from 477 to 1667 mg/l, whereas the TDS in the southern part ranges from 660 to 3650 mg/l. The EC and TDS distribution maps indicate two different trends for the northern and southern areas. In the northern area, there is a gradual increase in groundwater salinity westward (seaward) **(Fig. 3a)** and may referred to low rate of seawater intrusion, where the values are not so high as a result of high precipitation rates that dilutes and replenishes the aquifer system. In the southern area, the increase in groundwater salinity was in the southeastern part **(Fig. 3a)**, may attributed to the high salinity water penetrates the aquifer bottom through overpumping (Shavit and Furman, 2001), recharging from saline water of Eocene chalk and marl of the Hashepela Group (Rosenthal *et al*., 1992; Vengosh & Rosenthal, 1994), low precipitation rate (200 mm/yr), and anthropogenic activities such as agricultural, and septic tanks.

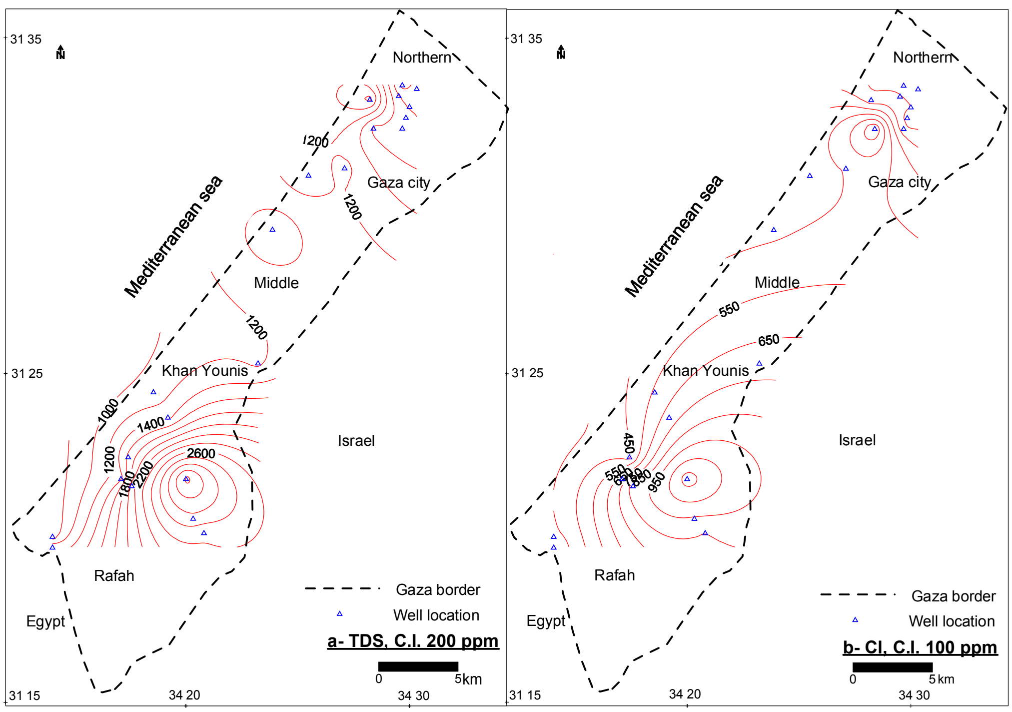

Fig. 3 Total dissolved solids (TDS) (a) and Cl (b) concentrations in Gaza aquifer

3.1.2. Total Hardness

The hardness of the water is measured by the presence of the divalent metallic ions (calcium and magnesium). Water for domestic uses should not contain more than 80 mg/l hardness.

According to Hem (1970), the majority of the groundwater samples classified as very hard class with some exceptions. In the southern area, the increase of total hardness coincides with the increasing of $NO3^{-}$ content confirms that Ca^{2+}, Mg^{2+} and NO_3 concentrations in groundwater are contributed by agricultural activity rather than seawater intrusion. In the northern area, the total hardness decreases seaward reflects that Ca^{2+}, Mg^{2+} and NO_3 are derived mainly from lithostratigraphic and anthropogenic sources rather than seawater intrusion.

3.1.3. Major ions and NO3 concentrations.

In the northern part of Gaza Strip, calcium and magnesium contents ranges from 44 to 314 mg/l; 18.2 to 66.3 mg/l (Fig. 4a); respectively. In the southern area calcium content ranges from 25 to 173.1 mg/l, and magnesium content ranges from 23.7 to 98.6 mg/l (Fig. 4b). The main sources of Ca^{2+} and Mg^{2+} in groundwater environment may attribute to the water–rock interaction in the Kurkar aquifer and the use of fertilizers. In the northern area, sodium content ranges from 30.3 to 152.7 mg/l, and potassium ranges from 1.5 to 4.2 mg/l. In the southern area sodium content ranges from 180 to 850 mg/l, and potassium content ranges from 3 to 13.7 mg/l. The sources of potassium and sodium ions may be resulted from the uncontrolled use of some specific type of fertilizers, and lithological impact (Vengosh *et al.* 1999, and Artzy, 1999), soil- water interaction (Bruins, 1976), ion-exchange processes in the aquifer aquitard diffusion (Mercado, 1989). Qahman and El Arabi (2003) reported that the natural water in most parts of Gaza Strip is believed to be brackish with Cl^- concentration more than 1000 mg/l. Chloride content in the northern area increases westward (seaward) from 35 to 749 mg/l which attributed to seawater intrusion. Whereas in the southern area, chloride content ranges from 242.7 to 1013.9 mg/l, and the increase was in the southeastern part of the study area. The source of chloride may be due to the saline water flowing to the aquifer from the east, seawater intrusion from the west and high pumping rate (Al Agha, 2004) as well as agricultural activity.

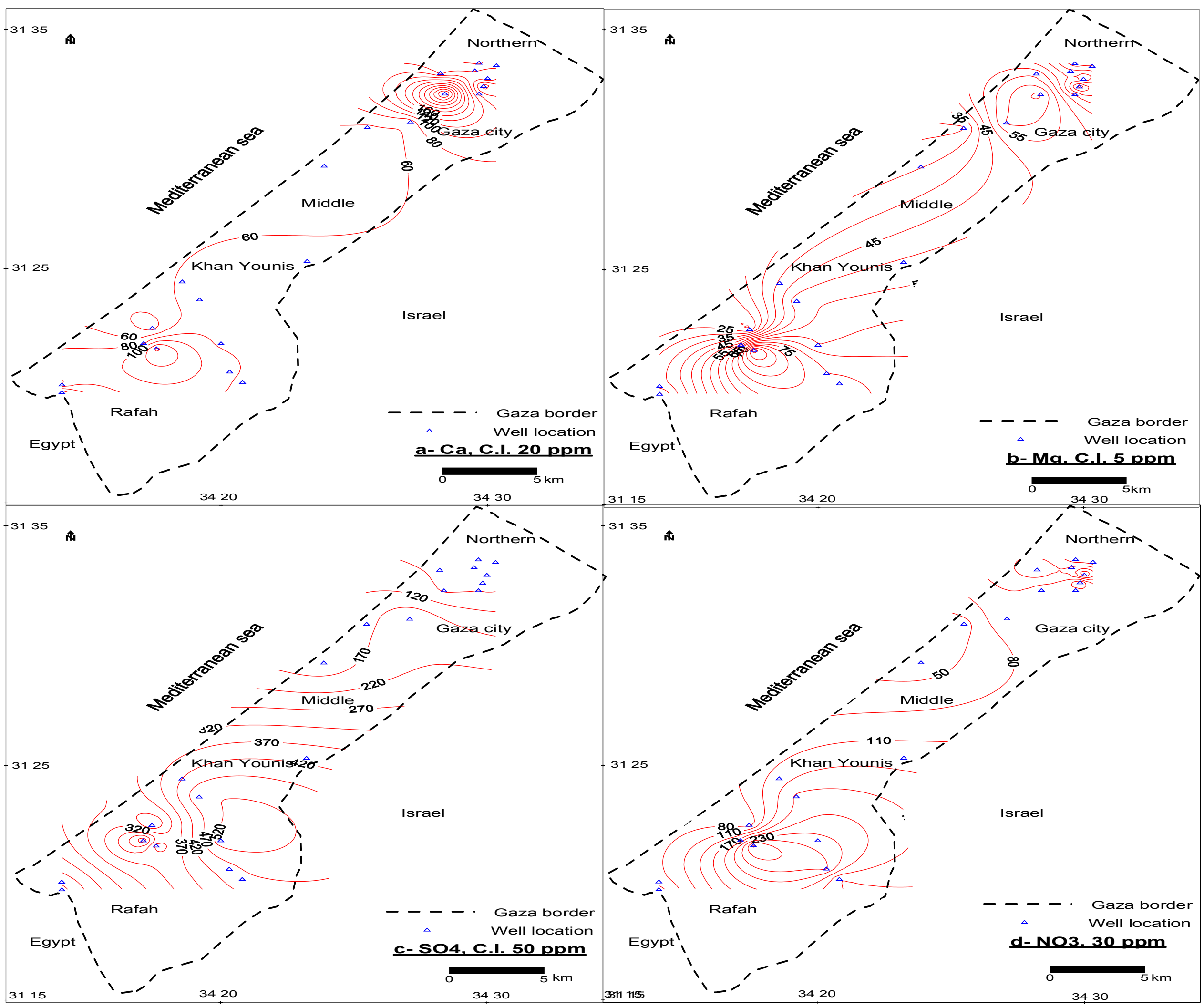

Fig. 4 Ca (a), Mg (b), SO_4 (c), and NO_3 (d) concentrations in Gaza aquifer.

Nitrate concentration in the northern area ranges from 32 to 196 mg/l, whereas in the southern area it ranges from 32 to 455 mg/l. The source of high nitrate in both northern and southern areas attributed to the lack of sewer system in the highly populated Palestinian refugee campus distributed allover the Gaza Strip. The wastewater is collected in cesspools and septic tanks which means long-Term pollution to the groundwater environment. When leak, they infiltrate through highly permeable sandy soils of the aquifer (Al Agha, 2004), also the uncontrolled use of fertilizers may contribute to groundwater pollution. Sulfate concentration in the northern area ranges from 11.7 to 70.4 mg/l **(Fig. 4c)**, whereas in the southern area it ranges from 51.7 to 513.8 mg/l. The sulfate concentration increases westward (seaward) in the northern area, and increases in the southeastern part of the southern area. The sulfate concentration may be derived from seawater intrusion in the northern area or related to sulphur deposits mined near Gaza Strip between 1930 and 1942, and anthropogenic activities. TDS anomaly (southeastern part) coincides with Cl^- **(Fig. 3b)** and SO_4^{2-} **(Fig. 4c)** anomalies and not coincide with NO_3^- **(Fig. 4d)** anomaly, that confirm the increase of groundwater salinity not only influenced by the intensity of rainfall but also may be by deep brine aquifer, seawater intrusion, lithology and agricultural impact. NO_3^- anomaly **(Fig. 4d)** coincides with Ca^{2+}, Mg^{2+} and Na^+ anomalies which confirm their agricultural source.

The aforementioned criteria indicate that the northwestern part of Gaza Strip is influenced by shallow seawater intrusion of low rate, while the southwestern part is less impacted by seawater intrusion and more affected by anthropogenic impact. The northeastern part is close to the recharge area of the aquifer, so it is characterized by lower salinity, whereas the southeastern part is influenced by deep saline water and saline water flowing from the east. Also the lithology in the surrounding areas (Israeli regions) of Gaza Strip especially from north and east affects the chemical content in Gaza Strip where they located in the flow direction of water flowing into Gaza Strip from Israel.

The salt combination assemblages of the groundwater from the study area reflect the following inferences:

1.The presence of Na_2SO_4 salt reveals the meteoric origin for the groundwater attributed to the leaching processes.

2.The presence of $MgCl_2$ salt reveals the marine origin for the groundwater and is attributed to the presence of marine sediments (marine Kurkar), the upconing of deep brines, and saline water intrusion from the east of Gaza Strip.

3.The presence of $CaCl_2$ in both northern and southern areas is an indicator of old marine water facies and this seems to be strange, because depths of wells allover the Gaza Strip are not so deep and mostly located in a shallow depths which

3.1.4. Hydrochemical Classification

The diagnostic chemical properties of water are presented by various methods, the most common of which is the hydrochemical facies by Piper**'s** diagram (1944). Four hydrochemical facies were reported in the studied area **(Fig. 5a)**:

Type I (Alkaline water; $Ca+Mg-CO_3+HCO_3$ facies)

This facies mostly concentrated in the northern and western areas. The hydrochemical properties affecting the hydrochemistry of these two locations were similar, high intensity of rainfall improve the groundwater environment. Another important factor is the existence of high thickness of sand dunes in the coastal line, which enhances the infiltration of rainwater to the aquifer system.

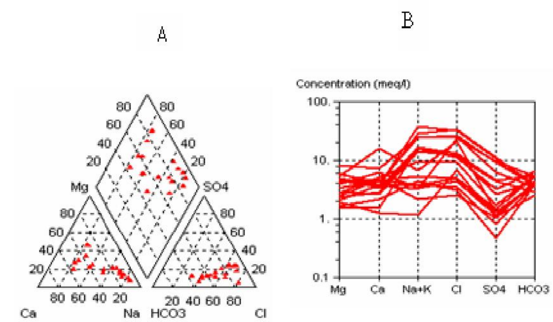

Fig. 5 Hydrogeochemical facies graphs of the Gaza aquifer.

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Type II (Saline water; $Na+K-Cl+SO_4$ facies)

This facies covers the southern and eastern areas. The occurrence of the saline water facies is attributed to the effects of brackish groundwater flowing from the east and/or seawater intrusion from the west.

Type III (Na- CO_3+HCO_3 facies)

This facies appears only in well (E11/C) in the northern area, it attributed to high precipitation and aquifer aquitard diffusion.

Type IV (Ca+Mg-Cl facies)

This facies appears in wells located in the northern area. They are characterized by $MgCl_2$ and $CaCl_2$ facies, the presence of these facies reflect the presence of old marine water and dissolution of carbonate rocks intercalated with the aquifer.

3.1.5. Classification Using Sulin´s Diagram (1946)

The Na_2SO_4 and $NaHCO_3$ water types of meteoric genesis reflect the hydrochemical composition of wells (D/67, D/68, E/11B, E/11C, E/157, L/179, L/41, P/144, R/112, R/254, R/25A, S/69), while the water samples collected from wells

(A/180, A/185, D/2, E/156, E/61, E/90, L/127, L/159, L/176, L/43, L/87 and P/124) indicates $MgCl_2$ and $CaCl_2$ types of marine genesis. Groundwater samples of marine affinity may be attributed to the presence of marine sediments in the lithostratigraphic succession of Quaternary Formation, Eocene chalk and marl of the Hashepela Group(Rosenthal et al., 1992; Vengosh & Rosenthal, 1994), high abstraction rate led to upconing of deep brines, saline water intrusion from the east of Gaza Strip and anthropogenic influences.

3.1.5.Classification using Schoeller diagram (1955)

The semi- logarithm graph of Schoeller (1955) indicates that the groundwater samples in Gaza Strip area is polluted with saline water and anthropogenic sources which resulted in non-identical lines (Fig. 5b). 3.2. Groundwater Evaluation.

The quality of water is as important as quantity for any evaluation of groundwater. The physical, chemical, and biological characteristics of water are of major importance in determining whether or not water is suitable for domestic, drinking, livestock and poultry, Industrial, and Irrigation purposes. According to the World Health Organization (WHO 1996) standards, the groundwater samples (A/180, A/185, D/2, D/67, D/68, E/11B, E/11C, E/156, E/157, E90 and P/144) can be classified as permissible water where (TDS 500-1500 mg/l). Whereas the rest wells were unsuitable for drinking purposes (TDS > 1500 mg/l), they are suitable for toilets and flushing. In the Gaza strip, the nitrate problem is acutely threatening the health of the people who use contaminated water (El-Nakhal 1968, Evans et al., 1993 and Uma, 1993) and several cases of blue babies were reported in the area in the last few years (Abu Nasr 2003). The nitrate values ranges from 32-455 mg/l. The nitrate limits in the investigated area were exceeded the maximum permissible limits established by World Health Organization. According to the National Academy of Science (1972); the evaluation of the Gaza Strip groundwater quality for livestock and poultry purposes can be classified as:

1. Excellent water; (T.D.S < 1000 mg/l) it includes wells (A/180, A/185, D/2, D/67, D/68, E/11B, E/11C, E/156, E/157, E/90 and P/144).

Very satisfactory; (T.D.S ~1000-3000 mg/l) it includes wells (E/61, L/127, L/159, L/176, L/179, L/43, L/87, P/124, R/112, R/254, R/25A and S/69).

Satisfactory; for all classes of livestock, but poor for poultry (T.D.S ~ 3000-5000 mg/l) it includes well (L/41).

The evaluation of groundwater quality for irrigation purpose depends mainly on many factors such as total salinity, sodium content and sodium adsorption ratio. The quantity of the salts, which can be withdrawn by plants, depends mainly upon the type of soil and plant, and the ease of drainage. According to Ayers (1975), the irrigation of water can be used without any problems when T.D.S < 480 ppm. The problem increase when T.D.S ranges between 480 to 1920 ppm, while at TDS > 1920 ppm the problem becomes severe. The total salinity of the groundwater samples of Gaza Strip ranges between 314 to 1828 ppm which is within suitable range, except for wells (L/41, L/43, L/87, M/2a, N/22 and N/9) they exceed the value of 1920 ppm. Wilcox classification (1948) is based on the relation between sodium % and the total concentration of cations and anions in epm. Sodium may cause an increase in the hardness of the soil as well as a reduction in its permeability (Todd, 1980). The sodium percent of wells in the study area ranges from 19 - 83. Wilcox classification distinguishes the studied wells into:

Group 1: well (D/67) lies in good to excellent class.

Group 2: wells (A/180, A/185, E/11B, E/11C, E/90, E/156, E/157, D/2, D/68 and P/124) lie in the good to permissible class.

Group 3: wells (P/144, R/112 and S/69) were in the permissible to doubtful class. The remaining wells were in the doubtful to unsuitable class.

Based on the classification established by U.S Salinity Laboratory classification (1954) for irrigation purposes, the groundwater of Gaza Strip can be classified as:

1. (TDS 250 - 750 mg/l and SAR < 10): one well lie in this class (D/67). It is suitable and can be used for irrigation on almost all soils.

(TDS 750 - 2250 mg/l and SAR<10): The wells (A/180, A/185, D/2, D/68, E/11B, E/11C, E/156, E/157 and E/90) fall in this class. They can be used in all soils except for soils with restricted drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

(TDS ~2250-5000 mg/l and SAR<10): well (E/61) was in this class. It is not suitable for irrigation under ordinary conditions, but may be used under very special circumstances.

(TDS ~750- 2250 mg/l and SAR 10-18): four wells (P/124, P/144, R/112 and S/69) were in this class. They can used on soils of moderate to good permeability; plants with moderate salt tolerance can be grown without special practices for salinity control.

(TDS >2250 mg/l and SAR 10-18) four wells (L/127, L/159, L/43 and R/25A) lie in this class. They generally were unsuitable for irrigation but can be used on soils of moderate to good permeability.

(TDS ~ 750-2250 mg/l and SAR 18-26) two wells (L/179 and R/245) lie in this class. They cannot be used on soils with restricted drainage, special salinity management is required.

(TDS >2250 mg/l and SAR 18-26) two wells (L/176 and L/87) lie in this class. They generally were unsuitable for irrigation except for high permeable soils with frequent leaching and good drainage and organic matter additions.

(TDS >2250 mg/l and SAR>26) one well (L/41) was in this class. It is unsuitable for irrigation except for high permeable soils with frequent leaching and high tolerant plants.

3.3. Statistical analyses:

Groundwater geochemical data were processed by SPSS in order to study the interrelationship among the chemical constituents. TDS strongly correlated with Na^+, Mg^{2+}, Cl^- and SO_4^{2-} due to the role of lithological impact, evaporation and dissolution of salts with precipitation, whereas it is weakly correlated with Mg and NO_3^- due to wastewater infiltration and fertilizers application. The Ca^{2+} correlated with Mg^{2+} as a result of dissolution of calcite, enriched Mg-calcite, and dolomite. Mg^{2+} is correlated with NO_3^- and Cl^- due to agricultural impact confirming the overuse of fertilizers. Na^+ is strongly correlated with Cl^- and SO_4^{2-} due to evaporation and/or seawater intrusion and also from surface saline soil.

3.3.1. Cluster analyses (Q - mode dendrogram):

The simple form of cluster analyses is to define a simple form of correlation analyses. The intercorrelation of variables (R-mode) or cases (Q-mode) in a two hierarchical diagram are called the dendrogram. The transformed data input of the main ions are used in dendogram (Fig. 6), which distinguished into 5 clusters.

Cluster 1, It is characterized by the lowest salinity (500-1320 µs/cm) and moderate nitrate concentration (43-240 mg/l), located in the northeastern part of Gaza Strip.

Cluster 2, It is characterized by higher salinity (1260-2490 µs/cm) and lower nitrate values (32-110 mg/l). The wells are distributed allover the middle area of Gaza Strip (Deir Al Balah and Khan Younis).

Cluster 3, It is characterized by higher salinity (1064-2132 µs/cm) and lower nitrate values (36-60 mg/l). They were located in the southwestern part of (Rafah).

Cluster 4, It is characterized by higher salinity (2654-2683 µs/cm) and high nitrate (93-455 mg/l).

Cluster 5, It is characterized by the highest salinity (2945-3940 µs/cm), and the highest nitrate concentration (323-355 mg/l). They located in the southeastern area (Rafah governorate).

There are three independent cases, Well P/124 (high potassium content, Well L/41 (the highest salinity content) and Well L/176 (lowest carbonate content). The cluster identification coupled with their graphical representation play a good vision of groundwater classification.

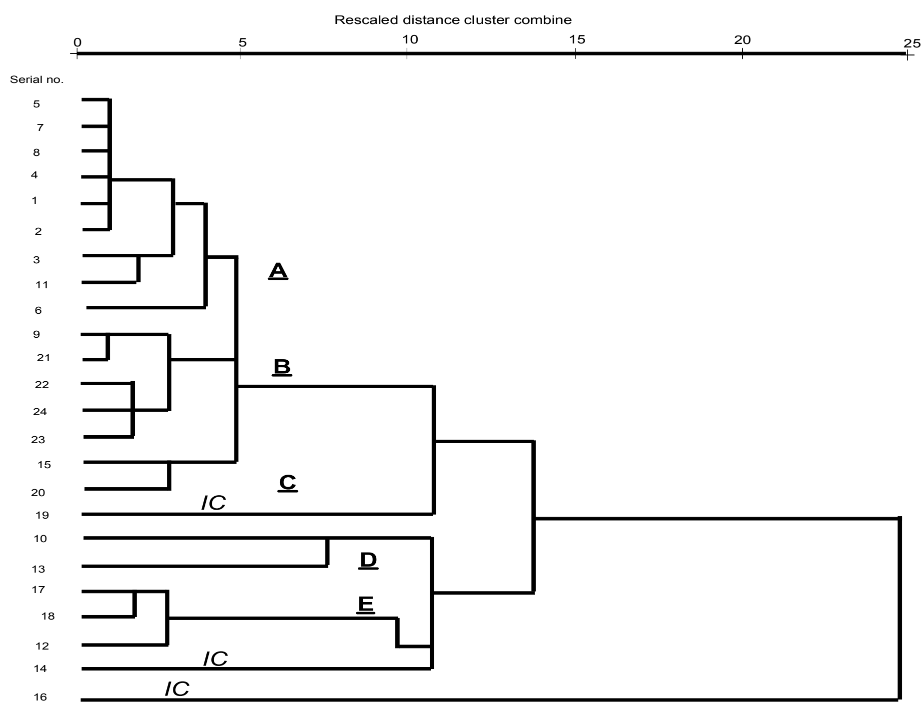

Fig. 6 Dendrogram analysis of the major ions and NO_3 contents of the Gaza aquife

3.3.2. Factor analyses (R-mode):

The identification and interpretation of factor analyses are applied in geochemistry by many authors e.g. Davis, 1986: Gardner et al.1990: Prethviraj and Prakash, 1990 among others. In order to get better results, beside the R-mode factor (principle component

The identification and interpretation of factor analyses are applied in geochemistry by many authors e.g. Davis, 1986: Gardner et al.1990: Prethviraj and Prakash, 1990 among others. In order to get better results, beside the R-mode factor (principle component

analyses) the rotated factor analyses is also computed. Three factors were extracted (Fig. 7)

Factor 1 (salinity factor) was highly positive loading with EC, TDS, pH, Na+, Cl¯ and SO42¯.

Factor 2 (lithognic and agricultural factor) was highly positive loading with Ca2+, Mg2+and NO3¯.

Factor 3 was highly positive loading with HCO3¯ and K+.

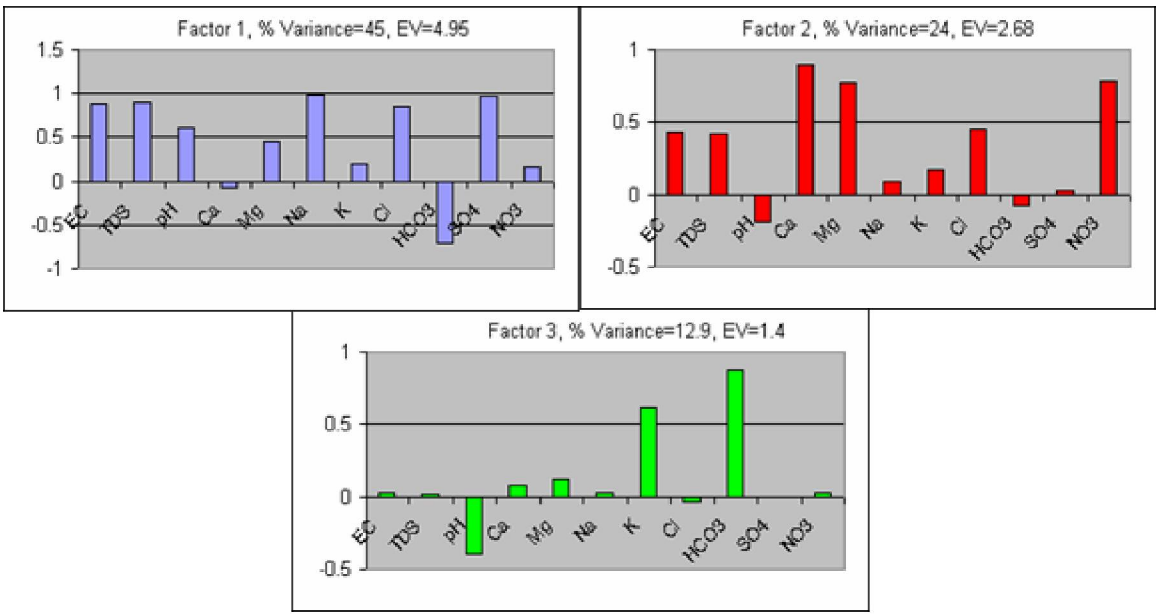

Fig. 7 Factor analyses of groundwater in the Gaza Strip

3.4. Saturation index:

PHREEQ-C model has addressed the problem of aqueous speciation and the calculation of mineral saturation. Calculation of a mineral saturation index (SI) is a convenient method of representing the equilibrium condition of a solution with respect to a mineral. A range of saturation indices with respect to mineral between successive samples reflects changes in the water chemistry due to stratification or mixing between two end members. The saturation indices of the carbonate minerals positively show supersaturation (precipitation) of calcite and dolomite. Considering the reaction for dissolution of dolomite:

In terms of thermodynamic considerations (Stumm and Morgan, 1981), the area supersaturated with respect to carbonate minerals (calcite and dolomite) in the northern and southeastern areas, but undersaturated in the southwestern area near the coast (Fig. 8a and b) as a result of dilution.

The undersaturation state of the calcite was extended along coast than dolomite state. The equilibrium zone was more or less in some positions for calcite and dolomite minerals. Calcite and dolomite undersaturation and/or carbonate dissolution has been reported in several mixing zones around the world, may attributed to oxidation of organic matter that produces additional CO2 and significantly enhances this undersaturation due the coast (Smart et. al. 1988; Whitaker & Smart, 1997, and Mohsen et. al., 2004).

Groundwater was undersaturated with respect to gypsum and anhydrite all over the area(Fig. 8c and d).

3.5. Conclusions and Recommendations

Gaza Strip is a coastal region and covers an area of 365 km². It has a coastal aquifer extending along the coastal plain. The aquifer was overpumped during the last few decades where population density is the highest allover the world. Geological data showed that the aquifer is mainly composed of Kurkar Group to the east underlain by chalk limestone and to the west intercalated with clay layers. The aquifer is divided into three subaquifers A, B and C separated by clay layers. High abstraction rates in the Gaza strip resulted in negative balance where outflows exceed inflows. Exploitation of groundwater has resulted in increasing water salinity and lowering of groundwater level. Both transmissivity (T) and hydraulic conductivity (K) increases due northeast and decreases slightly towards the southern area, and both showed that the aquifer is highly potential. Distribution pattern maps of salinity show limited seawater intrusion in the northwestern area (seaward) and salt intrusion in the southeastern area as a result of extensive discharge of groundwater which encourages the seawater and salt water intrusion from the west and east; respectively. Descriptive statistical results indicate that nitrate and chloride contents are so high and exceed the WHO maximum permissible limits. Nitrate and chloride are considered as the main pollutants of the aquifer Anderson (2004) reported that water in the Gaza Strip is in a dire state, containing high concentrations of contaminants leached out of the desert soil. They are derived mainly from the agricultural wastes and leaked wastewaters as well as the scarcity of the resource.

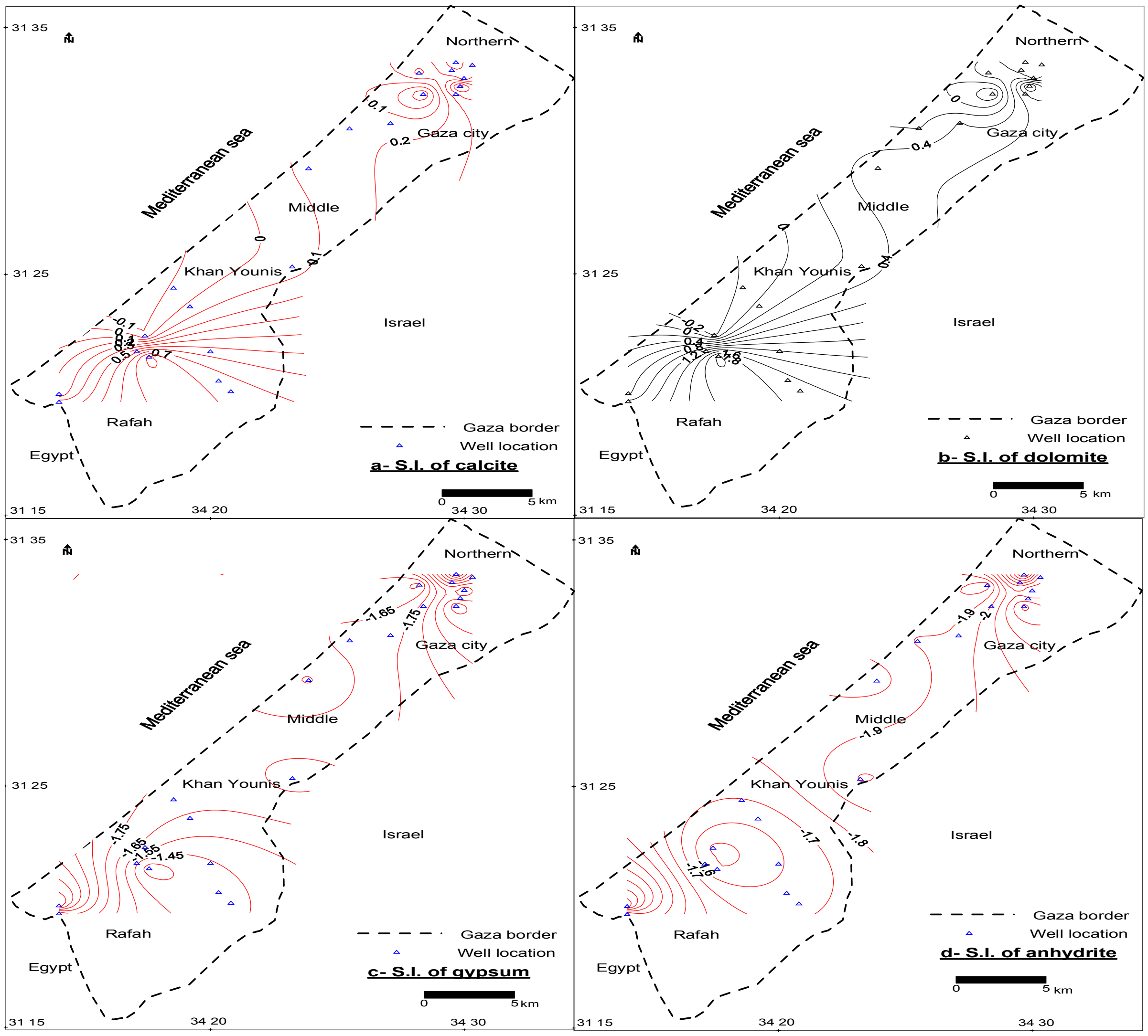

Fig. 8 Saturation indices of calcite (a), dolomite (b), gypsum (c), and anhydrite (d) in the Kurkar aquifer, Gaza, strip.

Four hydrochemical facies were identified by Piper's diagram in the Gaza Strip. Type I (Ca+Mg-CO_3+HCO_3), II (Na+K-Cl+SO_4), III (Na- CO_3+HCO_3), and IV (Ca+Mg-Cl). Schoeller diagram showed that groundwater samples in Gaza Strip are polluted with saline water and anthropogenic sources. and the ground waters of Gaza Strip are classified into five clusters on the basis of their salinity and nitrate contents. The lowest salinity and nitrate cluster is located in the northern area, whereas the highest salinity and nitrate cluster is located in the southeastern area. Principal factor analyses classified into three factors, factor 1 includes EC, TDS, pH, Na^+, Cl^- and SO_4^{2-} (Anthropogenic), factor 2 includes Ca^{2+}, $Mg^{2+}$and NO_3^- (Fertilizers), factor 3 includes HCO_3^- and K^+ (Leaching). Saturation indices of calcite and dolomite are higher than 1, indicating the super-saturation of water by these minerals. Water quality for domestic use is variable in Gaza Strip, being better in the north and deteriorates as it moves towards south and southeast. Water suitability for agricultural uses is found suitable in some locations and unsuitable in others according to salinity, sodium%, and SAR.

The authors suggest some recommendations in order to prevent the continuous deterioration of groundwater quality and quantity:

Water resources management program should be carried out.

Design proper sewer system and treatment plants.

Reuse of treated sewer water.

Storm water preservation projects in several localities.

Desalination of sea water.

Public awareness programs should be carried out to increase the public understanding of the water crises in the Gaza Strip.

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