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Water types and carbonate saturation model of groundwater in middle Governorate (Gaza strip, Palestine)

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Abstract

This study was carried out in the Middle Governorate of Gaza Strip, Palestine. The coastal aquifer is the main source of water for domestic, agricultural, and industrial purposes in the study area. During the last three decades the aquifer has deteriorated to a high degree in the quality and quantity due to the over-pumping and the encroachment of seawater. Hydrogeochemical analysis for groundwater samples from 21 domestic wells were done in 2015. The major cations and anions (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, NO_3^-, and HCO_3^-) that influence the water quality were determined. The results of analysis show that the groundwater was chemical highly enriched with Na^+ and Cl^- an indication of seawater intrusion into the aquifer, while K^+ and SO_4^{2-} sourced from fertilizers and wastewater. The regression analysis show significant positive correlation (more than +0.80) between the hydrochemical parameters Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2}. Due to main cations and anions five water types were distinguished in studied wells: (1) Na-Mg-Cl, (2) Na-Cl, (3) Na-Mg-Cl-SO_4, (4) Na-Cl-SO_4, and (5) Na-Ca-Cl. They represent around 48%, 19%, 19%, 10% and 5% respectively of the total wells. The calcite and dolomite were assessed in terms of the saturation index, where they show mainly negative values indicating under-saturation. The hydrogeochemical behavior is rather complicated and is affected by both anthropogenic and natural parameters.

Keywords: *Hydrogeology, Groundwater, Saturation index, Gaza Strip, Palestine*

1. Introduction

The Gaza Strip is located at the southwestern part of Palestine, at the southeastern coast plain of the Mediterranean Sea (Fig 1). Its area is about 365 km^2, it has a length of 45 km from Beit Hanon in the north to Rafah in the south, and its width range from 5 – 7 km in the north to a maximum of 12 km in the south. The Gaza Strip forms part of the coastal foreshore plain bordering El-Khalil mountains (part of the West Bank) in the northeast, the northern Negev desert in the southeast, and the northern Sinai desert in the south. The coastal plain is dissected by three valleys (locally termed Wadies). The Wadi Gaza in the central part, with a large catchment area stretching far beyond Beir El Sabaa. Since several decades, it rarely flows due to numerous water diversion and storage projects upstream in occupied land of Palestine. The Wadi Halib draining the depression of Biet Hanoun, flowing near Biet Hanoun in the north. The third valley is Wadi Salqa near Khan Younes, now a dry wash only flowing after torrential rains and no longer reaching the sea. Three elongated ridges characterized the Gaza topography, these are known as Kurkar ridges.

The groundwater is the only natural source for domestic, agricultural, and industrial purposes in the Gaza Strip with a population of about two millions. The groundwater is pumped from more than 4000 and 44 agricultural and domestic wells, respectively pumping around 155 million m^3 a year. While the current natural recharge by annual precipitation is estimated to be 120 m^3candidate to decrease due to the expansion of urban areas (Khalaf et al. 2006; Al-Najar 2007; Qahman et al. 2009). Current rates of aquifer abstraction are unsustainable and deterioration of groundwater quality is documented in many parts of the Gaza Strip (Al-Agha 2004; Al-Agha and Murtaja 2005). Saltwater intrusion presently poses the greatest threat to the municipal supply and continuous urban and industrial growth is expected to further impact the water quality (see e.g. Yakirevich et al.1998; Qahman and Zhou 2001; Moe et al. 2001; Qahman and Larabi 2003, 2006; Heen and Muhsen 2016).

Water quality of groundwater in Gaza Strip have been conducted by numerous authors in Gaza Strip (e.g. Mogheir and Singh 2002; El Kammar et al. 2013; PWA, 2013a; 2013b; Al-Agha and El-Nakhal 2004; Shomar 2006; Shomar et al. 2008; Basem et al. 2010; Gharbia et al. 2016). Whereas, hydrogeochemical for water types and carbonate saturation of groundwater in Middle Governorate, Gaza Strip are lack. Thus, this study was carried out in the Middle Governorate of the Gaza Strip to characterize the water types and hydrogeochemical models of the groundwater on the basis of the physico-chemical properties, by using the AquaChem5.0 simulation model.

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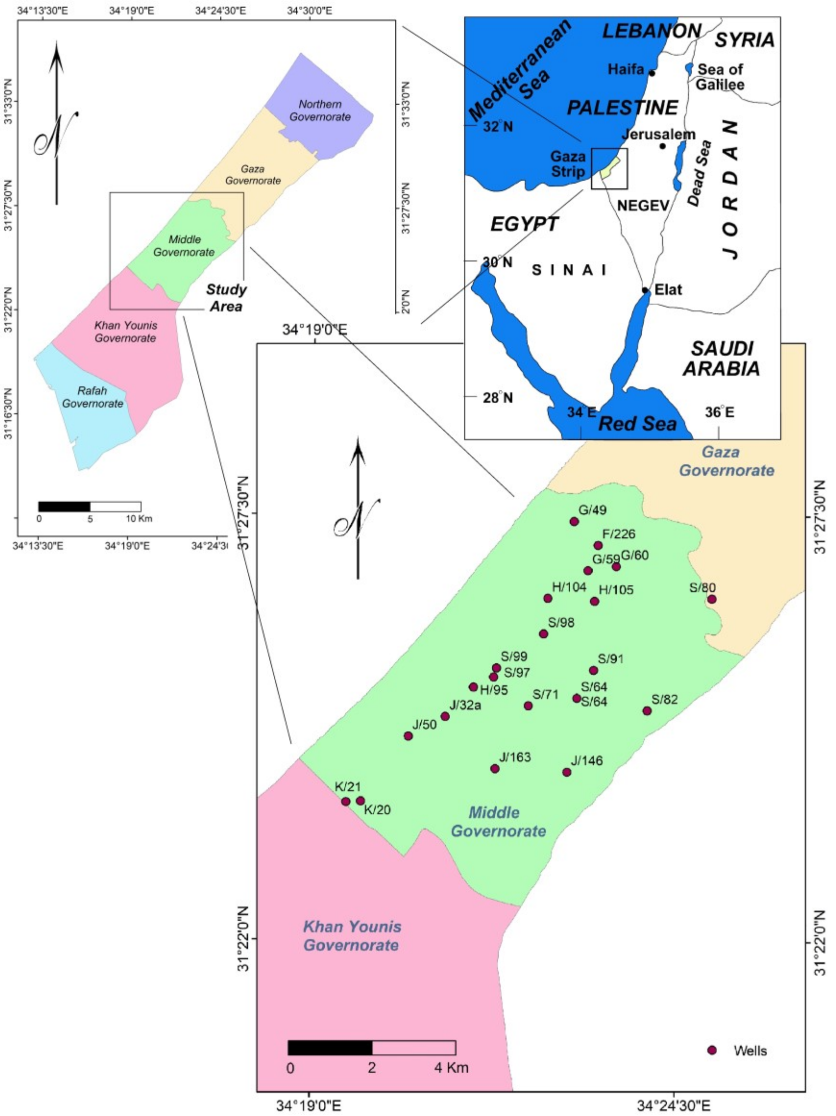

Fig 1. Location map of Middle Governorate, and studies wells.

2. Geology and hydrogeology

The common overall lithostratigraphic of the coastal plain of Palestine is shown in Fig 2. The stratigraphy of the Gaza Strip is a part of the coastal plain of Palestine which belongs to the Tertiary and Quaternary age. The lithostratigraphic units recognized in this region are the Mt. Scopus, Avedat, Saqiye and Kurkar Groups. The Kurkar Group has a Pliocene-Pleistocene age and consists of marine and continental deposits (Al-Agha and El-Nakhal 2004; Ubeid 2010). Three formations are distinguished (Fig 2A): (1) the Ahuzam Formation (0–15 m thick), which consists of conglomerates of limestone and chalk, (2) the Pleshet Formation (0–80 m thick), which consists of calcareous sandstones with a marine fauna, indicating a marine origin, and (3) the Gaza Formation, which consists mainly of alternating Kurkar and Hamra deposits with either gradational or sharp contacts, and which is 50–60 m thick (Fig 2B). This thickness of the Gaza Formation varies considerably, and a complete section is nowhere exposed (Abed and Al Weshahy 1999; Ubeid 2010). Lithologically, the Kurkar Member is composed of marine and continental calcareous sandstones (Ubeid 2010). The Hamra Member is built by red or brown palaeosols, which occasionally grade into blackish, clay-rich marsh deposits. The Hamra Member forms lenses of several meters thick that extend laterally for some hundreds of meters.

The Kurkar is the main water-bearing beds in this area, where it is highly porous and permeable. It constitute the southern part of the Palestinian coastal aquifer which extends from the foothills of Mt Carmel in the north to the Gaza Strip and northern Sinai in the south, paralleling the Mediterranean seashore for about 120 km, and between 5 km and 15 km inland (El-Nakhal 1968).

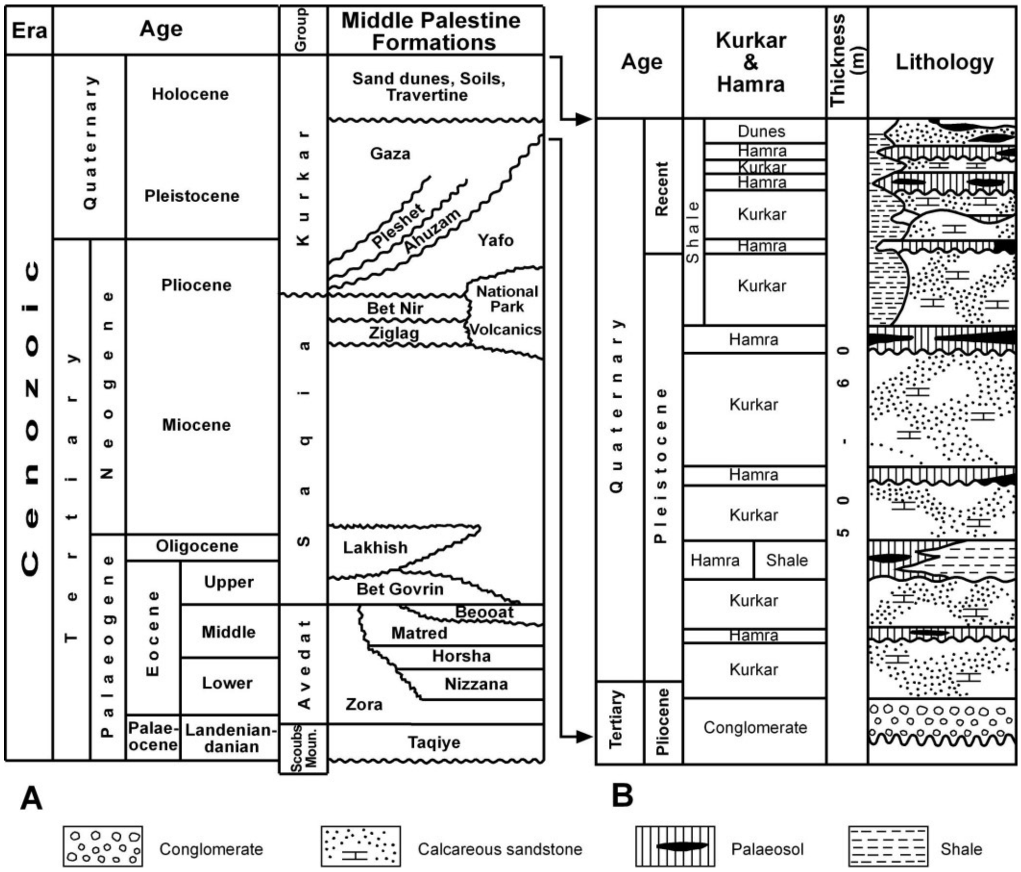

Fig 2. Stratigraphy and lithology. (**A**) Stratigraphic succession of the Tertiary and Quaternary in the central coastal plain of Palestine; (**B**) Lithology of the Plio-Pleistocene Gaza Formation (Ubeid 2011).

The schematization of hydrogeological cross section of the Middle Governorate of the Gaza Strip is shown in Fig 3. The coastal aquifer of Gaza Strip is divided by brownish lenses of fine-grained deposits (locally termed Hamra) into several divisions which locally termed sub-aquifers. It is implied that sub-aquifer A is phreatic, whereas sub-aquifers B and C become increasingly confined towards the sea. The regional groundwater flow is mainly westward towards the Mediterranean Sea (Qahman and Larabi 2006; Shomar et al. 2010). The maximum saturated thickness of the aquifer ranges from 120 m near the sea to a few meters near the eastern aquifer boundary. Natural average groundwater heads decline sharply east of the Gaza strip and then gradually decline towards the Sea. Depth to water level of the coastal aquifer varies between a few meters in the lowland area along the shoreline and about 70 m below the surface along the eastern border (Fig 4).

3. Methodology

Groundwater samples were collected from less than 10 m up to80 m depth of 21 wells in Middle Governorate of the Gaza Strip 2015 (Fig 1). Chemical analyses were done for major cations such as Ca^{2+}, and Mg^{2+} by Titration, Na^{+} and K^{+} by Flame Photometer; and anion such as Cl^{-} and HCO_3^{-} by Titration, NO_3^{-} by Spectrophotometer and SO_4^{2-} by Turbidity Meter. The ionic balance was determined for the results of the major cations and anions by:

Balance = C(meq/l) - A(meq/l) / C(meq/l) + A(meq/l)*100

Where C (meq/l) is the total cation mille-equivalents per liter. A (meq/l) is the total anions mille-equivalents per liter. Analyses were performed in Laboratories of Ministry of Agriculture, Gaza – Gaza Strip. These wells used for domestic water supply in the study area. Each sampling site is characterized by a large number of chemical and physical variables, making the hydrogeochemical study a multivariate problem. The water geochemical analyses of well no. S/71 between the years 2000-2015 were obtained from the archive of the Palestinian Water Authority.

Statistical analyses were processed by Statistical Package of Social Studies (SPSS). AquqChem software was used to set up the hydrogeochemical components of the groundwater, especially the saturation parameters for carbonates (calcite and dolomite), to test the mineral saturation. ArcGis software used to locate studied sites in location map.

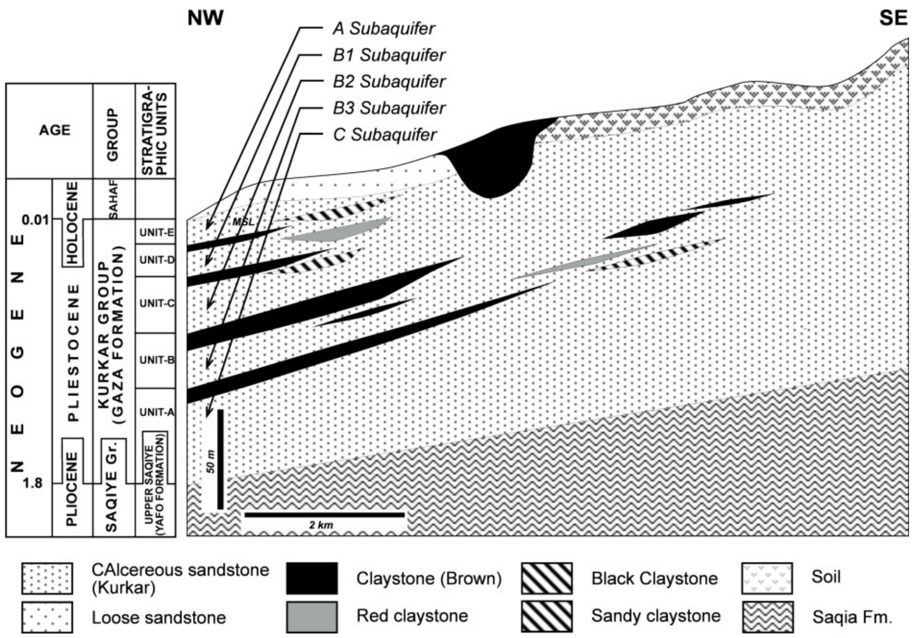

Fig 3. Generalized hydrogeological cross-section of the coastal aquifer (after Ubeid 2016).

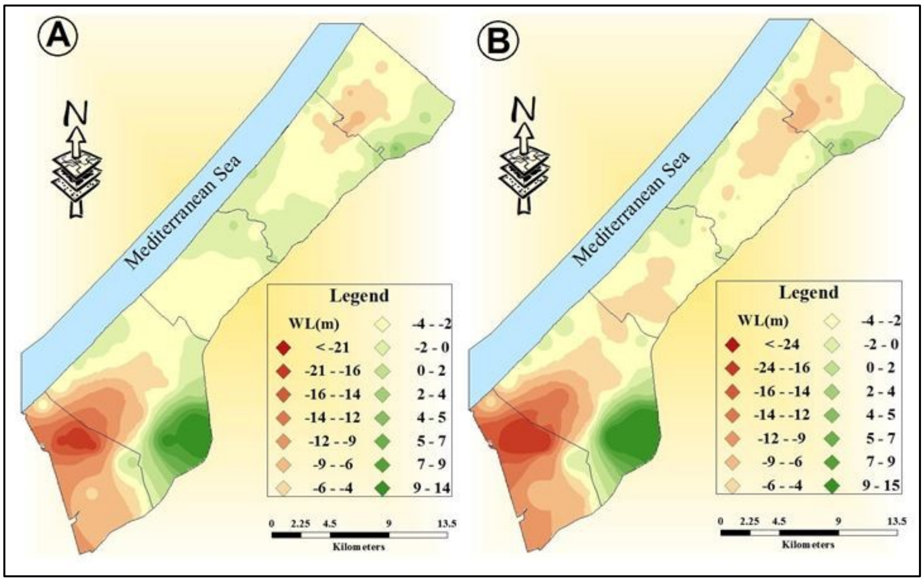

Fig 4. Prediction of groundwater level (with respect to mean sea level (MSL)) in Gaza Strip, (A) for Year 2017, (**B**) for Year 2022 (PWA 2013a).

4. Results and discussion

4.1. Descriptive statistics

Owing to data set obtained from hydrogeochemical analysis of water samples from 21 wells in Middle Governorate of Gaza Strip, the groundwater contains high minerals, as shown by electrical conductivity (EC) values which range from 3410 to 11840 µS/cm, with average value up to 5797 µS/cm. Table 1 presents the results of hydrogeochemical analysis and descriptive statistics for the study area. The total dissolved solids (TDS) values variable between 2114 and 7341 mg/L, with average value about 3570 mg/L. Both EC and TDS values were above exceeding the WHO standards (750 µS/cm, and 500 mg/L respectively) (WHO, 2004).

The anions parameters F^- , Cl^-, NO_3^-, SO_4^{2-}, and HCO_3^- have minimum values 0, 675, 36, 221, and 189 mg/L, and maximum values 1.5, 3550, 377, 1035, and 384 mg/L respectively. Their average values were 0.95, 1457, 128, 479, and 262 mg/L

Table 1. Shows the well coordinates, chemical analysis and statistical results of groundwater in the Middle Governorate of Gaza Strip.

Well No.	***Coordinates***		***EC***	***TDS***	***pH***	***Ca***	***Mg***	***Na***	***K***	***F***	***Cl***	***NO_3***	***SO_4***	***HCO_3***	***Hardness***
	X	***Y***	***(µS/cm)***	***(mg/L)***		***(mg/L)***	***(mg/L)***	***(mg/L)***	***(mg/L)***	***(mg/L)***	***(mg/L)***	***(mg/L)***	***(mg/L)***		
F/226	91949.00	95875.00	5330	3305	7.3	142	122	780	8	0.8	1243	190	471	296	856
G/49	91376.81	96448.35	5550	3441	7.4	139	138	800	6.5	1.3	1285	145	506	244	914
G/59	91705.00	95272.00	5530	3429	7.2	139	143	796	7.7	1.2	1264	211	462	254	938
G/60	92381.00	95368.00	3970	2461	7.3	101	152	500	6.4	1	675	377	462	384	881
H/104	90745.00	94611.00	5820	3608	7.5	142	151	796	6.9	1.2	1385	80	506	260	976
H/105	91864.00	94541.00	4770	2957	-	133	165	690	7	-	1112	122	340	257	1012
H/95	89463.17	92752.19	6270	3387	7.4	188	178	740	8	1.3	1583	54	651	244	1206
J/146	91200.34	90460.38	3410	2114	7.7	57	57	490	4.9	1.5	767	71	221	250	377
J/163	89480.00	90543.00	4970	3081	7.5	111	91	702	4.6	1.3	1221	127	388	236	653
J/32a	88290.00	91791.00	7890	4892	7.2	200	196	1000	20	1.3	2002	139	267	347	1306
J/50	87407.97	91322.88	4280	2652	7.7	189	99	550	7	0	1122	46	370	199	879
K/20	86265.30	89777.16	11840	7341	7.3	295	282	1776	17	1.3	3550	148	729	211	1897
K/21	85916.64	89758.36	11380	7056	7.3	350	332	1580	21.1	1	3408	117	864	219	2244
S/64a	91438.98	92220.58	3740	2319	7.1	133	104	500	11	0	731	296	506	374	760
S/71	90279.14	92046.58	3600	2232	-	90	67	570	5	-	889	36	356	191	502
S/80	94670.00	94590.00	3710	2300	7.5	95	83	458	5	0	873	65	292	220	581
S/82	93117.84	91923.24	3960	2455	-	104	80	660	6	-	990	38	389	189	587
S/91	91838.00	92890.00	4470	2771	7.25	120	119	545	9.6	0	1030	125	347	335	789
S/97	88965.42	92490.00	10580	6560	7.3	270	279	1550	14.9	1.4	2783	100	1035	282	1826
S/98	90643.00	93761.00	4850	3007	7.2	141	136	650	7.5	1.3	1200	120	379	267	913
S/99	89518.32	92949.76	5820	3608	7.3	196	161	650	8.6	1.2	1484	77	521	239	1152
Min			3410	2114	7.1	57	57	458	4.6	0	675	36	221	189	377
Max			11840	7341	7.7	350	332	1776	21	1.5	3550	377	1035	384	2244
Mean			5797	3570	7.3	159	149	799	9.2	0.95	1457	128	479	262	1011
St. Dev.			2530	1568	0.2	72	73	376	4.9	0.7	819	85	199	57	472.5

respectively. The chloride concentration in the studied wells was above the WHO standards (250 mg/L). The source of chloride in the groundwater of the study area is assumed to be related to the following: (1) Seawater intrusion from the west, (2) Saline water intrusion from the east, (3) Over-pumping. These sources were diagnosed by Al-Agha and El-Nakhal (2004) and Al-Agha (2005), more investigations are needed by using more sophisticated techniques e.g., isotopes and tracers. The pH and the hardness have minimum values about 7.1 and 377 mg/L, maximum values 7.7 and 2244 mg/L, and the average values were 7.3 and 1011 mg/L respectively.

The pH values were within WHO standards (6.5-8.5).Whereas, the hardness values were above the WHO standards (150-500 mg/L). The minimum values of the cations calcium, magnesium, sodium, and potassium (Ca^{2+}, Mg^{2+}, Na^+, and K^+) were 57, 57, 458, and 4.6 mg/L, and the maximum values were 350, 332, 1776, and 21 mg/L respectively. Whereas, their average values were 159, 149, 799, and 9.2 mg/L respectively. The values of $Ca^{2+}$and K^+ were below the WHO standards (159, and 9.2 mg/L respectively), whereas the Mg^{2+} and Na^+ values were above the WHO standards (50 and 200 mg/L respectively).

4.2. Correlation matrix

The correlation matrix allows to distinguish several relevant hydrogeochemical relationships. Table 2 predicts the correlation coefficient of anions and cations in the groundwater in the studied wells of the study area. The strong correlation was observed between Ca^{2+}, Mg^{2+}, Na^+, K^+, and Cl^-.

4.2.1.Calcium and magnesium

The Ca^{2+} and Mg^{2+} have a significant positive correlation in the groundwater of the studied wells (Table 2, Fig 5A) with value about +0.93. Additionally, these two elements correlate positively and significantly with EC, TDS, Na^+, K^+, and Cl^- with values range between +0.842 and +0.998 (Fig 5), and relatively less significant positive correlation with SO_3^{2-}, with values range between +0.801 and +0.8418.

The high significant positive correlation between Ca^{2+} and Mg^{2+} is attributed to the dissolution of dolomite, calcite, and high-Mg-calcite. Dissolution takes place during the surface run-off on the carbonate rocks in El-Khalil mountains at the West Bank, and the water–rock interaction in the Kurkar aquifer (Al-Agha 2004; Ubeid 2010). The cementing material of Kurkar aquifer is mainly made of calcite as the acid-carbonate test indicates. In calcite crystals, Mg substitutes Ca owing to the similarities in ionic radius and charge (Al-Agha 1995; 2005).

Table 2. Correlation matrix of the geochemical parameters.

	EC	TDS	pH	Ca	Mg	Na	K	F	Cl	NO_3	SO_4	HCO_3	Hardness
EC	1												
TDS	0.998	1											
PH	-0.272	-0.276	1										
Ca	0.933	0.927	-0.261	1									
Mg	0.948	0.942	-0.382	0.930	1								
Na	0.981	0.984	-0.245	0.886	0.905	1							
K	0.850	0.854	-0.477	0.850	0.842	0.799	1						
F	0.410	0.398	-0.011	0.201	0.363	0.416	0.141	1					
Cl	0.990	0.988	-0.212	0.939	0.923	0.977	0.837	0.369	1				
NO_3	-0.039	-0.0249	-0.562	-0.065	0.105	-.041	0.117	-0.096	-0.118	1			
SO_4	0.798	0.785	-0.277	0.801	0.818	0.792	0.563	0.278	0.767	0.0668	1		
HCO_3	-0.111	-0.106	-0.573	-0.140	0.035	-0.172	0.197	-0.176	-0.211	0.772	-0.062	1	
Hardness	0.958	0.952	-0.342	0.972	0.990	0.912	0.859	0.307	0.944	0.042	0.826	-0.031	1

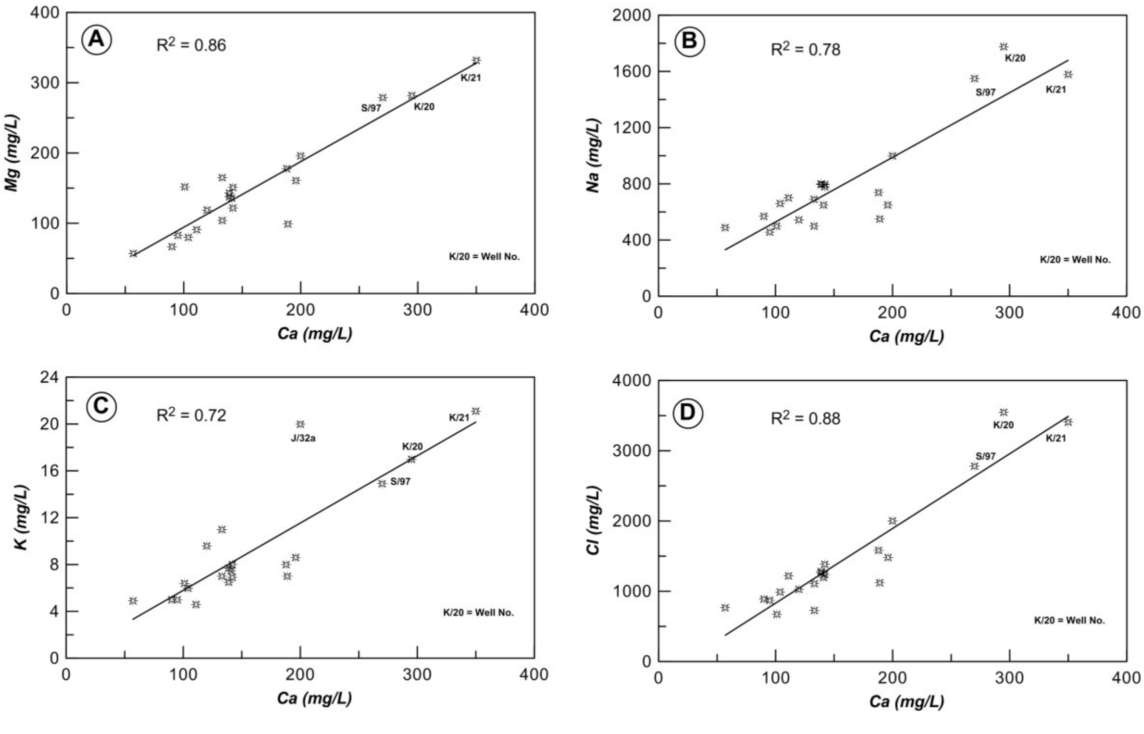

Fig 5. Significant correlation of selected parameters in the study area.
(A) Ca - Mg plot, (B) Ca - Na plot, (C) Ca - K plot, (D) Ca - Cl plot.

The significant positive correlation between Ca^{2+} and Mg^{2+} with SO_3^{2-} could be referred it to contamination by fertilizers and wastewater (Burg and Heaton 1998; Al-Agha 2005). The chemical reaction between SO_3^{2-} and calcite / dolomite ($CaCO_3$ / $CaMg(CO3)_2$), which constitutes the cementing material of the aquifer, results in producing correlated amounts of Ca/Mg and SO_3^{2-} in the groundwater.

4.2.2. Sodium and potassium

Sodium show significant positive correlation with the most of geochemical parameters EC, TDS, Ca^{2+}, Mg^{2+}, Cl^-, K^+, and SO_4^{2-}, with values ranging between 0.984

and 0.792 (Table 2, Fig6). The most important significant correlation was observed between Na^+ and Cl^- with value about 0.977 (Fig 7A), which referred to halite dissolution and/or seawater intrusion. The source of sodium could be derived from surface water and fertilizers, where there was good positive correlation between Na and K which predominated in fertilizers (Kadi and Al-Eryani 2012; Al-Arifi et al. 2013; Alshahri and Alqahtani 2015).

Potassium shows positive correlation with all the analyzed parameters except pH (0.477). It has positive significant correlation with EC, TDS, Ca^{2+}, Mg^+, Na^+, and Cl^- with values range between 0.799 and 0.854 (Table 2, Fig5), and equal or less than 0.563 with SO_4^{2-}, F^-, NO_3^-, and HCO_3^-. The significant positive correlation suggested the arising from the fact that most of parameters are derived from the interaction of groundwater with clay in the Hamra lenses that are very common in the coastal aquifer (Al-Agha and El-Nakhal 2004; Al-Agha 2005). Additionally, the positive and significant correlation of K^+ with both Mg^+ and Ca^{2+} due to interaction the groundwater with aquifer`s calcareous matrix which is very common coastal Kurkar aquifer. Moreover, the positive and significant correlation with Na^+ and Cl^- could be suggested as a high seawater intrusion.

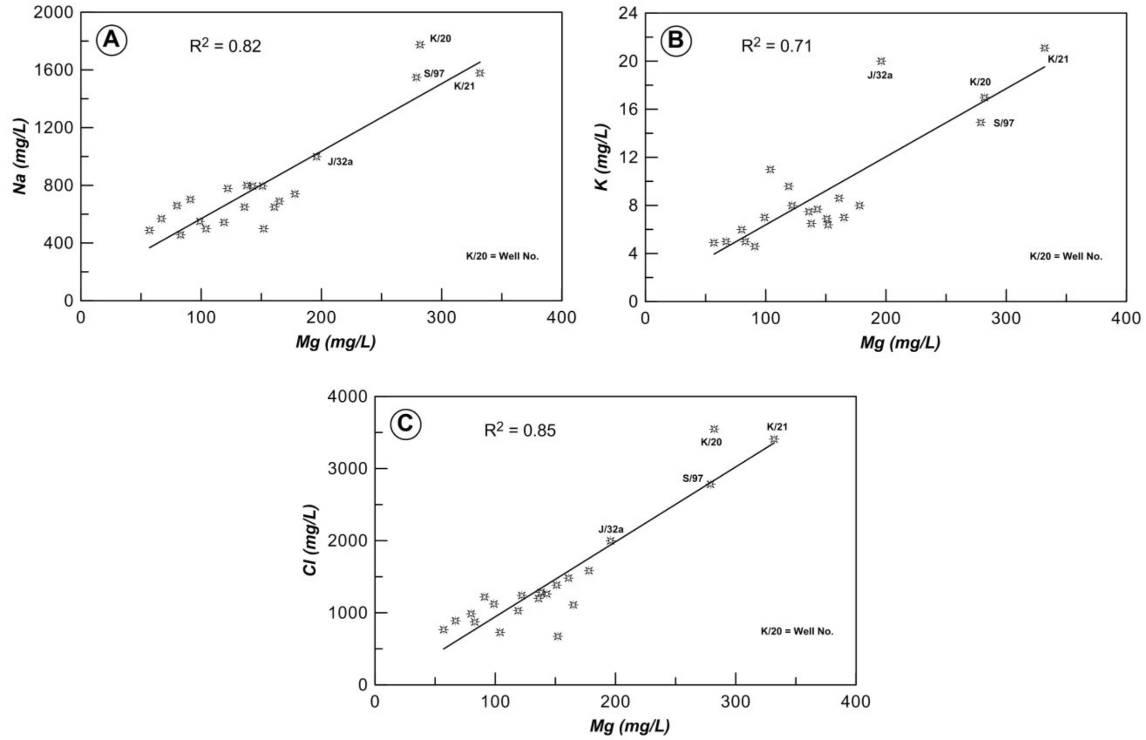

Fig 6. Significant correlation of selected parameters in the study area.
(A) Mg - Na plot, (B) Mg - K plot, (C) Mg - Cl plot.

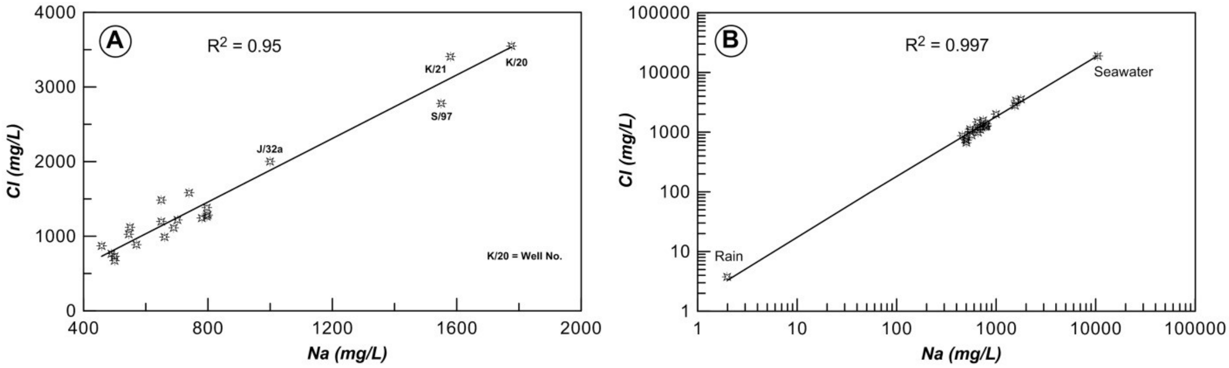

Fig 7. Correlation between Na - Cl in the study area.
(A) Normal plot for Na - Cl in studied wells. (B) Log plot Na - Cl in studied wells, rainwater, and seawater.

Overall, two main factors play a very important role in shaping the chemistry and the quality of the water in the aquifer. The first is the natural factors which include stratigraphic succession, composition of the aquifer, carbonate dissolution, and seawater intrusion. The second is anthropogenic factors, which include the pollution from wastewater, fertilizers, and over-pumping.

4.3. Water types

Based on the major cations and anions, five water types were distinguished in the study area (Table 3).

4.3.1. Water type (1): Na-Mg-Cl

This water type represents around 48% of the total water samples in the study area. This type is more abundant in the middle to western and northern parts of the study area (Fig 8 and 9). This type could be referred to both of seawater intrusion and dissolution of carbonate minerals (calcite and dolomite). Where its location is close to shoreline, and dominated by Na+, Mg^{+}, and Cl^{-}.

4.3.2. Water type (2): Na-Cl

This water type represents around 19% of the total water samples in the study area. Its source is referred to seawater intrusion, as Na^{+} and Cl^{-} are the main ions that form this type. Moreover, the over-pumping and decreasing in the annual rainfall rate produce more saline water than that in a higher level. This type is more abundant in the southern part of the study area (Fig 9).

Table 3. Water types in the study area.

Well No.	Water Type	% (Water Type)
F/226 J/146 J/163 K/20	Na-Cl	19.05
G/49 S/91 S/98 H/105 S/99 G/59 K/21 H/104 S/80 J/32a	Na-Mg-Cl	47.62
J/50	Na-Ca-Cl	4.76
G/60 H/95 S/97 S/64a	Na-Mg-Cl-SO_4	19.05
S/71 S/82	Na-Cl-SO_4	9.52

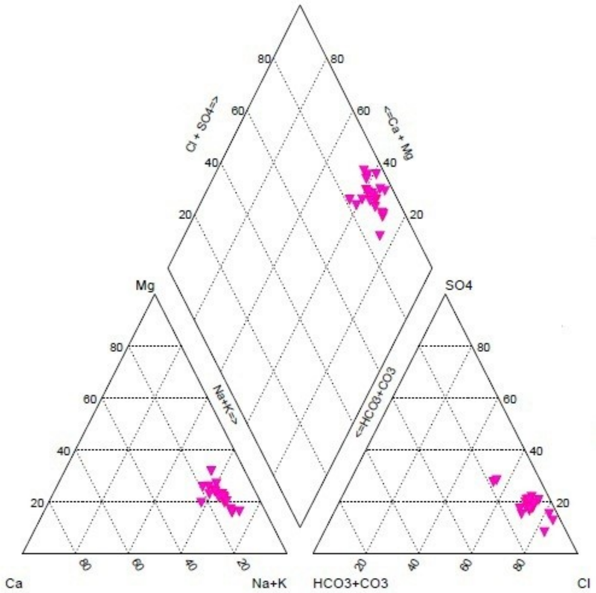

Fig 8. Piper plot showing the major ion composition of the groundwater samples in the study area.

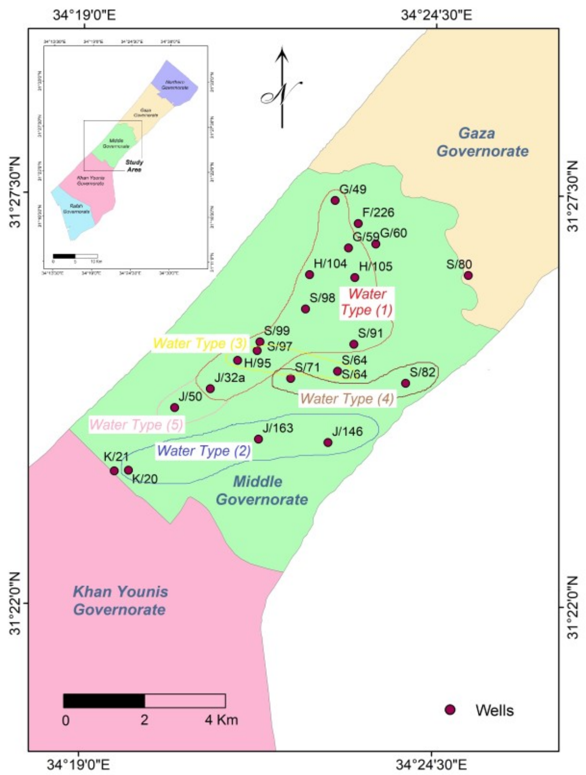

Fig 9. The distribution of the geographical zones of wells and the water types

4.3.4. Water type (4): Na-Cl-SO_4

The water type Na-Cl-SO_4 represents around 10% of the total water samples in the study area. This type is detected in two wells located in the middle to eastern part of the study area. The location of this type overlapswith the location of water type (3) (Fig 9). This may suggest that pollutants are from seawater intrusion and/or wastewater.

4.3.5. Water type (5): Na-Ca-Cl

This type detected only in well no. J/50, and represents around 5% of the total water samples. The cation and anions in addition to this location of this type suggest the same interpretation of water type (1) (Fig 9).

4.4. Saturation index

The saturation indices (SI) of calcite and dolomite for water sample of the wells in the study area show negative values (Table 4). The values of SI for dolomite relatively higher than SI for the calcite (Fig 10), this referred to thatcalcite is more soluble than dolomite.
Generally, the degree of calcite saturation is given by the calcite saturation index ($SI_{calcite}$),which is defined by:

$SI_{calcite} = \log 10 \{(Ca^{2+}) * (CO^{2-})\} - \log 10(K_{calcite})$

where, the saturation is scaled logarithmically, as a degree of saturation in natural waters vary by orders of magnitude. For this expression a SI calcite value of 0 corresponds to calcite solubility in equilibrium state, while values of +1 and -1 correspond to 10 times and 1/10 times saturation, respectively. The same was made for dolomite. The precipitation and dissolution of $CaCO_3$ and CaMg (CO_3) can be assessed in terms of the SI. However, dissolution is still ongoing if the water is under-saturated to any mineral, whereas super-saturated water could indicate an ongoing precipitation process. Consequently, the negative values in both SI for calcite and dolomite in most of water samples indicate that the dissolution of calcareous cement of the Kurkar is still ongoing over the study period, where the water is under-saturated (Xiao et al. 2015; Aris et al 2008; Al-Agha 2005). The historical development of SI in well no. S/71 was investigated between the years 2000 and 2015 (Table 5, Fig 10). It shows stable dissolution of carbonate with time. Exception in 2009 may referred to change in the rate of precipitation.

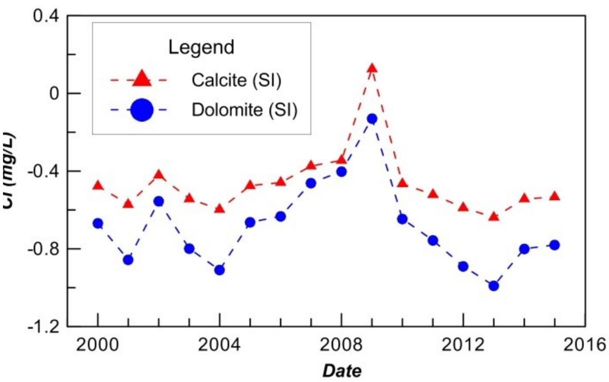

Fig 10. Saturation index for calcite and dolomite in well no. S/71 during 2000-2015

Table 4. Saturation index of calcite and dolomite in the groundwater of studied wells.

Well No.	Calcite (SI)	Dolomite (SI)
F/226	-0.2036	-0.184
G/49	-0.3023	-0.3187
G/59	-0.2809	-0.26
G/60	-0.2144	0.0358
H/104	-0.2699	-0.2237
H/105	-0.2721	-0.1606
H/95	-0.2015	-0.1374
J/146	-0.5713	-0.8557
J/163	-0.3808	-0.5595
J/32a	-0.0117	0.2627
J/50	-0.2175	-0.4273
K/20	-0.1601	-0.0416
K/21	-0.0805	0.1137
S/64a	-0.1084	-0.0373
S/71	-0.5289	-0.8996
S/80	-0.4312	-0.6341
S/82	-0.4892	-0.8052
S/91	-0.1856	-0.0863
S/97	-0.0774	0.1537
S/98	-0.2318	-0.1899
S/99	-0.1704	-0.1366

Table 5. Saturation index of calcite and dolomite for well no.S/71.

Analysis Date	Calcite (SI)	Dolomite (SI)
25/10/00	-0.477	-0.6687
30/04/01	-0.571	-0.8562
04/01/02	-0.4208	-0.5552
10/01/03	-0.5422	-0.7985
24/05/04	-0.5973	-0.9093
14/11/05	-0.4748	-0.6635
14/05/06	-0.4591	-0.6324
19/11/07	-0.374	-0.4608
01/10/08	-0.3447	-0.4021
06/10/09	0.1257	-0.1289
01/04/10	-0.4657	-0.6454
01/04/11	-0.5207	-0.7564
10/01/12	-0.5881	-0.8896
05/08/13	-0.6383	-0.9897
04/05/14	-0.5432	-0.7997
01/04/15	-0.5334	-0.78

5. Conclusion

Groundwater is a critical resource in the Middle Governorate of Gaza Strip as it is the main source of water. The aquifer has deteriorated to a high degree, during the last three decades both in quality and quantity. The over-pumping contributed to the deterioration of the water quality. Thus, anthropogenic and natural parameters play a significant role in polluting the groundwater. The Na^+ and Cl^- are the major pollutants of the aquifer, due to high pressure of human use as well as the scarcity of the resource. There were positive and significant correlation (more than +0.80) between main cations and anion (Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-). Five water types were distinguished in studied wells, type (1)Na-Mg-Cl, type (2) Na-Cl, type (3) Na-Mg-Cl-SO_4, type (4) Na-Cl-SO_4, and type (5) Na-Ca-Cl. They represent around 48%, 19%, 19%, 10% and 5% respectively of the total wells. The saturation indices of calcite and dolomite were of negative values indicating under-saturationof water by these minerals.The authors recommend more studies by using geophysical application, andbetter water quality management program applied by the key players.

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