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ANALYSIS OF NITRATE OCCURRENCE AND DISTRIBUTION IN GROUNDWATER IN THE GAZA STRIP USING MAJOR ION CHEMISTRY

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ABSTRACT

Nitrate in groundwater in the Gaza Strip, Palestine has become a serious problem in the last decade. As a result of extensive use of fertilizers, discharging of wastewater from treatment plants, and leakage of wastewater form cesspools, increased levels of nitrate up to 400 mg/l have been detected in groundwater. Nitrate concentrations more than 50 mg l^{-1} are very harmful to infant, foetuses, and people with health problems. The most efficient way to prevent nitrate impacts is to identify the sources of nitrate and to reduce them at the source. In this study, samples of groundwater from 63 wells were collected and chemically analyzed. Analysis of these samples revealed they have nitrate concentrations more than the maximum permissible limit recommended by World Health Organization (WHO). The major ion chemistry analysis was used to identify nitrate sources.

Based on the relation between land use and nitrate concentration in groundwater, sources of nitrate were identified. These sources are: (1) leakage from wastewater treatment plants, (2) leakage from cesspits, and (3) intensive agricultural activities. It was found that the leakage of wastewater from cesspits and over-loaded treatment plants has greater influence on groundwater nitrate contamination more than agricultural activities. This study shows the important role of the type of infiltrated water into the sub-soil, combined land use, in determining the source of nitrate in groundwater.

KEYWORDS: nitrate, groundwater pollution, Gaza Strip, geochemistry, environment.

1. INTRODUCTION

Human activities (e.g. agricultural practice, fertilizers application, wastewater discharge, etc.) have had a great influence on the quality of groundwater in different regions in the world. Nitrate groundwater pollution has become a serious problem because of its negative impacts. High concentrations of nitrate in the groundwater pose a serious threat to the quality of the groundwater resources, and consequently, to the public health.

Identification of the amount of nitrogen available in the soil is important. Then the calculation of crop requirement of nitrogen based on crop type should be made based on the estimation of nitrogen available in soil. After that, the required amount of nitrogen in form of fertilizer can be applied to crops. The application method of fertilizers has a great effect on the plant uptake of the applied fertilizers.

The Mediterranean coastal aquifer of the Gaza Strip is the only source of water supply for domestic, agricultural, and other use in the area. As a result of intensive agricultural activities, over-pumping, and sewerage outflow, the quality of groundwater has been severely affected in the last decade. According to the World Health Organisation (WHO), the nitrogen level in groundwater should not exceed 10 mg l^{-1} as N or 50 mg l^{-1} as nitrate (NO_3) (WHO, 2004). However, levels of 300 mg l^{-1} of nitrate in groundwater are very common in many areas in the Gaza Strip. The high levels of nitrate in some areas of the Gaza Strip have resulted from intensive application of fertilizers and pesticides. In addition, improper discharge of wastewater without any treatment is very common in some areas in the Gaza Strip (e.g. Khan Yunis area). As a result, the levels of nitrate concentrations in aquifer of the study area are above the maximum permissible value.

Nitrate itself is not a poisonous substance, and it is not a problem for adults but it is very dangerous for infants under six months of age. Because of their small size and liquid-based diet, the infants are susceptible to interruption of body processes resulted from high nitrate in drinking water. In the first few months of infant life, there are certain bacteria that live in their digestive system. These bacteria convert the nitrate, which is not harmful, to nitrite. When blood absorbs nitrite, it combines with haemoglobin, which carries oxygen, and forms methemoglobin. Methemoglobin cannot carry oxygen, and thus, the infant body turns into blue. If that happens it may lead to death if not treated. Several cases of methemoglobin have been reported in the Gaza Strip in the last few years (Abu Maila *et al*., 2004).

Besides its harmful impact on infant, it is found that young animals are affected by nitrate the same way as babies. Adults with chronic health problems may be at higher risk from elevated nitrate/nitrite levels. Pregnant and nursing mothers should also avoid drinking water polluted with nitrate because of potential effects passed on to the foetus or infant. Some livestock have been known to abort foetuses because of drinking nitrate-polluted water. Moreover, the increased nitrate level in drinking water may adversely affect the central nervous system (Chern *et al*., 1999).

Identification of nitrate sources in groundwater is very essential to take the proper measures to eliminate nitrate pollution. Therefore, the objectives of this study are to analyse the nitrate sources in the study area and to find out how to reduce the high concentrations of nitrate in the groundwater.

2. THE STUDY AREA AND HYDROGEOLOGY

The Gaza Strip area is part of the Palestinian occupied territories, located at longitudes 31° 30' North and Longitude 34° 28' East. It is a very small area located at the eastern coast of the Mediterranean, about 40 km long and its width varies between 6 to 12 Km (Figure. 1). The total area of the Gaza Strip is about 365 km^2. More than 1.3 million inhabitants are living in this small area, according to 2004 statistics (PCBS 2004). The population density in the Gaza Strip, especially in the eight refugee camps, is the highest in the world. Because of its location, the Gaza Strip forms a transitional zone between the semi-humid coastal area in the north and the semi-arid Sinai desert in the south.

The geological components in the area consist of a littoral zone, a strip of dunes from Quaternary era situated on the top of a system of older Pleistocene beach ridge, and more to the east, gently sloping alluvial and loessial plains. The aquifer is composed of Pliocene-Pleistocene calcareous sandstone, and layers of clays (EUROCONSULT and IWACO 1994).

The aquifer in the Gaza Strip is part of the coastal aquifer, which extends from Karmel Mountain in the north to Sinai desert in the south with a variable width and depth (Figure 2).
The total area of the coastal aquifer is about 2000 km^2 with a small part of it beneath the Gaza Strip. Alluvial sandstone and gravel from Tertiary era covered with Quaternary sand dunes are the main components of aquifer media (EUROCONSULT and IWACO 1994). The sand dunes extend along the shoreline up to few kilometres inland. The depth of the aquifer varies from about 170 meters at the shoreline to some few meters at the eastern boundary. Therefore, the thickness of the aquifer varies between 200 m in the west along the coastline to few meters in the east. There is a very thick impermeable clay layer from Neogene age underneath the aquifer and it is called “Saqyia Formation”. This layer has a thickness that varies from 400 to 1000 meters and it forms the bed of the aquifer. There are a number of clay layers of variable thicknesses up to 20 meters that divide the aquifer into three main sub-aquifers (Figure 3). These clay layers are generally aquiclude and extend from the shoreline to 5 Km inland. Therefore, the aquifer can be considered as unconfined in the eastern part and confined/unconfined multi-aquifer in the western part. The sub-aquifers, resulted from clay layers division, were classified into sub-aquifer A, which is at the top, sub-aquifer B in the

middle, and sub-aquifer C beneath. Groundwater flows usually in the east-west direction towards the sea (Al-Agha and El-Nakhal, 2004). However, groundwater flow direction may change locally due to over-pumping.

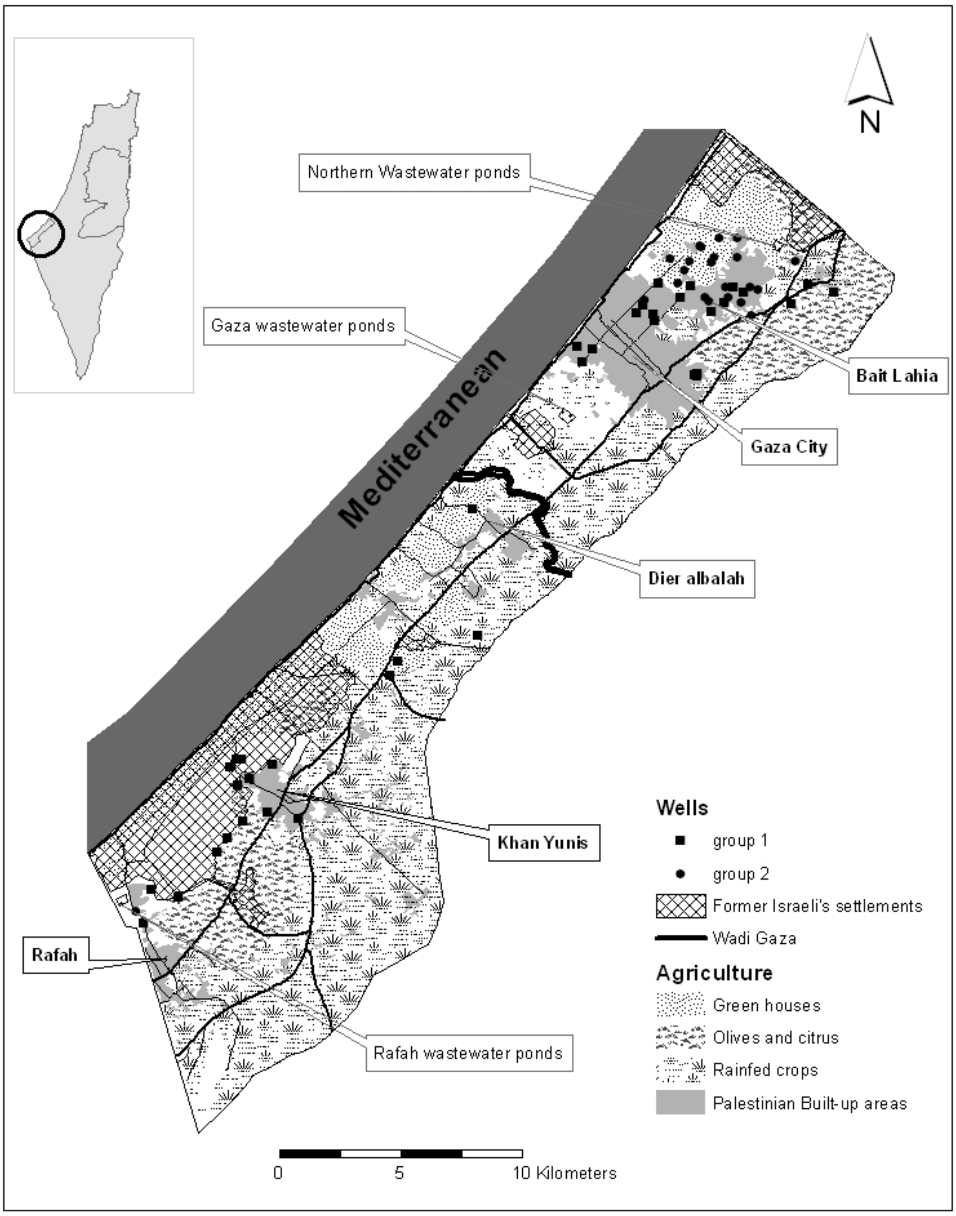

Figure 1. The study area, land use, and the locations of sampled wells

As there are no other sources of water in the Gaza Strip, the only mean of water supply is the coastal aquifer. The aquifer is recharged mainly by rainfall and other minor sources such as leakage of water system, irrigation return flow, and wastewater discharge. The average annual rainfall in the Gaza Strip varies between 500 mm in the north to 200 mm in the south. Thus, the average annual rainfall in the Gaza Strip based on 20 years average is 320 mm y^{-1}. The total amount of groundwater recharge from rainfall is about 43 million m^3 per year (Baalousha, 2005). According to Metcalf and Eddy (2000), the irrigation return flow in the Gaza Strip varies between 20 and 25 million m^3 (Metcalf and Eddy 2000)

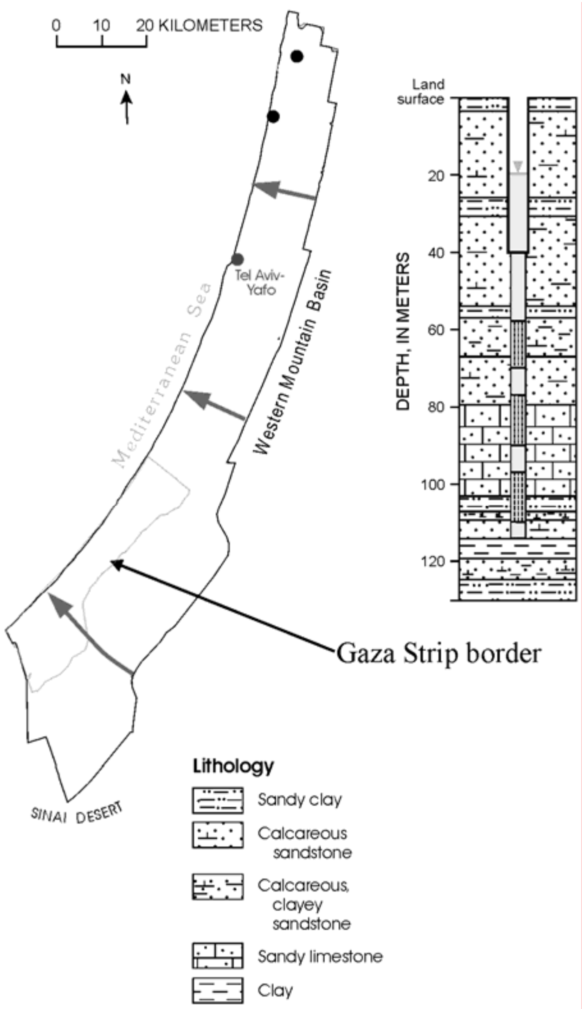

Figure 2. Coastal aquifer basin and lithology (Baalousha 2006)

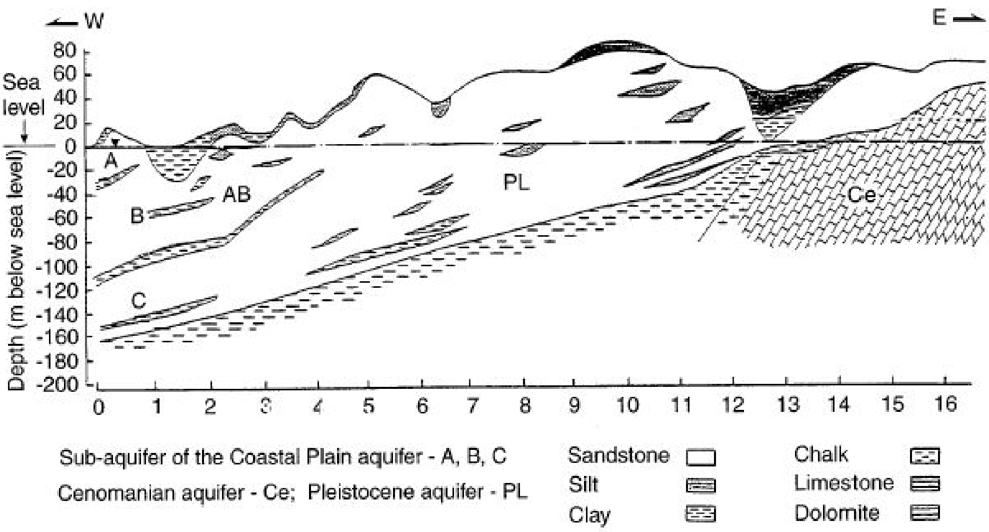

Figure 3. Typical cross-section in the study area (Baalousha 2003)

3. SOURCES OF NITRATE IN GROUNDWATER IN THE GAZA STRIP

The lateral groundwater inflow to the Gaza Strip aquifer does not contain any nitrate pollution (Vengosh *et al*., 2005). Therefore, it is believed that the nitrate in groundwater is of anthropogenic origin. Application of fertilizers and pesticides in agricultural areas is the main reason of increasing nitrate level in groundwater (Ronen and Magaritz, 1985). In addition to agricultural activities, nitrogen released from wastewater discharge plays a big role in aquifer pollution. Different factors affect the amount of nitrate pollution in groundwater resulted from nitrogen load at the land surface. Such factors could be fertilizers and manure application rate, thickness of unsaturated zone, crop management, and form of applied nitrogen (Bohlke, 2002).

About 60% of the total amount of groundwater in the Gaza Strip is polluted and not potable according to WHO standards (PWA, 1999). As pumping increases, the aquifer becomes more deteriorated, as brackish water encroach the aquifer. For instance, according to Palestinian Water Authority (PWA) records, the concentration of chloride has recently reached more than 1000 mg l^{-1} in many locations. High chloride concentrations have been detected in Gaza City and the southern area. In Khan Yunis City, seawater intrusion has been detected (Yakirevich, *et al*. 1998), causing high chloride concentrations.

Nitrate (NO_3) has also been detected at increased concentrations reaching 300 mg l^{-1}, especially in Khan Yunis area. It is believed that the leached wastewater from cesspits in this area is responsible for these increased concentrations of nitrate. In the northern part of the Gaza Strip (i.e. Bait Lahia) where the wastewater treatment plant is overloaded and wastewater has been flooding a wide area around, high concentrations of nitrate have been detected in groundwater.

The natural cycle of nitrogen can be severely disturbed by human activities and leads to harmful impact on the environment. According to Vengosh *et al*. (Vengosh *et al*., 2005), nitrate pollution in the Gaza Strip is derived from agricultural return flow, and wastewater discharge. Therefore, nitrate sources in groundwater can be classified into two categories: point sources and non-point sources.

3.1 Wastewater leakage (point sources)

Point source pollution represents those activities where pollutants are routed directly into receiving water bodies. Leakage of wastewater from treatment plants that are over-loaded, cesspits in non-sewered areas, landfills, and industrial spillages are considered as “point sources”. The leaked wastewater is rich in nitrogen and can be decomposed in aerobic conditions in the upper soil. As a result, nitrate infiltrates the water table and contributes in raising the nitrate level in groundwater. In the study area, there are three treatment plants: Bait Lahia treatment plant in the north, Gaza City treatment plant located southern Gaza City, and Rafah treatment plant in the south of the Gaza Strip. The northern one serves the northern part of the Gaza Strip. This plant is overloaded and the surplus sewage covers the sand duns around, causing environmental damage of the soil and groundwater. The Gaza City treatment plant recharges the aquifer with 3.6 million m^3 of treated wastewater annually, and the rest (11.7 million m^3) is being discharged to the sea. The effluent of Rafah treatment plant is being discharged to the sea. Sewerage outflow in different communities exceeds the capacity of the existing treatment plants, and there are many technical and environmental problems associated with these plants. Approximately 70-80 % of the domestic wastewater produced in the Gaza Strip is discharged into the environment without treatment through leakages and overloaded treatment plants.

In addition to leakage from treatment plants, leakage of wastewater by other means is very common in the Gaza Strip. Only 60% of the urban areas are connected to sewerage network (United Nations, 2003). This means many areas are discharging the wastewater using cesspits, especially in the densely populated refugee camps. Sewerage collected from cesspits is very often discharged to open fields without treatment, and thus, destroying the upper soil and increasing the aquifer pollution.

3.2 Agricultural sources (non point sources)

Non-point source water pollution, once known as "diffuse" source pollution, arises from a broad group of human activities for which the pollutants have no obvious point of entry into receiving watercourses. Agricultural activities are usually considered as “the nonpoint sources of nitrate pollution". As a result of the agricultural activities, different types of fertilizers and pesticides are usually applied. Organic, including manures, and inorganic types of fertilizers are used in the Gaza Strip. The applied fertilizers in agricultural areas is about 12,000 tons, of which 3,500 tons are chemical fertilizers and the rest are organic fertilizers (manure from cattle and poultry) (PNIC, 2005). As there is no proper guidance, farmers apply fertilizers intensively and more than the actual crop demand. Consequently, the excess of nitrogen leaches beneath the upper soil and infiltrates to the aquifer in form of nitrate. As a result, pollutants from agricultural activities are scattered in wide areas.

4. METHODOLOGY

Water samples from 63 wells, representing a wide range of land uses in the entire area of the Gaza Strip, were collected and analysed. Sampling points are shown in Figure 1. Collection of samples and analysis were done within one week in October 2002. Different municipalities are operating the municipal wells and use them for domestic water supply. Depths of the wells vary according to depth to water table, but they are generally between 30 to 50 m. Samples were taken at well-head directly from the pump, and were collected in tight capped high quality polyethylene bottles and were immediately transported to the laboratory under low temperature conditions in iceboxes. The samples were stored in the laboratory at 4 ◦C until processed and analyzed.

Chemical analysis of the collected samples was carried out the laboratory of Ministry of Health (MOH) and Ministry of Agriculture (MOA). The cations in the water samples were measured by inductively coupled plasma, the anions by ionic chromatography, and the bicarbonate by titration. Table 1 shows the results of the chemical analysis of the collected samples. The wells were classified into two groups based on the ratios of different ions and sources of nitrate at these wells. This will be explained later in this study. Chemical analysis was carried out to determine the sources of nitrate pollution in groundwater, based on major ion chemistry analysis.

5. ANALYSIS AND DISCUSSION

Chemical composition of groundwater in the Gaza Strip varies mainly according to land use. Agricultural areas are associated with water rich of calcium because of liming and the application of fertilizers. Residential areas, where leakage of wastewater takes place, produces water that is more enriched in sodium, nitrate and chloride. As the wastewater treatment plants are relatively away from the sea, the chloride concentration in the vicinity of these plants are probably resulted from wastewater and not seawater intrusion. Chloride concentration in wastewater in the Gaza Strip varies between 250 to 550 mg/l (Nashashibi and Van Duijl, 1995). As chloride is a conservative parameter, no changes in chloride concentrations occur through infiltration of pollutants.

Figure 4 shows the distribution of groundwater samples on a ternary plot of sodium, calcium, and magnesium. It is clear from the figure that some wells have higher Na/Ca ratio than others. Samples from group 1 of wells (Table 1) are characterised by high Na/Ca ratio as appears in Figure 4. They are also characterised by relatively high chloride concentrations, that is, low Na/Cl ratio, as shown in Figure 5. The chloride concentrations in wells of group 1 vary between 35 mg l^{-1} and 1127 mg l^{-1}, and their nitrate concentrations vary between 16 to 316 mg l^{-1}. Amongst this group, some wells have nitrate concentrations less than 50 mg l^{-1}. Despite their low nitrate concentration, the sodium level of some of these wells is high more than the sea " Na/Cl ratio in the Mediterranean is 0.86" (Vengosh and Rosenthal 1994). The high sodium concentration of these wells reflects either the displacement of seawater by fresh water (Vengosh *et al*., 2005) or freshening of the saline lateral groundwater inflow.

The remaining wells are located in residential areas where leakage of wastewater occurs (see well location maps in Figure 1). For example, the L-wells are located in Khan Yunis area where the use of cesspits is very common, as the area is not connected to the sewer system. Therefore, Khan Yunis area has a high-level of nitrate concentration in groundwater (Baalousha, 2003). The P-wells are located in Rafah refugee camp where leakage of wastewater takes place, and the R-wells are located in the vicinity of the Shati Camp near

Gaza City, where leaching of wastewater takes place. Pollution with domestic wastewater results in high concentrations of sodium and low concentrations of magnesium and calcium. As a result, Na/Ca and Na/Mg ratios are high in this type of polluted water (Figure 4).

Table 1. Chemical analysis of groundwater (mg l^{-1}) in the Gaza Strip in October 2002.

Agri. No.+	NO_3	Ca	Mg	Na	K	HCO_3	Cl	SO_4	TDS	Group*
A/180	72.71	95.5	14.96	52.59	1.3	300.3	84.7	28.3	550	2
A/185	98.67	63	23.91	65.12	6.9	256	84.7	43.3	609	2
C/127	54.28	54.7	18.03	63.11	1.9	211	77.7	17.2	462	2
C/128	50.88	68.5	30.55	202	2.4	297.2	247	41.9	851	1
C/76	77.29	127	41	250	3.1	485.1	579	37.3	1525	1
C/79	89.09	113	38.45	298	3.1	442	473	67.5	1425	1
D/60	138.9	116	8.01	57.8	2.8	322	118	57.2	671	2
D/67	29.35	52.2	10.92	35.06	1.5	175.6	35.3	16.3	330	2
D/67B	46.02	67.5	16.17	57.5	4.6	235.3	70.6	24.3	460	2
D/68	83.95	74.9	21.21	122.7	2.2	274.6	127	64.4	584	1
D/69	105.3	100	15.73	70.12	3.4	315.9	98.8	24	594	2
D/70	91.16	96.3	20.44	49.96	7.6	324.9	98.8	38.5	536	2
D/74	69.32	68	26.73	40.48	5.3	280.1	76.5	37.8	582	2
D/75	154.4	93	15.32	55.22	7.8	295.7	77.7	44.7	568	2
D/76	75.58	86.5	17.79	37.69	7.3	289.5	63.5	19.9	474	2
E/1	101.9	89.3	18.92	44.47	2.6	301.1	111	34.3	580	2
E/11A	53.98	41.7	25.14	126.2	1.33	201.7	146	13.6	671	1
E/11B	178.8	97.8	25.88	71.03	2.2	351	113	99	671	2
E/11C	38.94	34	24.31	125.7	1.16	185.2	111	65.2	577	1
E/138	66.67	82.5	21.09	78.62	1.68	293	125	27.2	596	2
E/142	99.12	94.4	17.78	39.87	1.6	309.1	90.4	48.1	586	2
E/15	46.51	54.7	23.17	153	3.9	232.1	177	56.8	751	1
E/154	59	133	26.93	207	3	442.9	466	52	1121	1
E/156	133	80.8	26.81	81.5	3	312.3	153	34.8	733	2
E/157	96.74	87.7	32.34	149	5	352.4	177	64.4	841	1
E/4	62.54	65.5	22.81	41.29	2.8	257.6	69.6	24.7	492	2
E/61	70.8	94.4	20.9	81.5	5.2	322	141	56.6	649	2
E/9	30.38	44.9	19.12	85	2.6	191	98.8	23.1	490	1
E/90	186.4	151	20.47	95	3.2	460.5	139	67.2	971	2
G/30	189.1	208	58.89	653.4	1.72	762.6	974	349	2579	1
J/1	38.35	45.9	19.43	175.1	1.6	194.8	188	125	756	1
J/2	54.57	30.6	21.68	196.5	1.2	165.8	188	104	767	1
L/127	316.2	156	56.37	349.7	2.6	621.7	668	161	1810	1
L/159	271.8	188	35.68	293.6	4.8	616.6	487	273	1774	1
L/159A	165.6	93.5	31.58	154	2.7	363.9	237	95	1048	1
L/176	113.3	36.9	50	517.6	3.3	94.96	744	260	1984	1
L/178	59.88	68.9	40.29	992.5	4.3	338.1	1127	680	3205	1
L/181	16.45	16.2	11.3	840	0.9	86.94	104	50.9	431	1
L/41	215.9	66.4	40.96	938.2	0.75	334.8	988	526	2800	1
L/43	182.9	166	64.33	436	3.9	679.4	696	240	2170	1
L/86B	35.69	77.4	39.43	778.4	5.4	355.8	1064	281	2700	1
L/87	301.8	154	57.48	565.5	4.1	621.5	918	302	2800	1
L/87Desal	103.2	3.26	9.6	420	5.0	47.74	127	56.6	366	1
P/124	131.9	95.2	35.24	78.62	7.11	383.2	424	95.2	1217	2
P/144	32.67	27.2	15.15	209	1.56	130.4	264	57	732	1

Table 2. Chemical analysis of groundwater (mg l^{-1}) in the Gaza Strip in October 2002 (continued)

Agri. No.+	NO_3	Ca	Mg	Na	K	HCO_3	Cl	SO_4	TDS	Group*
P/145	58.41	51	16.73	227.1	1.21	196.4	264	76.7	854	1
P/146	20.13	24.7	17.87	250	1.4	135.2	160	90.7	587	1
P/15	152.5	115	39.01	480	3.61	447.6	696	264	1852	1
Q/40B	59.59	85	20.72	92.91	7.4	297.9	174	51.2	761	2
R/112	75.22	118	48.74	559.1	5.75	494.8	842	132	2069	1
R/162B	111.5	165	9.237	214	3	450.8	417	40.4	1214	1
R/162C	75.81	127	17.83	105.8	2.4	390.5	275	45	803	2
R/162G	136	97.9	50.03	376.9	10	450.8	515	187	1639	1
R/162Ha	164.6	115	38.74	337	9.2	446.8	501	185	1590	1
R/162Hb	151	106	40.24	453	21	431.7	508	234	1794	1
R/162ia	113.9	150	23.93	254.7	4	473	452	82.2	1357	1
R/254	61.4	55.5	24.64	341.8	4	240.2	402	54.4	1214	1
R/25A	83.48	47.6	42.63	421.3	3.8	294.6	473	230	1575	1
R/25C	147.5	60.8	49.91	787.4	2.16	357.6	932	269	2600	1
R/25D	82.33	57.9	29.14	683.7	4.4	264.9	706	273	2141	1
R/271	67.85	93	19.43	221.1	10	312.6	304	57.2	1083	1
S/69	41.59	50.2	30.14	371	1.8	249.6	466	175	1332	1
R/265	47.67	59.6	20.2	119.3	1.7	232.1	184	30.3	635	1

+ Agri. No.: indicates the well agricultural number.
*Group: indicates the well group as shown in Figures 1,4,5.

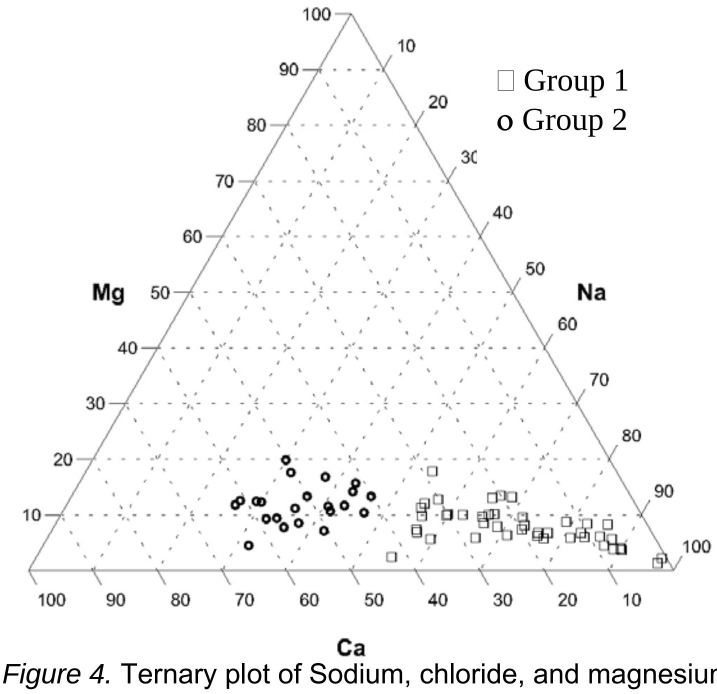

Figure 4. Ternary plot of Sodium, chloride, and magnesium

In addition to their low Ca concentration, groundwater samples polluted by domestic wastewater have low ratios of HCO_3/Cl (Figure 5). This indicates that a precipitation of calcite takes place in the unsaturated zone (Kass *et al*, 2005).

It is well known that domestic wastewater is rich in Na ions. In the Gaza Strip, the concentration of Na varies between 300 to more than 500 mg l^{-1} (Nashashibi and Van Duijl, 1995). Chloride concentration in wastewater in the area varies between 250 mg l^{-1} to more than 500 mg l^{-1} (Nashashibi and Van Duijl, 1995). Therefore, the Na/Cl ratio in wastewater is around 1. Figure 4 suggests that groundwater polluted by wastewater has a low Na/Cl ratio. Leakage of wastewater in the vadose zone disturbs the natural balance of the exchangeable cations and results in Na–Ca exchange whereby Na replaces Ca on the adsorbed sites of clay minerals (Kass *et al*, 2005). This leads to the reduction of Na/Cl and calcite precipitation.

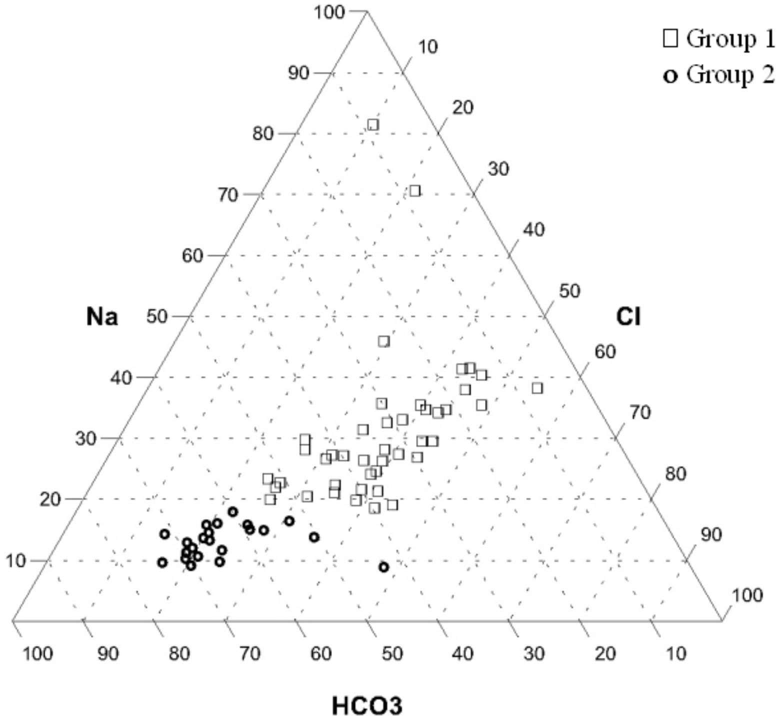

Figure 5. Ternary plot of chloride, sodium and bicarbonate

These chemical patterns are attributed to base exchange in the vadose zone beneath different land use areas. In areas at which wastewater leakage takes place, Na and K are absorbed by clay mineral while Ca and Mg are released to the water (Appelo and postma, 1993). This explains the high ratios of Na/Ca, and Na/Mg in samples under areas susceptible to wastewater leakage.

Samples from group 2 of wells represent another pattern of chemical composition. These wells are characterised by high value of HCO_3/Cl. As shown in Figure 1, these wells are located in areas of agricultural activity. The high carbonate concentration might result from dissolution of carbonate in the unsaturated zone.

Spatial distribution of nitrate concentration is shown in Figure 6. The contour map was prepared based on interpolation of measurements from the filed. The nitrate concentration varies between 50 and 420 mg l^{-1} as shown in Figure 6. The high nitrate concentration exists beneath the highly populated areas and heavy agricultural activities areas (refer to Figure 1).

This dissolution process could be induced by exchange reaction in which Ca is removed from water. This explains the low concentration of Ca in these wells as shown in Figure 4. It is assumed that the high nitrate concentration in these wells is caused by agricultural activities. Moreover, groundwater is characterized by a certain Ca-Mg-NO_3 composition with positive correlations between nitrate and Ca, Na, and Mg. This correlation is shown in Figure 6 where the positive correlations between nitrate and calcium, magnesium and sodium are illustrated.

The student t-test was used to check the null hypothesis of “no correlation” against the alternative hypothesis. In all cases, a positive correlation between NO_3 and Ca, Na, and Mg was detected with a 95% of confidence. The results of statistical analysis are shown in Table 2. The p-value in all three tests is small, which supports the argument of rejection of the null hypothesis. The relatively low correlation coefficient between Na and NO_3 is a result of Na-Ca exchange in the unsaturated zone, which leads to decrease of Na concentration.

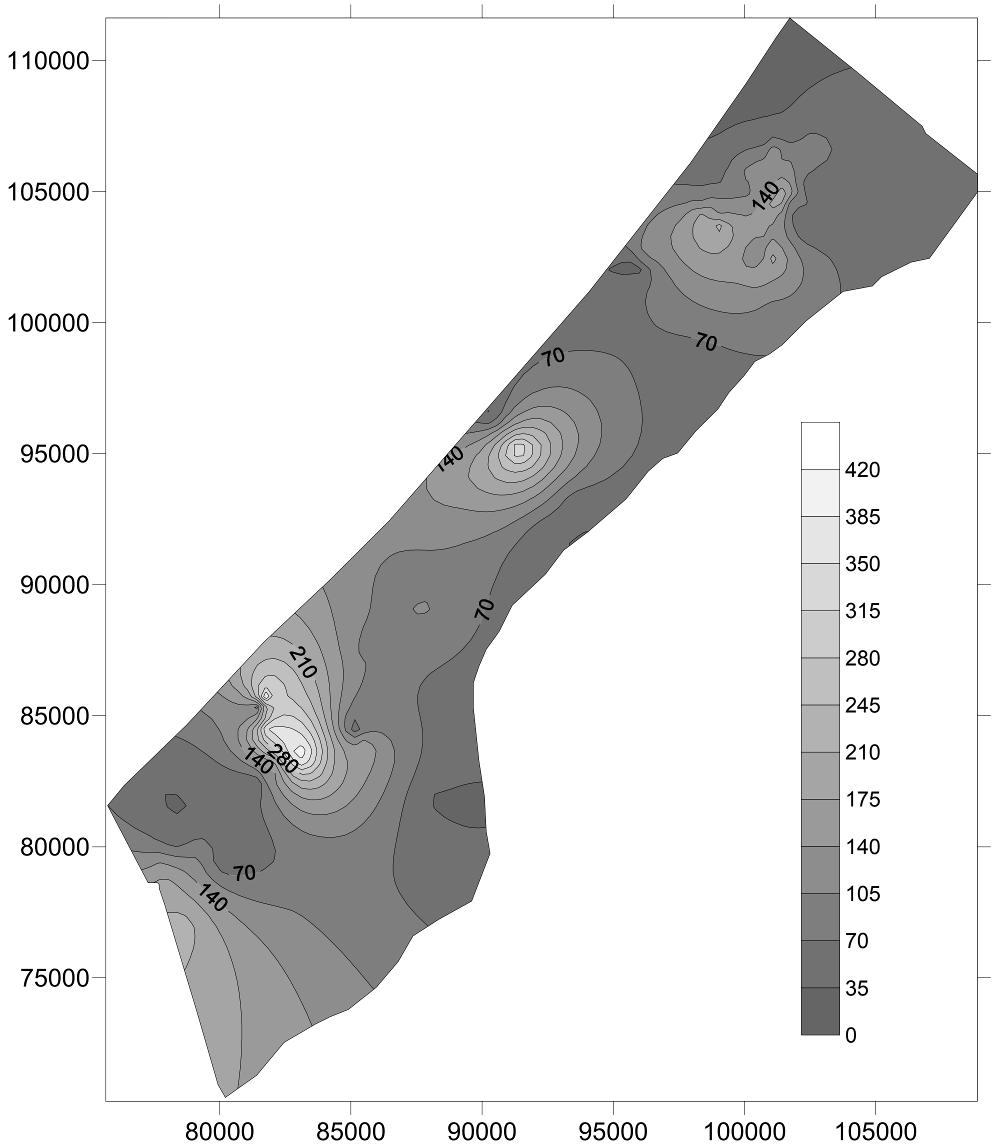

Figure 6. Nitrate concentration contour map

Table 3. Correlation and hypothesis test between NO_3, Ca, Na, and Mg.

Statistics	Parameter		
	Ca	Na	Mg
Correlation coefficient with NO_3	0.678	0.244	0.651
95% Confidence Interval	0.467 to 0.815	-0.069 to 0.513	0.430 to 0.799
t-test	5.754	1.57	5.36
P-value	0	0.125	0

It is noticeable that nitrate concentration in groundwater resulted form wastewater discharge is higher than that in agricultural areas. This can be explained as a result of the high decline in agricultural areas, the wide urbanisation in the last ten years, and high nitrogen content in wastewater.

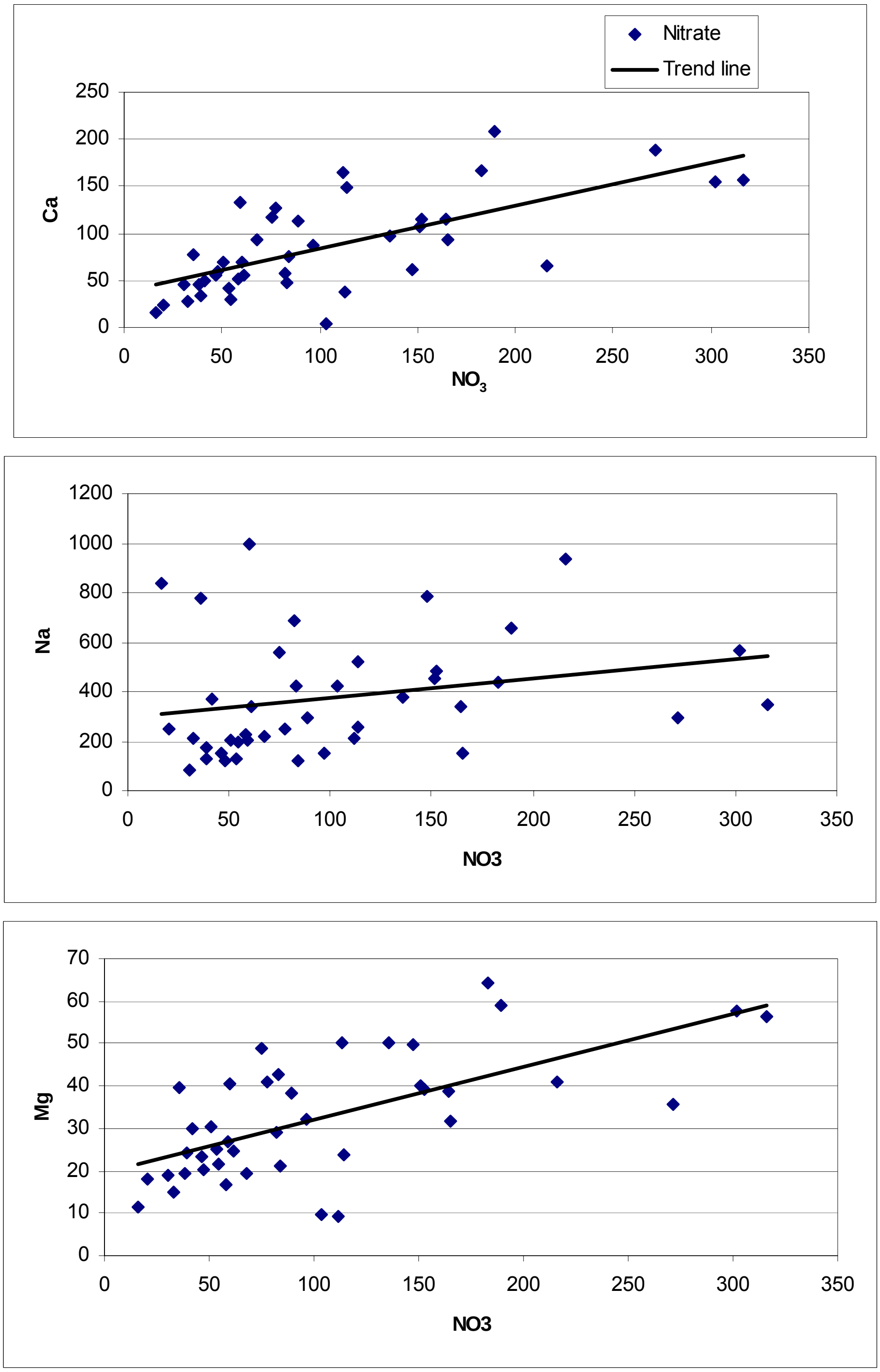

Figure 7. Correlation between NO_3-Ca, NO_3-Na, and NO_3-Mg

6. CONCLUSION

Two sources of nitrate, wastewater and agricultural activities, contribute to the groundwater nitrate pollution in the Gaza Strip. Samples of groundwater from 63 wells were collected and analysed. The major ion chemistry analysis was used to define the sources of nitrate in the area of study using different ions ratios (Ternary plots).

The results suggest that the primary source of nitrates in these wells is a function of land use. Since the lateral groundwater inflow has low Mg-Ca concentrations, high-level of these elements in the Gaza aquifer reveals that the pollution is anthropogenic sourced. The most severely nitrate polluted area in the Gaza Strip is Khan Yunis at which the maximum nitrate concentrations were recorded (more than 400 mg l^{-1}). Despite the intensive agricultural activities in the northern and southwestern areas, wastewater discharge has greater affect on nitrate pollution than agriculture. The heavy urbanisation of agricultural land in the Gaza Strip explains these findings.

Groundwater polluted by wastewater has a reduced ratio of Na/Cl when compared to Na/Cl ratio in wastewater. This suggests that Na-Ca exchange takes place in the unsaturated zone and leads to precipitation of Ca. A positive correlation between nitrate concentration and Ca, Na, and Mg was found particularly in areas polluted with wastewater. This implies that the increase in nitrates is accompanied by increase in other ions. The reason is that the wastewater is rich in Ca, Na, Mg and other ions.

As nitrate pollution is very dangerous for infants, public awareness is very important to avoid the impact of drinking nitrate-polluted water. The nitrate in groundwater cannot be discovered by tasting (like chloride), and it cannot be removed by boiling. Therefore, special care should be taken to ensure that the water does not contain nitrate. When the source of nitrate pollution is determined, the risk of nitrate pollution can be reduced by different means.

A good management program can reduce, but not totally eliminate the risk of nitrate in groundwater. To reduce the excess nitrogen potential, different steps are recommended. Installation of a proper sewer system at the places it does not exist (e.g. Khan Yunis area, refugee camps), and maintenance of the existing sewer system to prevent or minimise leakage of wastewater.

Finally actions should be taken to clean the sand dunes (e.g. northern area) that are flooded with wastewater from the northern treatment plants.

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