Environ Geol (2006) 50: 743–751
DOI 10.1007/s00254-006-0246-9

ORIGINAL ARTICLE

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Groundwater of the Gaza Strip: is it drinkable?

Received: 25 January 2006
Accepted: 3 March 2006
Published online: 21 March 2006

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Abstract Groundwater from 73 municipal and 21 private wells were analyzed for Ag, Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Sr and Zn over a 3 year monitoring program in the Gaza Strip. The results show that the trace elements of the groundwater of the Gaza Strip do not generally pose any health or environmental hazard. In spite of that, only 10% of the municipal wells meet the WHO standards. Cl^-, NO_3^- and F^- concentrations exceeded 2–9 times the WHO standards in 90% of the wells tested with maximum concentrations of 3,000, 450 and 1.6 mg/l, respectively. Several private wells should not be used for drinking purposes as the average of Zn, Cd, Pb, Fe and As was 58, 30, 270, 468 and 10 μg/l, respectively. A severe water dilemma will appear in the near future from both quality and quantity aspects.

Keywords Anions · Gaza Strip · Groundwater quality · Trace metals

Introduction

The environment in the Gaza Strip and the West Bank suffers considerable strain. In particular the shortage and pollution of resources, coupled with a high population growth and insufficient job opportunities have created many environmental problems (MEnA 2001). Groundwater is the only source of water in the Gaza Strip. Municipal groundwater wells are currently being used for drinking and domestic purposes while private wells are being used for irrigation. The Gaza Strip (Fig. 1), is one of the most densely populated areas in the world (2,638 people/km^2; PCBS 2000). More than 90% of the population is connected to the municipal drinking water network while the other 10% of the rural areas is dependent on the private wells.

The water quality in Gaza is affected by many different water sources including soil/water interaction in the unsaturated zone due to recharge and return flows, mobilization of deep brines, sea water intrusion or upconing and disposal of domestic and industrial wastes into the aquifer (Ghabayen et al. 2006). Previous reports on the water quality in Gaza have extensively discussed the high levels of chloride and nitrate in the drinking water, but they did not identify their exact source and their impacts on human health. Moreover, little or no information is available for trace constituents, hydrocarbons, pesticides, and microbes in the groundwater of the Gaza Strip (Shomar et al. 2006). Trace elements are contributed to the groundwater from a variety of natural and anthropogenic sources. Once elements are taken up by the groundwater, their distribution is continually reset by complex geochemical processes (e.g., equilibrium and non-equilibrium water/solid interactions, advection, dispersion, absorption, precipitation, coprecipitation, chelation, colloidal interaction) and biological processes (Newcomb and Rimstidt 2002; Al-Awadi et al. 2003).

During the preparation phase of this study, it became apparent that chloride and nitrate contamination of groundwater in Gaza are not the only threat to drinking water quality. Many of the agricultural wells have large surface openings (greater than 1 m) where oil products, fertilizers, or any other items stored in the well housing may enter the aquifer by carelessness or accidental spilling of materials into the well. In general the largest threat to the aquifer from these wells appear to be petroleum based products or pesticides, since both of

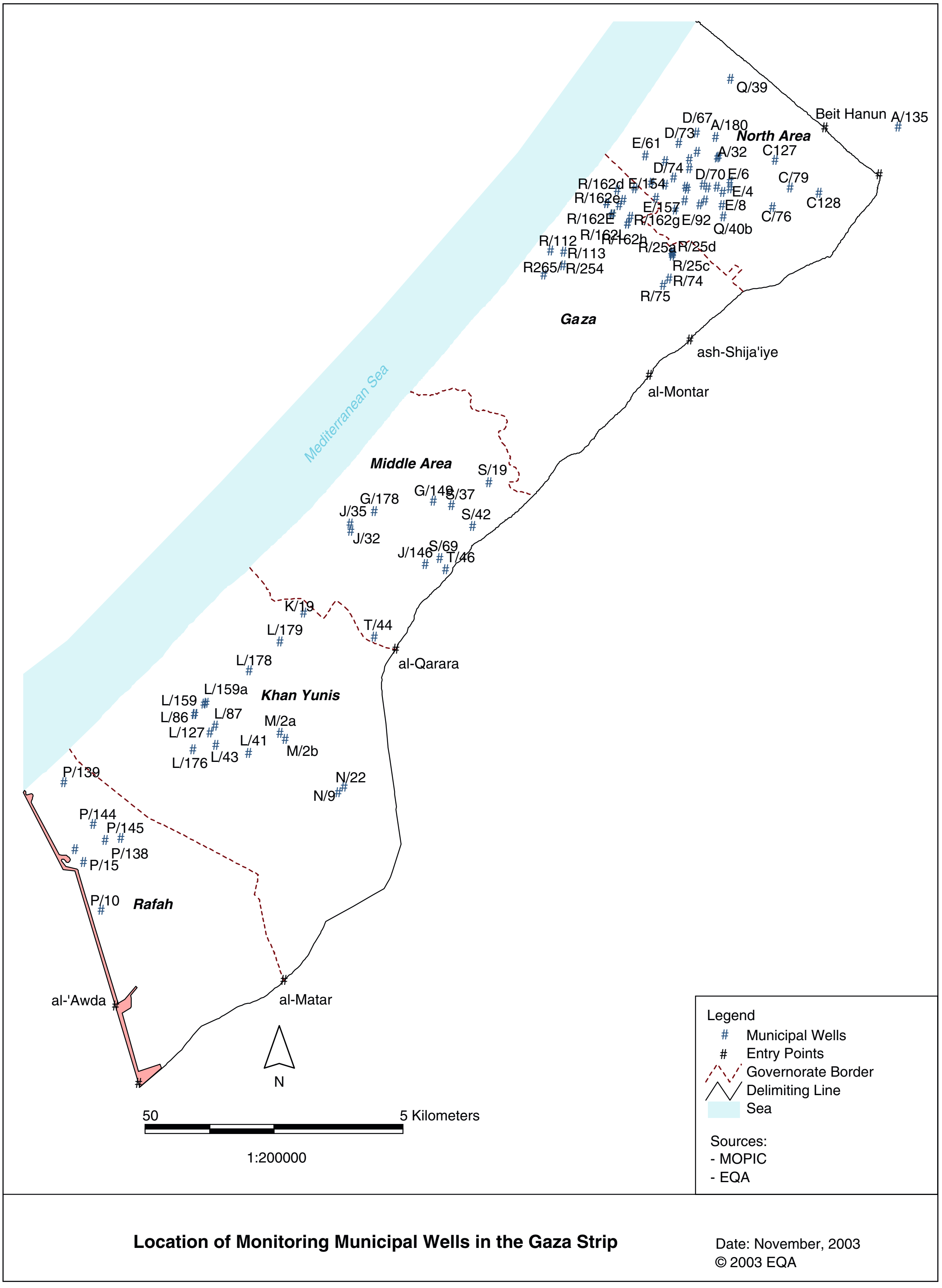

Fig. 1 The study area, classification of the Gaza Strip and the location of the groundwater wells

these products tend to be stored in the well building (Shomar et al. 2006).

The objective of this paper is to achieve an understanding of the groundwater quality as it currently exists and to determine if any of the parameters tested pose a threat to human health in the Gaza Strip. Specific analysis of contaminant such as finger printing of trace elements in this scale is being conducted for the first time.

Sampling and analysis

Water samples were collected at three separate time periods: 20 August-12 September 2002, 26 February-17 March 2003 and 25 July-17 August 2004. Water samples were from the 73 major municipal wells and 21 private wells (Table 1) selected to represent the five geographical regions (Fig. 1). At the municipal wells, samples were collected from a tap along the water distribution line. Prior to sampling, chlorine or sodium hypochlorite treatment of water was stopped to minimize interference during analysis.

In order to assure that the sample collected was from the groundwater and not water standing in the well, it was originally proposed that the well should be pumped for a minimum of 1–2 h. Assuming that the standing water in the well pipe is approximately 1 m^3, 1 h of pumping at a rate between 45 and 70 m^3/h is sufficient to purge at least three standing well volumes.

Groundwater samples

All samples were collected in laboratory certified clean bottles and labeled as to the well depth and location, date and time of sample collection, analyses to be performed, and field preservation performed, if any (APHA 1995). One-liter samples were collected and placed in a sampling ice-box and transferred to the laboratory. Each sample was divided into two subsamples: the first (500 ml) was filtered in an acid-washed filter holder and through 0.45 μm pore size membrane filters, the first few milliliters were used for rinsing, and then discarded. The filtrate was then transferred to clean acid-washed polyetheylene bottles and acidified with concentrated nitric acid (Ultrapur, Merck, v/v) to pH <2 and stored at 4°C until analyses by Inductively Coupled Plasma-Optical Emission Spectrometer, ICP/OES (VISTA-MPX, VARIAN). The total concentration of trace elements (Ag, Al, As, B, Ba, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Ni, Pb, Sr and Zn) was determined in addition to the major cations (Ca, K, Mg and Na). The other part of water sample was filtered with no additives and stored at 4°C for anion analyses by ion chromatography (IC DIONEX DX-120). Several

Table 1 73 Municipal and 21 private wells sampled for 3 years

Region	No	Well number	Region	No	Well number	Region	No	Well number	Region	No	Well number
73 Municipal groundwater wells											
North	1	D/67	Gaza	19	E/157	Gaza	37	R/25c	Khan Yunis	55	L 178A
	2	D/73		20	D/68		38	R/25d		56	L 179
	3	D/74		21	D/69		39	R/112		57	L 41
	4	E/06		22	D/70		40	R/254		58	L 43
	5	E/10		23	Q/39		41	R/265		59	L 86
	6	E/11A		24	R/162L		42	R/74		60	L 86A
	7	E/11B		25	R/162La		43	R/75		61	L 87
	8	E/11C		26	R/162Ha	Middle	44	G1/178		62	M 2A
	9	E/138		27	R/162H		45	J 146		63	M 2B
	10	E/148		28	R/162G		46	J 32		64	N 22
	11	E/156		29	R/162F		47	J 35		65	N 9
	12	E/45		30	R/162E		48	S 19		66	T 44
	13	E/61		31	R/162C		49	S 42	Rafah	67	P 10
	14	E/8		32	R/162B		50	S 69		68	P 124
	15	E/90		33	D/71		51	T 46		69	P 138
	16	E/92		34	D/72	Khan Yunis	52	L 127		70	P 138 old
	17	Q/40b		35	R/25a		53	L 159		71	P 139
Gaza	18	E/154		36	R/25b		54	L 176		72	P 144
										73	P 15
21 Private groundwater wells											
North	1	E/4	Khan Yunis	7	L/47	Khan Yunis	13	Priv. 1	Middle	19	Priv. 7
	2	E/1		8	S/15		14	Priv. 2		20	Priv. 8
Gaza	3	D/20		9	G/49		15	Priv. 3		21	Priv. 9
	4	A/185		10	K/121	Gaza	16	Priv. 4			
	5	A/107	Rafah	11	P/101		17	Priv. 5			
	6	A/180		12	F/191		18	Priv. 6			

parameters were also measured during the fieldwork: temperature, dissolved oxygen, turbidity, electric conductivity and pH.

Quality control

Analytical blanks and two samples with known concentrations of trace metals were prepared and analyzed using the same procedures and reagents. For the groundwater analysis, standard reference materials (SRM) 1643c and 1643d were used for the determination of trace elements (NIST 1991, 1994). The results of the analyses were also reviewed in terms of the milli-equivalent balance, which compares the ionic charges of the major anions and cations (APHA 1995). Because water is electrically neutral the charges should balance; however charge balance errors were less than 5% and are generally considered to be acceptable (Freeze and Cherry 1979).

Meteorology and hydrogeology

There are two well-defined seasons in the Gaza Strip: the wet season, starting in October and extending into April, and the dry season from May to September. Peak months of rainfall are December and January; the average annual rainfall is 335 mm/year (26 year average) (CAMP 2001).

Under natural conditions, groundwater flow in the Gaza Strip is towards the Mediterranean Sea, where fresh groundwater discharges into the sea. However, natural flow patterns have been significantly disturbed by pumping and artificial sources of recharge over the past 40 years (MEnA 2000). Within the Gaza Strip, large cones of depression have formed over extensive areas in the north and south. Water levels are presently below mean sea level in many places, inducing a hydraulic gradient from the Mediterranean Sea towards the major pumping centers and municipal supply wells (PEPA 1996). Between 1970 and1993, water levels dropped 1.6 m on average, mostly in the south. This is equivalent to 5 million cubic meters per year (Mm^3/y) decline in aquifer storage on average using a specific yield of 0.2 (Baalousha 2005; CAMP 2001).

The major documented water quality problems in the Gaza Strip are elevated salinity and nitrate concentrations in the aquifer (Shomar et al. 2005a). Depending on location, rates of salinization may be gradual or sudden. Chloride values are increasing at rates up to 10 mg/l per year in several wells. Salinization in the coastal aquifer of Gaza may be caused by a single process or a combination of different processes, including seawater intrusion, upconing of brines from the deeper parts of the aquifer, flow of saline water from the adjacent Eocene aquifer, return flow from irrigation water, and leakage of wastewater (Ghabayen et al. 2006).

Nitrate in 90% of the groundwater wells is more than 50 mg/l (CAMP 2001). Rates of aquifer replenishment are one of the most difficult parameters to derive.

Results

Due to the huge amount of data for the 3 year monitoring and analysis of more than 20 parameters, this section will only treat the environmentally significant results and the results that exceed the WHO standards that pose risks for human or environmental health. The average value is discussed and anomalous ones are rejected. The values of each well were averaged to provide the figures in this section. The variation in the concentration of several parameters of the same groundwater wells for the 3 years could be explained by seasonal variation (Abu Maila et al. 2005; Shomar et al. 2005b)

General physico-chemical parameters (pH, EC, DO and salinity)

The average temperature of the groundwater was 20°C in winter and 24°C in summer. The pH of groundwater (Table 2) ranges between 6 and 8. The electric conductivity (EC) of municipal wells increases from north to south (Table 2) with some exceptions in the Rafah area. The lowest average EC value was 1,198 μS/cm and the highest was about 3,800 μS/cm. The most deteriorated and salty water was in the eastern regions of Khan Yunis and Rafah with an average EC in the private groundwater wells of 5,000 μS/cm. The groundwater of the Gaza Strip is oxygenated and the average dissolved oxygen (DO) was 7.8 mgO_2/l in summer and 8.2 mgO_2/l in winter. This is in agreement with the findings of Shomar et al. (2005a).

Ions

Except for a few wells in the north area of the Gaza Strip, all wells tested showed high to very high concentrations of the major ions (Table 2). The anion-cation balance of the results obtained for each well showed that the majority of the cases were ±5%.

Major anions (NO_3, Cl, F, SO_4, PO_4)

Approximately 89% of the wells sampled showed nitrate levels above the WHO standard (50 mg/l). The average concentrations of NO_3 were very high and they were 463, 335, 313, 141 and 125 mg/l in the north, Gaza,

Table 2 Results of water quality-major parameters (average of 3 years)

	North area				Gaza				Middle area				Khan Yunis				Rafah			
	Max	Min	δ	Average	Max	Min	δ	Average	Max	Min	δ	Average	Max	Min	δ	Average	Max	Min	δ	Average
EC (μS/cm)	2,232	164	467	1,198	7,160	409	1,027	3,785	5,280	200	686	2,740	6,630	510	1,369	3,570	5,520	467	1,056	2,994
TDS (mg/l)	1,482	89	312	785	4,773	63	684	2,418	3,520	298	522	1,909	4,420	326	891	2,373	3,572	290	700	1,931
PH	8	7	0	7	8	6.8	0	6	8	6.1	0	7	7.8	6.6	0.2	7.2	8.2	6.8	0.1	8
DO (mgO_2/l)	8	7	0.3	7.5	8.2	7	0.4	7.6	8	7.2	0.3	7.6	8.1	7	0.3	7.6	8.1	7	0.3	7.6
Ca (mg/l)	605	28	66	317	226	16	27	121	262	8.3	42	135	288	3.3	38	146	190	19.8	34	105
Mg (mg/l)	68	19	13	42	86	26	17	50	128	6.8	18	67	130	12	19	71	475	12.3	81	244
Na (mg/l)	231	21	61	85	1,288	12	205	650	1,000	44	230	522	1,140	45	271	593	989	43	225	516
K (mg/l)	15	0.2	6	7	36	0.8	6	18	19	0.1	10	12	12	0.8	2	6	23	1.4	6	12
F (mg/l)	2.2	0.1	0.4	1	3.2	1.2	1	1.7	3	0.1	1	1.8	6	1.8	1	2.7	3.8	0.5	0.3	2
Cl (mg/l)	385	35	118	210	2,366	30	297	1,198	1,288	260	177	679	2,652	670	336	861	1,295	28	312	662
NO_3 (mg/l)	909	18	95	463	663	7	64	335	240	9	31	125	610	15	100	313	265	16.7	34	141
SO_4 (mg/l)	272	5	27	139	421	6	71	213	476	26	85	251	765	10	173	388	650	7.5	130	329
Alka. ($mgCaCO_3$/l)	345	19	46	182	587	125	73	356	425	25	40	225	485	100	90	293	1,875	100	312	988
Hardn. ($mgCaCO_3$/l)	791	41	106	416	1,368	68	154	718	791	39	136	415	1,096	26	181	561	570	59	117	315

Khan Yunis, Rafah and the middle area, respectively. All private wells except three showed nitrate concentrations 3–9 times higher than the WHO standards. Chloride was corresponded to the electric conductivity. The lowest value of Cl for a municipal well was 35 mg/l while the highest value of a well in Khan Yunis was 2,652 mg/l. Some wells also showed low Cl concentrations but high nitrate levels and vise versa. Except for the north area, the average concentration of fluoride in the groundwater in the Gaza Strip is higher than the WHO standards (1.5 mg/l). The most affected areas are Khan Yunis (2.7 mg/l) and Rafah (2 mg/l) and the findings agree with the previous study of Shomar et al. (2004). The F concentration is increasing from north to south. Most of the wells in Gaza had SO_4 levels less than the WHO standard (250 mg/l), especially in the north area. The highest levels of SO_4 were in Khan Yunis and the southeast, where concentrations averaged 380 mg/l. Phosphate was not detected in the groundwater of Gaza using vanadomolybdophosphoric acid method, while the average concentration using IC was 1 mg/l. Figure 2 shows a comparison between the average contents of the major anions in the different regions using the well numbers given in Table 1.

Major cations (Na, Ca, Mg, K)

The lowest Na levels were found in the north, and the highest levels were in the eastern regions of Gaza and in the areas of Khan Yunis and Rafah (Table 3). In most of the wells analyzed for K the average value was less than 5 mg/l; however, few wells showed levels of K more than 15 mg/l. The wells with high K levels include R/162H, R/162C, J/35, E/154 and F/88. Neither the USEPA (2002) nor the WHO (1998) has standards or guidelines for potassium levels in drinking water. The average concentration of $CaCO_3$ for all wells tested was 380 mg/l and the average concentration of Ca was 93 mg/l. The average concentration of Mg was 48 mg/l. The middle region wells showed the highest levels of both Ca and Mg and the results were 262 and 128 mg/l, respectively.

Trace elements (Fe, Mn, Cu, Zn, Ag, As, Pb, Cd, Cr, and Co)

Table 4 shows the results of trace elements from selected wells of the five regions. Because Ag, As, Co, Hg and Ni were detected in only five wells and Cd was not found in any of the sampled wells these elements are not listed in Table 4. The Fe concentrations were lower than the WHO standard (300 μg/l). The average Fe concentration was 10–50 μg/l, although some wells in the north had Fe up to 140 μg/l. Several wells showed high con-

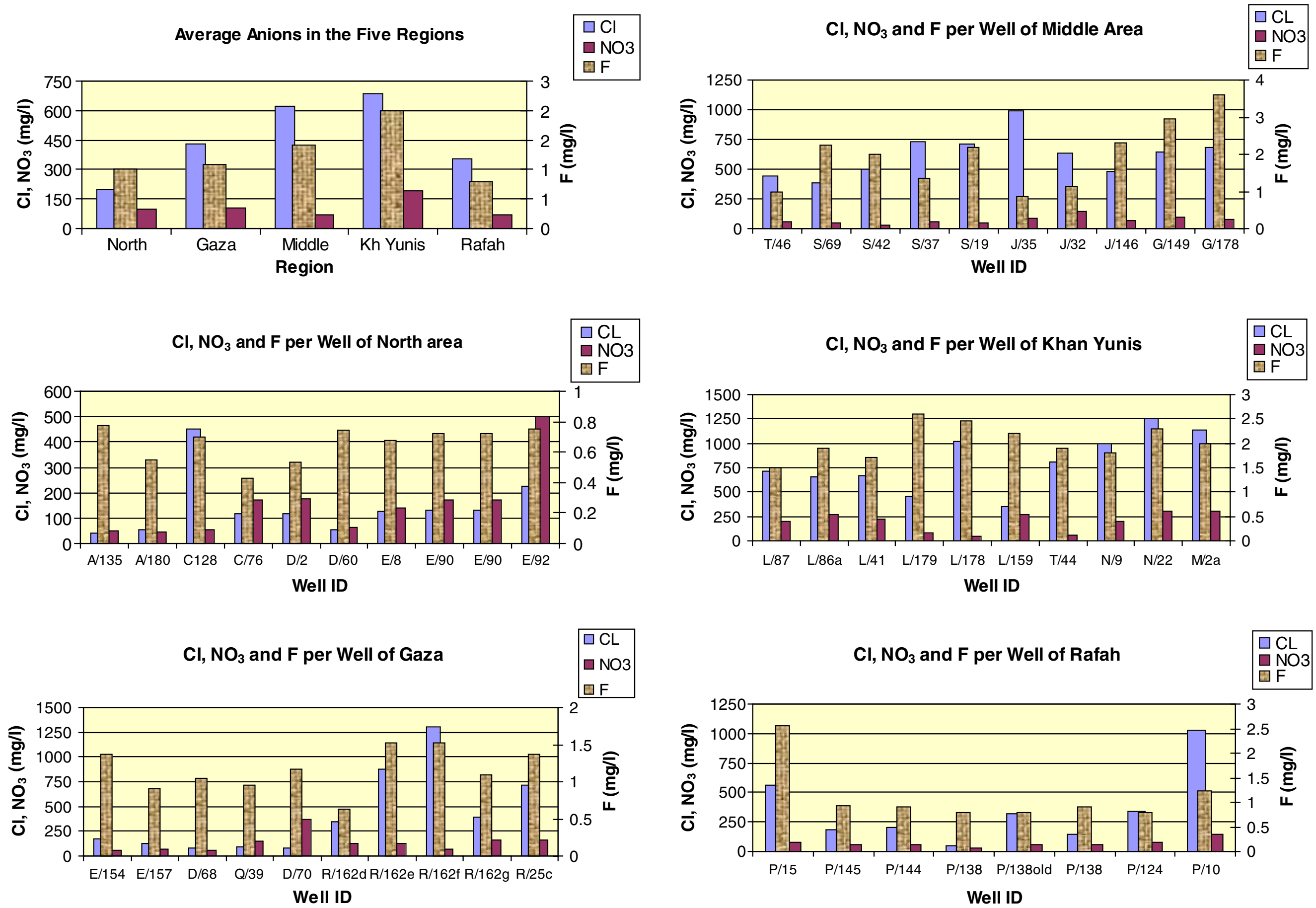

Fig. 2 Average concentrations of major anions in the five regions of the Gaza Strip

centrations in the year 2002, such as 6,200, 1,855, and 1,040 μg/l for the wells C/127, C/76 and R/112, respectively. None of these wells showed similar results for the other 2 years. Agricultural wells showed a 3–5 times higher Fe concentration than the municipal wells.

Manganese concentrations averaged 10 μg/l while the lowest WHO standard is 100 μg/l. All results for Cu were below the WHO standards (1–2 mg/l). The Cu ranged between 1–50 μg/l and wells of the middle and the south areas showed higher Cu contents than the north and Gaza. Zn concentrations averaged 1 to 30 μg/l, while the WHO standard for Zn is 3 mg/l. A good indication of quality control is the Zn results for well R/162L which showed similar results for the 3 years of monitoring (113, 117 and 102 μg/l, respectively). All Ag results levels were below the USEPA standard (100 μg/l). The well R/162E showed the same Ag results for the years 2001 and 2002 (0.5 μg/l), while in 2003 rose to 7 μg/l. The average of As concentrations in the wells tested was 1 μg/l, and the highest well had about 4 μg/l; most standards of As in drinking water are 10 μg/l. The results of 2001 showed an anomalous As result (50 μg/l) for a well (L/178). The range of Pb standards in drinking water is 10–50 μg/l, and the results showed that all wells tested were below these standards. One municipal well (E/4) in the north area showed high concentrations of Pb (69 μg/l) in the year 2001 which is seven times higher

Table 3 Comparison of the results of major Ions and WHO standards

Parameter	WHO[a]	WHO (%)	
TDS (mg/l)	1,000	< 37	> 63
Cl (mg/l)	250	< 46	> 54
NO_3 (mg/l)	50	< 10	> 90
F (mg/l)	1.5	< 80	> 20
SO_4 (mg/l)	250	< 86	> 14
Ca (mg/l)	50[b]	< 11	> 89
Mg (mg/l)	30[a]	< 13	> 87
Na (mg/l)	200	< 47	> 53
K (mg/l)	10[b]	< 93	> 7
Hardness ($mgCaCO_3$/l)	300	< 30	> 70

[a]WHO 1998
[b]ICON 2001, European Community guide level

Table 4 Examples of trace elements in 15 municipal wells of the Gaza Strip (average ± SD, $n = 3$)

WHO (μg/l)	200	300	700	50	1,000	300		100	10		3,000
LD (μg/l)	10	10	10	1	1	8		0.5	2.5	0.01	0.5
Well ID	Al	B	Ba	Cr	Cu	Fe	Li	Mn	Pb	Sr	Zn
E/4	< 10 ± 2	111 ± 24	197 ± 24	7.7 ± 2	3.6 ± 1	12 ± 2	3 ± 1	1.1 ± 0	< 2.5 ± 0	1,228 ± 45	6.8 ± 1
D/20	47 ± 9	104 ± 20	251 ± 33	7.3 ± 2	< 1 ± 0	28 ± 5	5 ± 1	< 0.5 ± 0	< 2.5 ± 0	2,223 ± 60	82.8 ± 11
E/11C	43 ± 11	348 ± 34	21 ± 4	11 ± 2	1.0 ± 0	19 ± 2	7 ± 1	0.6 ± 0	< 2.5 ± 0	836 ± 33	41 ± 8
C/127	13 ± 8	135 ± 28	124 ± 15	10 ± 2	< 1 ± 0	25 ± 3	3 ± 1	0.7 ± 0	< 2.5 ± 0	854 ± 28	19.4 ± 3
D67	15 ± 6	79 ± 17	216 ± 40	10 ± 2	1.1 ± 0	19 ± 2	2 ± 1	< 0.5 ± 0	3 ± 1	687 ± 42	8.7 ± 2
R/162E	28 ± 10	284 ± 40	219 ± 36	344 ± 28	1.3 ± 0	528 ± 44	8 ± 2	7 ± 1	11 ± 1	4,951 ± 88	24.5 ± 3
R/162B	38 ± 15	202 ± 32	316 ± 51	17 ± 5	1.1 ± 0	22 ± 2	8 ± 2	0.6 ± 0	3 ± 0	4,682 ± 98	24.4 ± 3
R/162H	12 ± 3	1,105 ± 52	78 ± 11	25 ± 6	6.1 ± 1	29 ± 3	19 ± 4	1.5 ± 0	< 2.5 ± 0	2,056 ± 91	35.5 ± 4
R/162G	28 ± 12	608 ± 46	105 ± 18	16 ± 3	9.3 ± 2	54 ± 7	13 ± 3	2 ± 0	6.1 ± 1	2,536 ± 97	50.5 ± 5
D/72	25 ± 9	93 ± 26	268 ± 35	10 ± 2	2.9 ± 0	39 ± 6	5 ± 1	1.7 ± 0	< 2.5 ± 0	1,377 ± 67	20.9 ± 4
S/71	20 ± 7	691 ± 54	63 ± 9	12 ± 2	3.6 ± 1	25 ± 4	11 ± 2	0.7 ± 0	4.1 ± 1	1,256 ± 95	19.3 ± 3
K/20	29 ± 11	747 ± 48	120 ± 12	30 ± 4	< 1 ± 0	13 ± 2	11 ± 2	< 0.5 ± 0	< 2.5 ± 0	1,328 ± 94	10.3 ± 2
L/178	113 ± 30	3,084 ± 125	35 ± 7	111 ± 19	1.9 ± 0	28 ± 5	26 ± 4	1.8 ± 0	7.7 ± 2	1,561 ± 67	19.3 ± 2
L/43	46 ± 13	951 ± 87	62 ± 11	32 ± 8	6.0 ± 1	66 ± 9	21 ± 6	1.4 ± 0	8.9 ± 2	4,668 ± 88	31.7 ± 4
P/24	< 10 ± 4	469 ± 64	122 ± 14	31 ± 7	< 1 ± 0	25 ± 3	12 ± 3	10.4 ± 2	5.5 ± 2	2,382 ± 100	12.8 ± 3

than the WHO standard. The results of the following years for the same well were < 2.5 μg/l. The different standards (including the WHO) for Cd in drinking water are 3–10 μg/l. All results were below the limit of detection. The different standards of Cr in drinking water range from 50 to 100 μg/l; all of analyzed wells tested had less Cr than these standards. The average concentration of Cr in the southern area of the Gaza Strip (40 μg/l) was higher than those of the northern area (10 μg/l). The well R/162E showed similar results for Cr for the first 2 years (24, 27 μg/l, respectively) while the last year only showed 344 μg/l.

Although the WHO has no standard for cobalt in drinking water, the results showed very low Co concentrations in all wells tested. Only two wells (R/162E and L/43) showed Co concentrations of 1 and 0.7 μg/l, respectively. On the other hand, the private-agricultural well A/107E showed 1.5 μg/l in the year 2001 while the results of the other 2 years were < 0.5 μg/l.

The last group of elements showed very low concentrations in general; Al, Hg, and Ni were found to be less than the WHO standard for all wells for the 3 years of monitoring. All wells had Ba less than the WHO standard (700 μg/l). The B results showed that more than 75% of the wells had B less than 300 μg/l. Li results were 5–20 μg/l and few private wells showed Li more than 30 μg/l. Sr is a typical alkaline earth element and it ranged between 0.8 and 6 mg/l for all samples.

Discussion

Generally, the depth of the well determines the groundwater quality of Gaza. The depth of the old wells ranges between 40 and 60 m, however the municipal wells are deeper than the private ones. The wells dug after the year 1995 have depths of 90–120 m. The small variation in the groundwater pH is independent of the geographical dimension and seasonal variation. The best aquifer, in terms of fresh water, was located at the north western corner of the Gaza Strip. Based on the variation in groundwater quality not only in the five regions but also in the region itself, the municipalities of the Gaza Strip decided to mix relatively fresh water and salt water before supplying the consumers. Sources that contribute to high NO_3 concentrations include the infiltration of domestic sewage through cesspits and septic tanks, solid waste leachate, manure and agriculture fertilizers. The areas with the highest concentrations of NO_3 do not have wastewater collection systems, and when present it is only implemented recently. Unpublished data (B. Shomar et al., in preparation) confirmed the relationship between the high concentrations of NO_3 in drinking water and the occurrence of methaemoglobinaemia in the areas where babies are not breast fed.

The high average F concentration in the groundwater of the Gaza Strip (1–2.7 mg/l) was the primary cause of the dental fluorosis in school children of the Gaza Strip (Shomar et al. 2004). The study revealed that the main source of high F in the groundwater of the Gaza Strip is natural. Fluorite (CaF_2) was the main source mineral of fluoride ions to groundwater. The concentration of SO_4 in drinking water needs to be addressed not only because of its effect on public health but also on the municipal well infrastructure.

Approximately 65 of the wells tested (> 50% of the wells sampled) showed Na levels higher than the WHO standard (200 mg/l). Sodium had the same trend as Cl for all wells analyzed. Groundwater of most areas is hard and this could indicate the origin and geochemical characteristics of the groundwater system in Gaza. The aquifer is composed mainly of sand, sandstone and conglomerate strata of Pleistocene age (Abu Maila et al. 2005). The Ca results indicated that there was no significant difference in the results between the different seasons. All wells were below the seawater Mg/Ca ratio (5:1).

With some exceptions, the Gaza Strip could be classified according to the freshness of the municipal groundwater into: north, Rafah, Gaza, middle and Khan Yunis; the ranking is based on the increase of the salinity. For the wells that had extremely high Cl and NO_3 concentrations the trace metal concentrations were very low. The variation in the concentrations of major ions, represented by the EC, is due to the variation in the precipitation levels in each area. The Gaza Strip is about 45 km long and each region has a different annual precipitation; the north has 500 mm/a while the south has 250 mm/a. In spite of that, the decrease of some parameters values in winter does not bring them to comply with the WHO standards. Trace element concentrations were not affected by well depth for both municipal and private wells. Moreover, several private wells (A/40, A/42, F/130, F/160, and N/2) showed higher concentrations of Zn, Cd, Pb, Fe and As. These wells are located in the regions with heavy agricultural areas, wastewater treatment plants and solid waste dumping sites.

Conclusions

1. More than 89% of the groundwater wells are not suitable for drinking purposes because of high concentrations of NO_3, Cl and F and some trace metals which exceed 2–7 times the WHO standards.

2. Some wells have a permissible limit of NO_3 but high amounts of Cl or F and vice verse.

3. Trace elements in the groundwater indicated that they do not generally pose any health or environmental hazard in the Gaza Strip. Private wells exposed to contamination sources of solid waste dumping sites, wastewater and manure disposal sites showed high concentrations of Zn, Pb, As and Cd.

Recommendations and actions to be taken

- Several studies should be conducted mainly on the health risk assessment and water toxicology. Examples of these studies are the methaemoglobinaemia as a result of high nitrates, the dental fluorosis as a result of high fluorides and the cancers as a result of high levels of carcinogenic pesticides.
- An integrated monitoring program should be conducted. The municipal wells should be sampled 2–4 times a year for the analysis of anions, cations, heavy metals and pesticides. The data of the groundwater quality should be centralized in a data bank or a water archive.
- The objective of the Palestinian water institutions should be how to safeguard the water resources system from pollution. The protection of water quality and the reduction of the risk contamination are of great importance to a reliable and sustainable water supply.
- Several initiatives could be taken such as wastewater management through full collection and treatment, solid waste management to prevent leaching and infiltration into the groundwater aquifer, setting up a management system for use of pesticides and fertilizers through proper handling, storage measures and safe application, setting up groundwater protection zones in the areas vulnerable to pollution, and finally setting up an early warning and emergency response system, that will enable appropriate actions.

Acknowledgments This research was funded by Bundesministerium für Bildung und Forschung-BMBF, Germany through a project called "Monitoring of Groundwater and Soil Pollution Levels in the Gaza Strip". The author would like to acknowledge Prof. Dr. G. Müller, Dr. A. Yahya and Prof. Dr. R. Schuiling for his critical reading and comments on the manuscript and Mr. B. Gilfedder for his English language editing.

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