

DRINKING WATER QUALITY: EVALUATION OF CHLORIDE AND NITRATE CONCENTRATION OF WELLS SUPPLEIS GAZA GOVERNORATES (1990-2002)-PALESTINE

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ABSTRACT

Gaza Strip is one of the most highly populated areas in the world with limited water resource. This study aimed to evaluate the quality of drinking water wells supplies residence of Gaza Strip for Chloride and Nitrate (Cl &NO₃) concentrations during the period from 1990-2002 and match (Cl &NO₃) with World Health Organization (WHO) standards. Seasonal variations for (Cl &NO₃) and variations among Governorates were evaluated. During the period from 1990-2002 for all Gaza Governorates, the mean of Cl concentration (397.1 mg/l) and of NO₃ concentration (126.2 mg/l) were found statistically higher than WHO-recommended guidelines (250 mg/l and 50 mg/l) for Cl and NO₃ respectively (P-value <0.001). 50.8% and 77% of analyzed wells were significantly higher than WHO guidelines in Cl &NO₃ respectively. Mean of both Cl & NO₃ concentrations in Khan Younis (777.8 mg/l, Cl ; 190.0 mg/l, NO₃) were found significantly the highest among all Governorates. Seasonal variations shows that mean of both Cl & NO₃ concentrations were significantly higher in autumn (392.7 mg/l, Cl; 126 mg/l NO₃) than spring (382.6 mg/l, Cl; 122.1 mg/l, NO₃) (P-value <0.01). Real problem of drinking water quality in respect to Cl and NO₃ is concluded among all Governorates especially Khan Younis. Both Cl and NO₃ concentrations have been decreased in spring season.

KEYWORDS: Chloride, Drinking wells, Gaza Strip, Groundwater, Nitrate, Seasonal variations.

INTRODUCTION

The Gaza Strip is an elongated area of 365 Km² located in a semi-arid region (approximately 45 Km in length and 7 to 12 Km in width). It is situated in the southern part of the Mediterranean Sea of the Palestinian coastal plan. Egypt borders the Strip from the south, the

Negev desert from the east and the Mediterranean Sea from the west. It consists of five governorates, North, Gaza, Middle, Khan Younis, and Rafah. The population count in year 2002 was estimated at 1299403 inhabitants. The population density is about 3457.3 inhabitants per km², taking into consideration that some parts of Gaza strip is occupied by Israeli settlements, makes the real population density higher than what it was estimated. The fertility rate is estimated at 3-3.5% and average member per family is at 6.9% (PCBS, 1999a and PCBS, 2003).

Ground water is the most precious natural resource in the Gaza Governorates as it is the only source of water supply for domestic and agricultural use. Annual average rainfall varies considerably from 400 mm in the north to about 200 mm in the south of the Strip, which is the main conventional source, became insufficient to refresh the groundwater system. There are two well-defined seasons starting in October and extending through March, and the dry season from April to September. Peak months for rainfall are December and January. The average mean daily temperature in Gaza ranges from 26 degrees centigrade (C) in summer to 12 C in winter (PCBS, 1999b and MEnA, 2001).

The groundwater is confined in the coastal aquifer, which is divided into three sub-aquifers composed mainly of sand, sandstone and pebbles of Pliocene age. The sub-aquifers overlie each other and are separated by impervious silt clayey and/or impervious clayey layer. The thickness of the aquifer in the eastern boundary is about 10 m and increasing gradually to about 150 m thick in the north-western area along the coast. The water bearing horizons are underlined by impermeable marl clayey layers of Pliocene age. Water level of aquifer system ranging between 10 m and less than 2 m above mean sea level in the southeastern area and a long the coastal line respectively. Depth to water ranges between 90m in the east and less than 8 m in the west. The permeability of the aquifer is ranging between 700-1000 m²/day while porosity is about 25% (PWA, CAMP 2000).

By year 2002, the available yield of ground water is about 91 MCM/year, while the total abstraction for domestic and agricultural purposes is 153 MCM/year (PWA, CAMP 2000). This result is

affected in negative way the quality and the quantity of the municipal water that pumped to the consumers. More than 16 municipalities and 9 Village councils in the Gaza Strip Governorates manage their own water supply system. The average total water production for domestic use was by year 2002 at 62 MCM /year. The domestic water demand in 1990 was estimated at 25MCM/yr, while 75MCM/yr was used for irrigation (CDM, 1993). By year 2002, average per capita consumption for both domestic and industrial overall the Gaza Strip was estimated at 91 liter/capita/day including the livestock (PWA, LEKA 2003). There are an estimated 3,000 wells within the Gaza Strip. Almost all of these are privately owned and used for agricultural purposes. Approximately 90 wells are owned and operated by individual municipalities and are used for domestic supply. In addition, there are estimated 1000 illegal (unregistered) wells (PWA, CAMP 2000).

Nitrate is the most common pollutant found in shallow aquifers due to both point and non-point sources (Postma et al., 1991). The main groundwater quality problem in Gaza is elevated chloride and nitrate concentrations. Not only are there numerous sources of pollution, but also the aquifer is highly vulnerable to pollution. Many years of over-pumping have resulted in seawater intrusion and upconing of saline groundwater. Furthermore, human activities including agriculture and inadequate waste management have increased groundwater contamination levels. Intensive cultivation and efforts to boost production have led to excessive use of fertilizers, pesticides, herbicides and soil fumigants, while collection, treatment and disposal of wastewater and solid waste (including hazardous materials) are wholly inadequate in many areas (Al-Yacubi, 2001 and UNEP, 2003). Elevated nitrate concentrations in drinking water are linked to health problems such as methemoglobinemia in infants and stomach cancer in adults (Lee et al., 1991; Hall et al., 2001; Wolfe and Patz, 2002). A health-based guideline value for nitrate of 50 mg/litre was recommended in the second edition of the WHO Guidelines for drinking-water quality to prevent methaemoglobinaemia. Chloride concentrations in excess of about 250 mg/litre can give rise to detectable taste in water. Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure (WHO, 1998). Ensuring

the Safety of our drinking water is one of the most importance and critical issues for public health protection.

The present study is aimed to evaluate the quality of drinking water wells, which supplies Gaza Strip Governorates over the period (1990-2002) through evaluation of wells water for Cl and NO₃ concentrations and matching those with World Health Organization (WHO) standards, in addition to comparison of both (Cl & NO₃) among Gaza Governorates, as well as their seasonal variations (Spring Vs Autumn) were assessed.

METHODS

Data about chloride and nitrate concentrations for 73 drinking wells during the period from 1990 to 2002 were collected from the records of public health laboratory-Palestinian Ministry of Health (MOH). MOH control measures on drinking water, in coordination with municipalities and environmental health departments (water control sector in MOH). Chemical tests were conducted twice per year (autumn and spring) for drinking water wells according to the standard methods for the examination of water and wastewater, 1989 and 1995. All these wells are municipal and being used for drinking purposes. They represented all geographic areas: 24 in the North, 26 in Gaza, 6 in the Middle, 11 in Khan Younis and 6 in Rafah Governorate.

Data were computer analyzed using SPSS/PC (Statistical Package for the Social Sciences Inc, Chicago, Illinois). Cl & NO₃ concentrations averaged for the calendar year. Means and standard deviations (S.D.) were calculated and matched with WHO guidelines (250 mg/l for Cl and 50 mg/l for NO₃) by using one sample t-test. Paired t-test was applied for seasonal variations analysis. Analysis of variance (ANOVA) test was used for evaluating Cl &NO₃ concentrations among Governorates. All wells that have not met the inclusion criteria (>five years available data) were not considered for t-tests. All years that have not met the inclusion criteria (> five wells available data) were not considered for one sample t-tests. The results were accepted as statistically significant when the p-value was ≤ 0.05 .

RESULTS AND DISCUSSION

Evaluation of drinking wells water for Cl concentration

In the North Governorate, the mean of Cl concentration, for 24 wells shows that during each year from 1990 to 2002, it was significantly lower than WHO guidelines, $P < 0.01$. Twenty-two out of 24 wells, included for t-test analysis, for the same period prevailed that Cl concentration for 20 wells of them was also significantly lower than WHO guidelines, while only one well shows significant increase, $Cl = 465.5 \text{ mg/l}$, $P < 0.05$ (Table 1). In Gaza Governorate, the result, for 26 wells shows that during each year from 1990 to 2002 the mean of Cl concentration (402.4 mg/l) was increased by 60.9% compared with WHO guidelines. This increase during each year from 1990 to 2002 was significantly higher than WHO guidelines, $P < 0.05$. Twenty out of 26 wells, included for t-test analysis, for the same period prevailed that Cl concentration for 18 (20%) of them was significantly higher than WHO guidelines, while only two wells showed insignificant increase, of Cl concentration (Table 2). In middle Governorate, the result, for 6 wells shows that during years from 1990 to 2002 the mean of Cl concentration (488.9 mg/l) was increased by 95.5% compared with WHO guidelines (Table 3). In Khan Younis Governorate, the result, for 11 wells shows that during each year from 1990 to 2002, the mean of Cl concentration (777.8 mg/l) was significantly increased by 211% compared with WHO guidelines, $P < 0.01$. All drinking wells were significantly higher than WHO guidelines for the same period, p value < 0.02 (Table 4). In Rafah Governorate, the result, for 6 wells showed that during each year from 1990 to 2002 the mean of Cl concentration (514.7 mg/l) was increased by 106 % compared with WHO guidelines. Five out of 6 wells, included for t-test analysis, for the same period prevailed that Cl concentration for 3 (60%) of them was significantly higher than WHO guidelines, p value = 0.00, while only one well showed insignificantly lower than WHO guidelines (Table 5).

Table 1 Chloride concentration (mg/l) in drinking wells (North Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
N1	180.5	207	231	231	230	245	NA	NA	NA	NA	NA	NA	NA	220.8	23.2	-03.1	0.03
N2	157.5	154	161	151	168	175	150	143	142	91	140	NA	NA	148.4	21.9	-15.4	0.00
N3	NA	210	196	189	NA	168	100	136	144	131	122	NA	NA	155.3	37.3	-07.6	0.00
N4	112	104	112	123	133	140	144	150	119	151	177	139	191	138.1	25.5	-15.8	0.00
N5	147	147	NA	NA	NA	NA	131	143	121	140	151	153	142.5	141.7	10.1	-32.1	0.00
N6	NA	NA	NA	NA	NA	NA	NA	124	130	126	126	118	181	134.2	23.3	-12.2	0.00
N7	NA	NA	NA	NA	125	140	133	121	120	144	165	174	177	144.9	23.9	-12.4	0.00
N8	84	84	94.5	80.5	84	77	98	85.5	81	70	77	70	60.5	80.5	10	-60.9	0.00
N9	NA	NA	NA	NA	NA	NA	NA	NA	100	109	91	90	109.5	99.9	9.4	-35.8	0.00
N10	NA	NA	NA	NA	NA	NA	NA	60.5	63.5	77	77	91	92	76.8	13.2	-32.1	0.00
N11	NA	NA	NA	NA	NA	NA	NA	110	120	NA	126	125	127	101.6	46.1	-7.2	0.00
N12	NA	NA	NA	98	119	-	147	136	142	142	140	153	163	137.8	19.1	-17.6	0.00
N13	NA	NA	NA	98	119	84	160	125	125	112	110	118	102.5	115.4	20.2	-21.0	0.00
N14	68	45.5	49	49	NA	56	60	57.5	56	42	38.5	35	39	49.6	10.1	-68.9	0.00
N15	NA	NA	NA	NA	NA	NA	NA	NA	NA	63	59.5	71	67.5	65.3	NA	NA	NA
N16	49.5	49	49	52.5	NA	49	59	53.5	52.5	64.5	73.5	85	102.5	61.6	17.1	-38.1	0.00
N17	88	87	91	98	NA	98	97	98	81	80.5	91	85	109.5	92	8.4	-64.8	0.00
N18	175	172	214	235	234	245	NA	247	217	NA	NA	247	NA	220.7	29.3	-3.0	0.02
N19	NA	NA	NA	NA	NA	NA	NA	427	NA	469	469	473	489.5	465.5	23.1	20.8	0.00
N20	84	91	94.5	98	70	105	77.5	96	70	77	77	78	85	84.9	11.2	-53.3	0.00
N21	NA	NA	NA	NA	NA	NA	NA	234	235	221	238	247	255	238.3	11.7	-2.4	0.06
N22	NA	NA	NA	NA	NA	NA	NA	72	70.5	73.5	91	97	95.5	83.3	12.5	-32.6	0.00
N23	35	35	35	NA	35	NA	48	NA	NA	NA	NA	NA	NA	37.6	5.8	-81.7	0.00
N24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	105	111	148.5	121.5	NA	NA	NA
Mean	107.5	115	121	125	132	132	108	138	115	125	131	138	144.1				
S.D.	50.6	61.2	69.3	63.2	64.3	66.5	38.6	87	49.5	93.5	89.8	95.8	98.7				
T-test	-9.3	-7.6	-6.2	-6.8	-5.8	-6.2	-13.3	-5.6	-11.9	-5.8	-6.1	-5.2	-4.7				
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				

Table 2 Chloride concentration (mg/l) in drinking wells (Gaza Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
G1	483	482.5	522	504	511	504	560	497	513.5	490.5	321	534	502	494.2	56.2	15.7	0.00
G2	350	350	371	392	NA	399	419	421.5	431.5	458.5	470	477.5	491.5	419.3	48.6	12.1	0.00
G3	794.5	794.5	805	829.5	NA	NA	802	734	NA	766	NA	937	929	821.3	68.7	24.9	0.00
G4	567	551	584.5	542.5	480	588	582	609.5	574.5	601	693	711	730	601.1	71	17.8	0.00
G5	850	569.5	444.5	328.5	490	476	438	447	581	633	622	647	607.5	548.8	131.8	8.2	0.00
G6	448	476	455	433	434	403	428	401	352.5	378.5	392	407.5	402.5	416.2	33.6	17.8	0.00
G7	NA	NA	NA	NA	NA	NA	NA	NA	135	147	173	NA	210	141.3	NA	NA	NA
G8	NA	NA	NA	NA	NA	NA	NA	NA	206	235	269.5	NA	329	259.9	NA	NA	NA
G9	212	231	253	252	252	280	288.5	278.5	309.5	286	420.5	487	519.5	313	98.3	2.3	0.04
G10	NA	NA	NA	238	238	252	253	278.5	285.5	269.5	371	511	687	338.4	148.5	1.9	0.09
G11	420	721.5	1512	NA	NA	NA	NA	NA	NA	255.5	318.5	NA	577	634.1	462.7	2.0	0.09
G12	161	189	248	462	539	700	735	740	513.5	490.5	NA	NA	NA	477.8	217.6	3.3	0.00
G13	665	1306	2180.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1383.8	NA	NA	NA
G14	413	427	443	486.5	497	532	557.5	561	546	483	483	506.5	488	494.1	47.3	18.6	0.00
G15	NA	NA	NA	434	469	455	483	504	470.5	354	490	507	488	465.5	44.9	12.5	0.00
G16	77	86	91	98	105	105	129	184.5	185	228	346.5	466	207	177.5	115.6	-2.3	0.04
G17	84	84	80.5	105	105	112	136	150	146	160	182	NA	153.5	124.8	34.1	-12.7	0.00
G18	42.5	61	71	69.5	91	105	98	122	116	108.5	126	126	124.5	97	27.9	-19.8	0.00
G19	NA	NA	NA	70	72	84	99.5	93	78	70	94.5	103	99.5	86.4	13.1	-39.4	0.00
G20	NA	NA	NA	NA	NA	NA	74	79	77.5	86	91	99	92.5	85.6	9.1	-74.6	0.00
G21	336	364	385	390	399	406	467.5	489	451	452	502	NA	662	441.9	86.1	7.7	0.00
G22	NA	NA	NA	NA	NA	NA	NA	NA	74	70	73.5	NA	85.5	75.8	NA	NA	NA
G23	NA	NA	NA	NA	NA	NA	NA	NA	71	77	66.5	NA	82	74.1	NA	NA	NA
G24	NA	NA	NA	NA	NA	NA	NA	NA	NA	154	171	NA	163.5	162.8	NA	NA	NA
G25	525	574	623	661.5	686	414	705	710	724.5	669.5	781	NA	NA	643	104.1	12.5	0.00
G26	NA	NA	NA	709	725	742	781	797.5	798	651	NA	NA	NA	743.4	53.8	24.3	0.00
Mean	402	454	566.8	389.2	380.8	385.7	423	426.2	347.3	342.9	339	465.7	392.3				
S.D.	246.6	318.1	552.7	222.4	211.1	204.5	243.2	233.6	225.3	215.1	206.6	233.8	250.4				
T-test	2.5	2.6	2.3	2.7	2.5	2.7	3.1	3.3	2.0	2.02	2.1	3.5	2.7				
P-value	0.03	0.02	0.04	0.03	0.02	0.02	0.00	0.00	0.05	0.04	0.05	0.00	0.01				

Table 3 Chloride concentration (mg/l) in drinking wells (Middle Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
M1	511	452	465	501	511	532	532	529	541	532	571	578	566	524.7	37.6	26.4	0.00
M2	454	336	357	380	399	378	384	391	400	385	385	469	NA	393.2	36.6	13.6	0.00
M3	NA	NA	NA	NA	NA	NA	NA	664	512	497	464	485	NA	524.4	80.0	07.7	0.00
M4	NA	NA	NA	NA	NA	NA	NA	635	661	630	679	NA	NA	651.3	NA	NA	NA
M5	NA	NA	NA	NA	NA	NA	NA	738	724	NA	NA	NA	782	748.0	NA	NA	NA
M6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	157	189	198	181.3	NA	NA	NA
Mean	483	394	411	440	455	455	458	591	568	511	451	430	515				
S.D.	NA	NA	NA	NA	NA	NA	NA	134.8	127.6	NA	198.2	NA	NA				
T-test	NA	NA	NA	NA	NA	NA	NA	5.7	5.6	NA	2.3	NA	NA				
P-value	NA	NA	NA	NA	NA	NA	NA	0.00	0.00	NA	0.08	NA	NA				

Table 4 Chloride concentration (mg/l) in drinking wells (Khan Younis Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
Kh1	399	413	385	389	434	406	462	NA	342	353.5	424	NA	433	403.3	35.5	14.4	0.00
Kh2	NA	668.5	1187	1183	1295	NA	NA	396	315	NA	NA	NA	NA	840.8	435.3	03.3	0.02
Kh3	1029	1005	1026	984	959	945	NA	1141	945	889.5	929	NA	NA	985.3	70.3	33.0	0.00
Kh4	458.5	479.5	493.5	497	525	546	476.5	722	542.5	NA	654	672	700	563.9	95.8	11.4	0.00
Kh5	600	588	NA	595	623	630	630.5	684	645	682	676	696	719	647.4	43.2	31.8	0.00
Kh6	266	322	343	378	427	490	504	NA	579	630	501	349	375	430.3	110.7	05.6	0.00
Kh7	784	794.5	812.5	847	861	924	891.5	914	906	945	983	1058	972	899.4	79.8	29.3	0.00
Kh8	840	836.5	861	868	868	862	864.5	663	828.5	835	921	918	935	853.9	66.9	32.5	0.00
Kh9	NA	1061	1208	1225	NA	1210	1050	1036	1190	NA	NA	NA	NA	1140	86.0	27.4	0.00
Kh10	NA	1173	1288	1260	NA	1580	NA	1100	1200	NA	NA	NA	NA	1266.3	167.1	14.9	0.00
Kh11	NA	NA	NA	NA	NA	NA	897	791	1001	1125	1148	1128	1276	1052.3	166	12.8	0.00
Mean	625.2	734	844.8	823	749	843.7	722	827	772.2	780	779	803	773				
S.D.	271.7	288.6	265	342.5	301.9	378.2	230.2	242.4	310	250	253.7	289.3	316.5				
T-test	3.7	5.3	4.9	5.3	4.7	4.7	5.8	7.1	5.6	5.6	5.9	4.7	4.4				
P-value	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01				

Table 5 Chloride concentration (mg/l) in drinking wells (Rafah Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
R1	1236	1036	1201	1183	1190	1190	1124	1169	1089	1104	1113	NA	NA	1148.6	059.6	50.0	0.00
R2	536	553	562	585	560	588	645	656.5	604	630	658	NA	435	598.0	043.8	26.4	0.00
R3	375	329	343	336	371	350	367	364.5	354	383	424	425	556	382.9	59.7	08.0	0.00
R4	NA	NA	NA	165	189	364	NA	NA	428	404	244	264	226	285.5	100.0	01.0	0.35
R5	350	347	361	378	385	182	190	198	168	95	120	NA	173	245.6	109.0	-0.14	0.89
R6	NA	NA	NA	NA	NA	NA	NA	NA	NA	228	248	265	283	256.0	NA	NA	NA
Mean	624	566	617	529	539	535	581	597	528	474	468	318	334				
S.D.	NA	NA	NA	394.9	386.9	393.7	NA	NA	350.2	357.2	367	NA	157.6				
T-test	NA	NA	NA	1.6	1.7	1.6	NA	NA	1.8	1.5	1.5	NA	1.2				
P-value	NA	NA	NA	0.18	0.17	0.18	NA	NA	0.15	0.18	0.21	NA	0.30				

Table 6 Chloride & nitrate concentration (mg/l) in drinking wells among (Gaza Governorates 1990-2002).

Governorate	Chloride						Nitrate					
	No of Samples	Mean	S.D	Maximum	F	P-value	No of Samples	Mean	S.D	Maximum	F	P-value
North	198	126.9	76	489.5			196	114.4	77.4	360		
Gaza	242	402.4	266.7	2180.5			244	121.3	57.3	291		
Middle	40	488.9	141.9	782.0	146.1	0.00	40	65.0	19.2	104	29.9	0.00
Khan Younis	109	777.8	290.0	1580			109	190.0	107.0	383		
Rafah	60	514.7	334.1	1236			61	110.1	56.7	240		
Total	649	397.1	319.5	2180.5			650	126.2	78.6	383		

Intensive deterioration has been occurred in drinking water quality in Gaza Governorates, in term of Cl concentration. Increasing salinity in most areas. Salinization may be caused by a number of different processes, including: over pumping, has resulted in seawater intrusion; migration of brines from the deeper parts of the aquifer a

and dissolution of soluble salts in the aquifer (water-rock interaction). In addition, potential man-induced (anthropogenic) sources include agricultural return flows, wastewater seepage, and disposal of industrial waste (CAMP, 2000).

Evaluation of drinking wells water for NO₃ concentration

In the North Governorate, the result, for 24 wells showed that during each year from 1990 to 2002 the mean of NO₃ concentration (114.4 mg/l) was increased by 128.8% compared with WHO guidelines. This increase during each year from 1991 to 2002 was significantly higher than WHO guidelines, $P < 0.03$. Twenty two out of 24 wells, included for t-test analysis, for the same period prevailed that NO₃ concentration for 14 (63.3%) of them was significantly higher than WHO guidelines, while only one well showed significant decrease, of NO₃ concentration (Table 7). In Gaza Governorate, the result, for 26 wells showed that during each year from 1990 to 2002 the mean of NO₃ concentration (121.3 mg/l) was increased by 142.6% compared with WHO guidelines. This increase during each year from 1990 to 2002 was significantly higher than WHO guidelines, $P = 0.00$. Twenty out of 26 wells, included for t-test analysis, for the same period prevailed that NO₃ concentration for 18 (90%) of them was significantly higher than WHO guidelines, while only two wells showed insignificant increase, of NO₃ concentration (Table 8). In Middle Governorate, the result, for 6 wells showed that during years from 1990 to 2002 the mean of NO₃ concentration (65 mg/l) was increased by 30% compared with WHO guidelines (Table 9). In Khan Younis Governorate, the result, for 11 wells showed that during each year from 1990 to 2002, the mean of NO₃ concentration (190 mg/l) was significantly increased by 280% compared with WHO guidelines, $P < 0.02$. Ten out of 11 drinking wells were significantly higher than WHO guidelines for the same period, p value < 0.02 (Table 10). In Rafah Governorate, the result, for 6 wells showed that during each year from 1990 to 2002 the mean of NO₃ concentration (110.1 mg/l) was increased by 120.2 % compared with WHO guidelines. Five out of 6 wells, included for t-test analysis, for the same period prevailed that NO₃ concentration for all of them was significantly higher than WHO guidelines, p value < 0.05 (Table 11). As shown in Table 6, there was a significant variation in NO₃ concentration among Governorates. In general, all Gaza Governorates had NO₃ concentration exceed the WHO guidelines of 50 mg/l. The highest

concentration of NO₃ was found in drinking well located in Khan Younis, Gaza, and North Governorate. In Khan Younis Governorate, the lack of any sewer system coupled with densely populated area, situated in highly permeable sandy soils, relies on septic systems and cesspits, may led to high NO₃ levels in this area (Ghbn, 2000). In Gaza Governorate, the current inflow of the treatment plant is about 45,000 to 50,000 m³/day, which exceeds the capacity of the plant. Two third of the partially treated effluent discharged to 3 of infiltration lagoons located in the sand dune at the east of the plant, which increase the NO₃ levels in the groundwater. Furthermore, the discharge of untreated sewage from the Middle Camps to Wadi Gaza may duplicate the concentration of NO₃ in Gaza Governorate (El-Madhoun, 2001). The effluent in Beit Lahia wastewater treatment plant (North Governorate) merely overflows from the last pond of the works, spreading in a large sand dune area in the immediate vicinity of the plant, where it infiltrates to groundwater (Shomar et al., 2004).

According to the results, the quality of the drinking water in Gaza Governorates is generally poor. Nitrate content in most cases is unsuitable for drinking. The main potential sources of NO₃ pollution in Gaza Governorates are believed to be fertilizer and domestic sewage effluent. Human activities including agriculture and inadequate waste management have increased NO₃ contamination levels. Intensive cultivation and efforts to boost production have led to excessive use of fertilizers, pesticides, herbicides and soil fumigants, while collection, treatment and disposal of wastewater and solid waste (including hazardous materials) are wholly inadequate in many areas (Al-Yacubi, 2001 and UNEP, 2003).

Table 7 Nitrate concentration (mg/l) in drinking wells (North Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
N1	250	288	288	318	265	360	NA	NA	NA	NA	NA	NA	NA	294.8	39.4	15.2	0.00
N2	280	290	268	265	250	350	260	237	205	175	NA	NA	NA	258.0	47.5	13.8	0.00
N3	NA	298	288	255	NA	350	250	212	207	205	196	NA	NA	251.2	52.4	11.5	0.00
N4	146	160	145	128	115	130	160	158	182	185	180	187	223	161.5	29.7	13.6	0.00
N5	150	155	240	NA	NA	NA	105	126	120	130	108	133	139.5	140.7	38.5	7.5	0.00
N6	NA	NA	NA	NA	NA	NA	NA	110	172	200	170	178	181	168.5	30.6	9.5	0.00
N7	NA	NA	NA	NA	125	100	NA	60	65	62.5	53	60	63	73.6	25.2	2.6	0.03
N8	95	72	97.5	77.5	100	110	NA	67.5	65	65	62.5	70	57	78.3	17.6	5.6	0.00
N9	NA	NA	NA	NA	NA	NA	NA	NA	130	129	73	99	89	104.0	25.1	4.8	0.00
N10	NA	NA	NA	NA	NA	NA	NA	63	70	71.5	75	69	86	72.4	7.7	7.1	0.00
N11	NA	NA	NA	NA	NA	NA	NA	95	100	NA	96.5	67	121	95.9	19.3	5.3	0.00
N12	NA	NA	NA	113	135	NA	180	231	223	223	213	245	247.5	201.2	48.3	09.4	0.00
N13	NA	NA	NA	113	135	125	160	157	140	143	134	139	109.5	135.5	16.5	16.4	0.00
N14	23	27.5	31	35	NA	70	66	72.5	81	72	50.5	30	27.5	48.8	22.0	-0.18	0.86
N15	NA	NA	NA	NA	NA	NA	NA	NA	NA	68	56	47	42	053.3	NA	NA	NA
N16	38	38	43.5	53.5	NA	80	59	57	57.5	56.5	65.5	72	63.5	057.0	12.8	1.9	0.08
N17	105	80	90	77.5	NA	150	97	105	97	95	100	99	95.5	99.3	18.1	9.4	0.00
N18	40	39	40.5	38	55	55	NA	53.5	67	NA	NA	56	NA	49.3	10.2	-0.2	0.85
N19	NA	NA	NA	NA	NA	NA	NA	35	NA	45	63	89	106	67.6	29.7	1.3	0.26
N20	35.5	35	36.5	36	80	40	62	64.5	65	64.5	53.5	54	53.5	52.3	14.6	0.6	0.58
N21	NA	NA	NA	NA	NA	NA	NA	52	43	41.5	53	51	61.5	50.3	7.3	0.1	0.92
N22	NA	NA	NA	NA	NA	NA	NA	35	37	32.5	27	22	31	30.8	5.4	-8.6	0.00
N23	20	34	50	NA	65	NA	114	NA	NA	NA	NA	NA	NA	56.6	36.3	0.04	0.70
N24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	96.5	102	64.5	87.7	NA	NA	NA
Mean	107.5	126	135	126	133	160	138	105	112	109	96.2	93.5	97.97				
S.D.	91	109.3	106	98.7	71.6	120.8	71.2	65	60	62.5	54.1	57.2	61.8				
T-test	2.1	2.4	2.8	2.7	3.6	3.2	4.1	3.7	4.5	4.1	3.8	3.4	3.4				
P-value	0.06	0.03	0.02	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00				

Table 8 Nitrate concentration (mg/l) in drinking wells (Gaza Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
G1	261	270	228.5	207.5	225	280	208	236.5	224	215	230	241.5	230.5	235.2	22.7	29.5	0.00
G2	226	217	219	197.5	NA	160	108	133	130	173.5	130	112	175.5	165.1	42.8	09.3	0.00
G3	180	203	247.5	190	NA	NA	178	187	NA	200	NA	185	291	206.8	37.9	12.4	0.00
G4	79	82.5	72.5	70	105	50	85	74	75	72	87.5	78	82	77.9	12.4	08.1	0.00
G5	100	134.5	82.5	80	125	160	137.5	191	111	106	67	87	101	114.0	34.9	06.6	0.00
G6	64	78	57	59.5	85	70	66	61	67	60.5	39	55	58.5	036.1	11.2	04.2	0.00
G7	NA	NA	NA	NA	NA	NA	NA	NA	35	34	46	NA	37.5	038.1	NA	NA	NA
G8	NA	NA	NA	NA	NA	NA	NA	NA	80	85.5	82	NA	105	088.1	NA	NA	NA
G9	163	168.5	115	157.5	135	180	128.5	125.5	128.5	125	123	144.5	138.5	141.0	20.2	16.2	0.00
G10	NA	NA	NA	135	138	135	139	134	132	122.5	137	136	179.5	138.8	15.0	18.7	0.00
G11	53.5	69.5	54	NA	NA	NA	NA	NA	NA	126	239	NA	218	126.7	83.5	02.2	0.07
G12	132.5	142.5	125	123.5	150	185	124.5	186.5	224	215	NA	NA	NA	160.8	38.6	09.0	0.00
G13	143	121	55	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	106.3	NA	NA	NA
G14	165	200	182.5	245.5	220	205	180	192	200	194	201	159.5	213.5	196.8	22.8	23.3	0.00
G15	60	NA	NA	170	195	145	127.5	135	167.5	139	172	145.5	206	151.1	39.2	08.6	0.00
G16	64	70.5	55	72.5	90	78	75	62.5	67.5	78	73.5	59	100	072.7	12.3	06.7	0.00
G17	70.5	75.5	59	70	80	80	74	82.5	97	86.5	95	NA	102.5	081.0	12.6	08.5	0.00
G18	20	37	34	45	50	40	61	52	59	78	95	84	105	058.5	25.4	01.2	0.25
G19	NA	NA	NA	80	90	70	77	64	90	85.5	100.5	109	69.5	83.6	14.3	07.4	0.00
G20	NA	NA	NA	NA	NA	NA	76	63	83	83.5	107.5	110	117	091.4	20.2	05.4	0.00
G21	110	137.5	88.5	107.5	115	115	190	100	135	140	132	NA	103	122.8	26.7	09.4	0.00
G22	NA	NA	NA	NA	NA	NA	NA	NA	78	85	94.5	NA	101	089.6	NA	NA	NA
G23	NA	NA	NA	NA	NA	NA	NA	NA	77	97	96.5	NA	109.5	095.0	NA	NA	NA
G24	NA	NA	NA	NA	NA	NA	NA	NA	NA	38	40	NA	161	079.7	NA	NA	NA
G25	116	152.5	175	140	135	140	158	130	131.5	123	106.5	NA	149	138.0	18.9	16.1	0.00
G26	NA	NA	NA	57.5	85	85	56	61	62	84	NA	NA	NA	70.1	13.8	3.8	0.01
Mean	118	135	115.6	123	126.4	128.1	118.4	119.5	111.6	113.8	113.4	121.9	137.2				
S.D.	65.3	64.9	71.7	60.6	50.8	63.7	48.1	57.1	53.2	51.7	55.3	51.4	62.8				
T-test	4.3	5.2	3.7	5.1	6.0	5.1	6.2	5.3	5.4	6.2	5.4	5.2	6.7				
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00				

Table 9 Nitrate concentration (mg/l) in drinking wells (Middle Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
M1	75	59	41	50	80	100	65	69.5	60	64.5	50	51.5	60	63.5	15.4	3.2	0.01
M2	67.5	56	33.5	44	60	65	57.5	45	45	50	50	45	NA	51.5	9.9	0.5	0.60
M3	NA	NA	NA	NA	NA	NA	NA	104	84	103	76.5	74	NA	88.3	14.4	5.9	0.00
M4	NA	NA	NA	NA	NA	NA	NA	87	98.5	95	104	NA	NA	96.1	NA	NA	NA
M5	NA	NA	NA	NA	NA	NA	NA	50	50	NA	NA	NA	64	54.7	NA	NA	NA
M6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	53	56	58	55.7	NA	NA	NA
Mean	71.3	57.5	37.3	47	70	82.5	61.3	71.1	67.5	78.1	66.7	56.6	60.7				NA
S.D.	NA	NA	NA	NA	NA	NA	NA	24.8	22.9	NA	23.6	NA	NA				
T-test	NA	NA	NA	NA	NA	NA	NA	1.9	1.7	NA	1.6	NA	NA				
P-value	NA	NA	NA	NA	NA	NA	NA	0.13	0.16	NA	0.19	NA	NA				

Table 10 Nitrate concentration (mg/l) in drinking wells (Khan Younis Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
Kh1	78.5	72	65	60	90	85	75	NA	83.5	70.5	60	NA	85	74.9	10.4	7.9	0.00
Kh2	NA	40.5	52.5	46.5	80	NA	NA	69	87	NA	NA	NA	NA	62.6	18.9	1.6	0.16
Kh3	174	153	150	155	165	155	NA	310	300	237.5	281	NA	NA	208.0	66.7	7.5	0.00
Kh4	168.5	216	235	195	205	350	337	321	266	NA	345	318	346	275.2	68.2	11.4	0.00
Kh5	200	245	NA	275	215	360	290	285	305.5	310	365	286	383	293.3	56.9	14.8	0.00
Kh6	33	57.5	57.5	45	80	80	90	NA	85	100	102	107	125	80.2	27.3	3.8	0.00
Kh7	240	234	230	200	195	310	320	201	190	197.5	188	174	134	216.4	51.6	11.6	0.00
Kh8	314	333.5	347.5	260	225	300	326	307	340	315	344	302	348	312.5	36.1	26.3	0.00
Kh9	NA	112.5	150	110	NA	90	120	99	95	NA	NA	NA	NA	110.9	20.2	8.0	0.00
Kh10	NA	315	280	245	NA	250	NA	249	240	NA	NA	NA	NA	263.1	29.0	18.0	0.00
Kh11	NA	NA	NA	NA	NA	NA	50	60	50	67.5	56	61	66	58.6	7.0	3.3	0.02
Mean	172.6	177.9	174.2	159.5	157	220	201	211	185.6	185.4	218	208	212				
S.D.	94.6	106.2	105.8	89.4	63.4	117.7	127.5	108.1	108.4	107.7	132.6	109.6	139.6				
T-test	3.4	3.8	3.5	3.86	4.8	4.3	3.4	4.5	4.1	3.3	3.6	3.5	3.1				
P-value	0.01	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.01	0.02	0.02				

Table 11 Nitrate concentration (mg/l) in drinking wells (Rafah Governorate 1990-2002).

Wells	90	91	92	93	94	95	96	97	98	99	00	01	02	Mean	S.D.	T-test	P-value
R1	183	190	158	178	205	200	238	211	220	223	240	NA	NA	204.2	25.6	19.9	0.00
R2	124	103	96	92.5	115	130	116	130	144	140	146	NA	148	123.7	19.4	13.1	0.00
R3	102	108	89	92.5	100	130	117	121.5	120	114	139	132	165	117.7	20.8	11.7	0.00
R4	NA	NA	NA	47.5	65	50	NA	35	42.5	35	34	32.5	33	41.6	10.9	-2.3	0.05
R5	68	59	62.5	65	65	85	35	38	60	85	93	NA	87.5	66.9	18.5	3.2	0.01
R6	NA	NA	NA	NA	NA	NA	NA	NA	NA	55	84	58.5	83	70.1	NA	NA	NA
Mean	119	115	101	95	110	119	126	107.1	117	109	123	74.3	103				
S.D.	NA	NA	NA	49.9	57.4	65.4	NA	73.3	70.9	67.6	70.2	NA	53.3				
T-test	NA	NA	NA	2.0	2.3	2.7	NA	1.7	2.1	2.1	2.5	NA	2.2				
P-value	NA	NA	NA	0.11	0.08	0.05	NA	0.16	0.10	0.08	0.05	NA	0.08				

Table 12 Seasonal variations of Cl and NO3 concentrations during (1990-2002) in Gaza Governorates

Parameter	No of samples	<u>Spring</u>		<u>Autumn</u>		T-test	P-value
		Mean	S.D	Mean	S.D		
Chloride	413	382.6	304.1	392.7	308.7	3.4	0.00
Nitrate	413	122.1	078.7	126.0	079.6	2.6	0.01

Seasonal variations of Cl and NO₃ concentrations

The results showed that, both Cl & NO₃ concentration were significantly decreased in spring season in comparison with autumn season (**Table 12**). This could be attributed to rainwater infiltration that occurred after the wet winter season (spring), which diluted the pollutants (Cl and NO₃). In the other hand, overexploitation of groundwater for domestic and irrigation in summer season and the absence of recharge, which increase the concentration of both Cl and NO₃ in autumn.

CONCLUSION

The main aim of this study was to evaluate chloride and nitrate levels over the period (1990-2002) within a five Governorates of the Gaza Strip. Real problem of drinking water quality in respect to Cl and NO₃ was found among all Governorates. The levels of Cl and NO₃ showed a general increasing trend from northern to southern areas of the Gaza Strip. Mean of both Cl & NO₃ concentrations in Khan Younis (777.8 mg/l, Cl ; 190.0 mg/l, NO₃) were found significantly the highest among all Governorates. 50.8% and 77% of analyzed wells were significantly higher than WHO guidelines in Cl & NO₃ respectively. Both Cl and NO₃ concentrations have been significantly decreased in spring season.

The overall quality of drinking wells water in the Governorates of Gaza is in a very real danger if no solution is found and quickly acted upon. Real and wise intervention at the local, regional and international levels for solving the problem of drinking water quality is urgently needed. Desalination, public awareness programs and campaigns about the wise-use of drinking water. Integrated solid waste and wastewater management maybe contribute of solving problem. Rainwater harvesting also recommended.

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